Sabrina Uecker

MEASURING PATELLOFEMORAL JOINT ANGLES USING A SMARTPHONE CAMERA – HOW RELIABLE IS IT?

Degree Programme in Physiotherapy
2019

samk
Satakunnan ammattikorkeakoulu
Satakunta University of Applied Sciences

MEASURING PATELLOFEMORAL JOINT ANGLES USING A SMARTPHONE CAMERA – HOW RELIABLE IS IT?

Uecker, Sabrina
Satakunta University of applied sciences / Satakunnan ammattikorkeakoulu
Degree programme in Physiotherapy
April 2019
Supervisor: Maija Kangasperko
Number of pages: 31
Number of appendices: 7

Keywords: Patellofemoral pain, anterior knee pain, biomechanics, subgrouping, reliability

---

Background: Patellofemoral pain is a great burden on the society as well as many individuals. To improve treatment outcomes, a subgrouping system was developed. To perform subgrouping a Smartphone App can be used. This study is testing if one of the conducted tests on the smartphone, specifically measuring patellofemoral joint angles using the smartphone camera, is a reliable test.

Method: 15 healthy individuals aged 18 to 40 years were recruited for testing. They performed several step down trials from a 20 cm step, touching the floor either with their heel or toe. The trials were recorded with the smartphone camera and afterwards the patellofemoral joint angles were measured from the recorded video material.

Results: All trials showed a high intratester reliability and low smallest detectable differences.

Conclusion: The test was performed reliable by the researcher and results suggest a high reliability for future studies. Next it will have to be tested if the measured angles show significant differences for a population with patellofemoral pain.

Table of terms

ACL	Anterior cruciate ligament
AKP	Anterior knee pain
AKPS	Anterior knee pain score
ANOVA	Analysis of variance
BMI	Body mass index
FPI	Foot posture index
FPPA	Frontal plane projection angle
ICC	Intraclass correlation coefficient
ITB	Iliotibial band
KAM	Knee abduction moment
LR	Likelihood ratio
Max.	Maximum
Min.	Minimum
MPFL	Medial patellofemoral ligament
MRI	Magnetic resonance imaging
PFJ	Patellofemoral joint
PFOA	Patellofemoral osteoarthritis
PFP	Patellofemoral pain
PFPS	Patellofemoral pain syndrome
PIS	Patient information sheet
PPV	Positive predictive value
SD	Standard deviation
SDD	Smallest detectable difference
SEM	Standard error of measurement
TFJ	Tibiofemoral joint
TFRA	Tibiofemoral rotation angle
VMO	m. Vastus medialis oblique

1 INTRODUCTION

Patellofemoral pain (PFP) is a frequent condition which places a considerable burden both on affected individuals and on healthcare systems worldwide. It is the most common overuse injury of the lower extremity, especially in runners. (Davis & Powers, 2010; Harbaugh, Wilson & Sheehan 2010; Dierks, Manal, Hamill & Davis 2011; Collins et al., 2013; Myer et al., 2015.)

Excessive costs are caused to healthcare systems, as symptoms are usually worst in individuals who have undergone several (unnecessary) surgeries for initially mild discomfort in the anterior knee area (Dye 2001).

PFP is an umbrella term for patellofemoral pain syndrome (PFPS), chondromalacia patella, anterior knee pain (AKP) and runner's knee. PFP is defined by pain around the anterior knee joint which is usually aggravated by high knee flexion, prolonged sitting as well as repetitive flexion and extension of the knee joint. This pain has to occur in absence of any other patellofemoral joint (PFJ) disorder. Disorders of the joint are present in a great variety of active individuals. (Harbaugh, Wilson & Sheehan 2010; Nunes, Stapait, Kirsten, de Noronha & Santos 2013; Crossley et al. 2016a; Loudon 2016.)

2 PATELLOFEMORAL JOINT ANATOMY

2.1 Skeletal structure and patella cartilage

The anterior distal end of the femur, called the trochlear surface, and the posterior surface of the patella yield the patellofemoral joint. It is a hinge joint that allows free motion, also called an abarticulative or diathrodial joint. (Loudon 2016.)

The patella bone is the largest bone in the body that is embedded in a tendon, these kinds of bones are called sesamoid bones. Its usual shape is triangular with the “tip” pointing inferiorly. This inferior tip is called the apex, while the superior surface is called the base of the patella. The size of the patella can vary with a high of up to 4-4,5 cm lengths, 5-5,5 cm width and 2-2,5 cm depth. The posterior surface of the patella, which contributes to the patellofemoral joint, is divided into two halves by the vertical ridge. Each half is divided into a proximal, middle and distal facet, the medial half has an additional odd facet. Most of the posterior surface is covered with a layer of up to 7 mm of cartilage, which is needed to disperse the forces placed on the bone during quadriceps contraction. More information about the role of cartilage during movement can be found in section 3.1 Kinesiology. (Loudon 2016.)

The distal part of the femur end in the trochlear groove, also called femoral sulcus, which is covered with a thin layer of cartilage. The facets are concave in shape with the lateral facet being larger and more proximal than the medial facet. If straight lines were to be drawn along the femoral sulcus, one medial and one lateral sulcus line, the angle measured between these is called the sulcus angle (see fig. 1). This angle averages from 132 to 144 degrees. (Loudon 2016.)

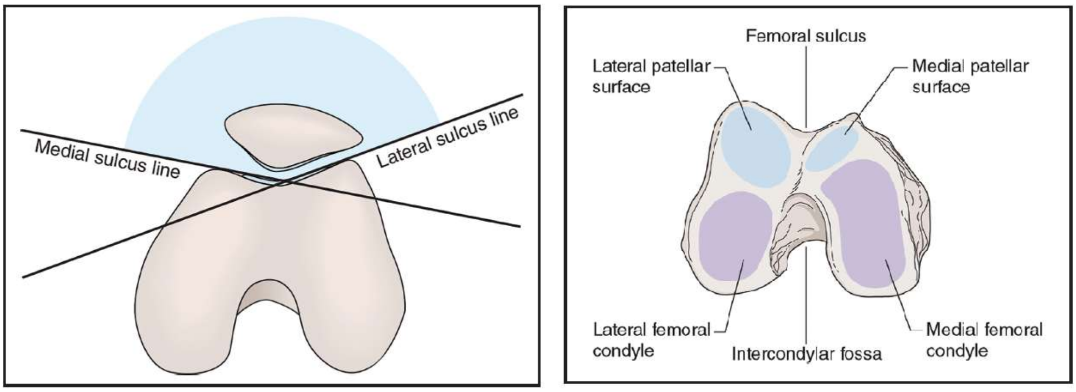


Fig. 1: Femoral sulcus (Loudon 2016)

2.2 Soft tissues

2.2.1 Tendons and ligaments

The static soft tissues around the patellofemoral joint, like patellar tendon, joint capsule and ligaments, contribute to its stability. Medially, the most important ligament providing up to 60 % restraint at 20 degrees knee flexion is the medial patellofemoral ligament (MPFL). The MPFL attaches to the medial border of the patella and the adductor tubercle. Other medial restraints are the medial meniscopatellar ligament, the medial retinaculum, the medial collateral ligament and the medial patellar tendon. Laterally static stability is provided by the lateral patellofemoral ligament, iliotibial band (ITB) ending in the lateral retinaculum, and the joint capsule. The patella tendon stabilizes the patella inferiorly. For illustrative purposes refer to figure 2. (Desio, Burks & Bachus 1998; Loudon 2016.)

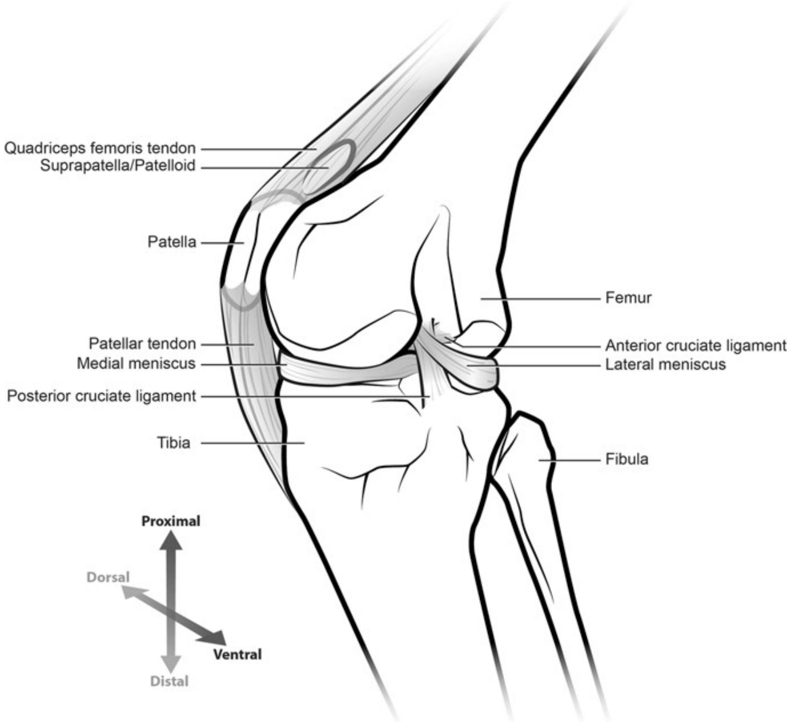


Fig. 2: Main osseous structures, ligaments and tendons of the knee joint (Samuels & Campeau 2019)

2.2.2 Muscles

Dynamic structures, which include the quadriceps muscles, m. biceps femoris and the pes anserine muscle group, also stabilize the patellofemoral joint. The quadriceps muscle group is composed of the m. rectus femoris and the three mm. vastii (lateralis, intermedius and medialis). The most distal part of the m. vastus medialis inserting to the mid portion of the medial patella, called the m. vastus medialis oblique (VMO), has been discussed as a medial stabilizer to the patellofemoral joint extensively, and its stabilizing role was proven in cadaveric studies. Proximally, the patella is stabilized by the rectus femoris attaching anteriorly and by the vastus intermedius attaching to the posterior base of the patella. The m. vastus lateralis, as the name commences, provides lateral stability to the patellofemoral joint. (Davis & Powers 2010; Loudon 2016.)

3 PATELLOFEMORAL JOINT BIOMECHANICS

3.1 Kinesiology

Different sexes have differing mechanics during functional activities like running or squatting (Davis & Powers 2010). Therefore, when considering underlying mechanics of PFP, the biological sex should be kept in mind.

The purpose of the knee joint is to accept, redirect and dissipate biomechanical loads, therefore basically being a biological force redirector or transmitter. The patella itself is a dynamic lever for the quadriceps muscles, and experiences some of the highest loads of all structures in the human body with the whole PFJ enduring the highest loads of all human joints. (Dye 2001; Powers, Bolgla, Callaghan, Collins & Sheehan 2012.)

During knee flexion the patella moves distally and posteriorly. Forces acting on the PFJ can range from half the body weight during walking to over seven times the bodyweight during squatting. (Davis & Powers 2010; Powers, Bolgla, Callaghan, Collins & Sheehan 2012.)

The bony geometry and patellar position within the trochlear groove largely affect patellar tracking (Davis & Powers, 2010). Proprioception is important in dynamically stabilizing the PFJ and tibiofemoral joint (TFJ) (Powers, Bolgla, Callaghan, Collins & Sheehan 2012).

3.2 Pathokinesiology and pathomechanics provoking PFP

The specific causes of PFP are not known and various structures could have a role in PFP development (see 4.1.3 Etiology). In individuals suffering from PFP the stress in the PFJ is greater during walking than in healthy individuals. Increased contact pressure between the lateral facet and the lateral femoral condyle caused by patellofemoral maltracking can lead to articular cartilage damage and its degradation, which over time results in pain. Increased joint contact pressure can also be caused by present knee valgus, as this increased the angle in which the quadriceps acts on the patella. At 45 degrees of knee flexion, for example during squatting, cartilage stress and bone strain are elevated. The peak resultant PFJ reaction forces of individuals with PFP are lower when compared to pain-free individuals during walking, running or stair walking. (Davis & Powers 2010; Dierks, Manal, Hamill & Davis 2011; Powers, Witvrouw, Davis & Crossley 2017.)

Ligamentous laxity or injury, especially of the medial patellofemoral ligament, can alter patellar tracking. Maltracking of the patellar can diminish the contact area of the PFJ, which elevates the PFJ stress during walking, dependent on the amount of knee joint flexion. Another cause of maltracking is the height of the patella and patellar alignment. Mediolateral maltracking of the patella is influenced by the inclination of the lateral anterior femoral condyle rather than the sulcus angle. Femoral adduction as seen from the frontal plane can contribute to PFP development. Another approach is that abnormal motion of the femur may change the PFJ kinematics, opposing the patella maltracking approach. Lateral patellar tilt and displacement during weight-bearing is provoked by internal rotation of the femur against the patella. (Davis &

Powers 2010; Dierks, Manal, Hamill & Davis 2011; Powers, Witvrouw, Davis & Crossley 2017.)

It has been shown that the ITB is tighter and thicker in individuals with PFP when compared to pain-free controls, which affects patellar alignment as well as lateral patellar translation. Still, it is not sure if ITB thickness and tightness is a cause of lateral patellar tilt and translation, or if the constantly laterally translated patella causes the ITB to shorten and thicken. (Powers, Witvrouw, Davis & Crossley 2017.)

If cartilage thickness is decreased, this can cause a vicious cycle of PFP. Thinner cartilage leads to increased cartilage stress, which reduces cartilage thickness even further, which can ultimately even lead to patellofemoral osteoarthritis (PFOA). Nonetheless, even when chondromalacic changes are already advanced, individuals can be asymptomatic, while individuals without articular cartilage changes can exhibit great AKP. (Dye 2001; Powers, Witvrouw, Davis & Crossley 2017.)

During gait, individuals with PFP exhibit lower knee flexion and increased knee abduction. Knee abduction is also increased by a shift of the center of body mass towards the stance limb, which individuals with PFP exhibit through ipsilateral trunk lean during single limb tasks. This increased knee abduction can also be seen at initial ground contact when landing from a jump, where individuals with PFP exhibit higher knee abduction than healthy controls. A peak knee abduction moment (KAM) of >15,4 Nm during a drop jump task is associated with a 6,8 % risk for PFP, compared to a 2,9 % risk when the KAM was <15,4 Nm. (Nakagawa, Moriya, Maciel & Serrão 2012; Hall, Foss, Hewett & Myer 2015; Myer et al. 2015; Powers, Witvrouw, Davis & Crossley 2017.)

Excessive eversion of the foot during weight bearing can alter patellofemoral mechanics through altered motion of the tibia. It can increase tibial and femoral rotation, but evidence of association with PFP is limited. In detail, with excessive eversion the foot is displaced medially. Through this, tibial abduction can be observed, leading to a knee valgus position, which correlates with an increased angle of the quadriceps acting on the patella. This in turn generates a larger lateral force to the patella, predisposing it to lateral maltracking and therefore increases lateral PFJ stress (see fig. 3). (Dierks, Manal, Hamill & Davis 2011; Nakagawa, Moriya, Maciel & Serrão 2012; Powers, Witvrouw, Davis & Crossley 2017.)

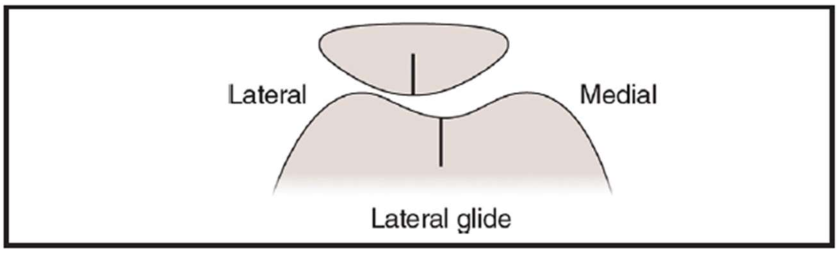


Fig. 3: Lateral glide/maltracking (Loudon 2016)

Altered kinematics of the tibiofemoral joint, which can be caused for example by abnormal hip kinematics, also influence PFJ reaction forces, as it influences the available contact area for force distribution. Knee valgus is also increased through excessive hip adduction. Additional to increased knee abduction, subjects with PFP also exhibit increased contralateral pelvic drop (Trendelenburg sign). It can sometimes be observed that individuals with PFP decrease their knee flexion to decrease the load on the joint and its movement, which could reduce pain. (Dierks, Manal, Hamill & Davis 2011; Nakagawa, Moriya, Maciel & Serrão 2012; Powers, Witvrouw, Davis & Crossley 2017.)

It has to be kept in mind that the osseous morphology, implying the palpable osseous structures, may not match the cartilage morphology. Thus, when osseous morphology implies malalignment, the cartilage surfaces may actually be well aligned. (Dye 2001.)

It would go beyond the scope of this thesis to present all influencing factors, therefore the interested reader can refer to Appendix two and three for further reading.

3.3 Biochemical reactions in PFP

Next to mechanical problems aiding in the development of PFP, biochemical reactions can influence it as well. For a body to function well biomechanical reactions have to be kept within a certain stable range. This active maintenance of bodily functions to remain stable is called homeostasis. As a simple example, body temperature or oxygen contents of the blood have to remain stable for the body to survive. (Rodolfo 2000.) PFJ homeostasis can be disturbed if loading on the joint is outside the "envelope of function". This can be either too little loading (e.g. through bed rest), ultimately leading to muscle atrophy and osteopenia, or overloading leading to microfracturing. It should be kept in mind that the envelope of function diminishes after every injury to the PFJ and its surrounding structures. (Dye 2001.)

Perception of pain can be changed through chemical nerve irritation caused by increased cytokine production (inflammation), which can be stimulated through the occurring breakdown of fibrillated cartilage. PFP can lead to repeated swelling of the synovial tissues which impacts on the mechanical irritation around the PFJ and possible nerve impingements. Through the pain, distressful neuromas, meaning either swollen nerves or benign excessive growth of nerves, can occur. Furthermore, the neuroactive peptide "substance P", which the body releases immediately in response to pain, can be present in PFP for extended periods of time, ultimately leading to chronic pain. (Dye 2001.)

As the PFJ tissues are usually loaded to the limits of its load acceptance, they are often the first to be loaded to their point of physiologic failure. This changes perception of pain through loss of tissue homeostasis. Pain perception can also be impacted by ischemia around the PFJ. (Dye 2001; Powers, Bolgla, Callaghan, Collins & Sheehan 2012).

It is not known if osteal remodeling correlates to the etiology of PFP, however increased patellar uptake and osseous metabolic activity of the patella have been shown in subjects with PFP. Even though increased bone metabolic activity can be shown through a scintigraphy, it is not clear if the outcome is a loss or gain in the patella bone mass. Nevertheless, there seems to be a correlation between pain intensity and osseous metabolic activity. (Dye 2001; Naslund, Naslund, Odenbring & Lundeberg 2006; Powers, Bolgla, Callaghan, Collins & Sheehan 2012.)

As a physiotherapist it is not necessary to know the exact mapping of tissue homeostasis, cytokine and substance P in every patient, but it is important to understand the possible underlying biochemical causes and influences on PFP.

4 PATELLOFEMORAL PAIN SYNDROME

4.1 Background

PFP is a mechanical disorder of the knee that presents with diffuse pain located around the patella and is provoked or worsened by activities like squatting, stair walking or running. It usually presents with subtle onset of pain in the anterior aspect of the knee which worsens over time. (Davis & Powers 2010; Dierks, Manal, Hamill & Davis 2011; Nakagawa, Moriya, Maciel & Serrão 2012; Collins et al. 2013; Witvrouw et al. 2014; Selfe et al. 2015; Crossley et al. 2016a; Crossley et al. 2016b; Selfe et al. 2016; Collins et al. 2018.)

It is important to note that PFP is not, like commonly assumed, a self-limiting condition, but can persist for many years (Collins et al. 2013; Crossley et al. 2016b; Selfe et al. 2016).

4.1.1 Diagnostic criteria and tests

No single subjective or objective evaluation can diagnose PFP, instead it is a diagnosis of exclusion. It should be kept in mind that other disorders, like degenerative joint diseases, PFOA, chondral lesions, medial meniscus tears or medial overload syndrome, patellar tendinopathy, Baker's cysts, morbus Osgood-Schlatter, morbus Sinding-Larsen, morbus Johansson or anterior cruciate ligament (ACL) tears can present similar to PFP. (Naslund, Naslund, Odenbring & Lundeberg 2006; Cook, Hegedus, Hawkins, Scovell & Wyland 2010.)

Diagnostic criteria include an increase of AKP by sitting, stair walking or squatting movements, pain in or around the patella or retropatellar pain with an insidious onset which lasts for at least six week and is provoked by said activities. The international knee documentation committee created the subjective knee evaluation form (International Knee Documentation Committee 2000), which is used for patient's perception of pain, symptoms, functions, activity and tenderness. (Cook, Hegedus, Hawkins, Scovell & Wyland 2010; Hall, Fass, Hewett & Myer 2015.)

Tests include manual compression of the kneecap against the femur at either rest or isometric quadriceps contraction, palpation of posterior patella borders both medially and laterally, active instability tests, tilt tests, and resisted isometric quadriceps contraction. The latter has a positive predictive value (PPV) of 95 %, a likelihood ratio (LR) of 95 % and a specificity of 82 %. Tests most sensitive to PFP are pain during squatting (91%) and pain during kneeling (84 %). One score with high test-retest reliability, which is also responsive to changes in patients with PFP, is the Kujala anterior knee pain score (AKPS). Another test used with high specificity is the vastus medialis coordination test. (Naslund, Naslund, Odenbring & Lundeberg 2006; Cook, Hegedus, Hawkins, Scovell & Wyland 2010; Nunes, Stapait, Kirsten, de Noronha & Santos 2013; Hall, Fass, Hewett & Myer 2015; Ittenbach, Huang, Foss, Hewett & Myer 2016.)

4.1.2 Epidemiology

The true prevalence of PFP is unknown, but it may account for 25-40% of knee problems seen in sports clinics and 11-17 % of knee problems seen in general practice. High incidences of PFP may not be true numbers, but instead could be caused by failure in excluding other diagnoses. (Naslund, Naslund, Odenbring & Lundeberg 2006; Witvrouw et al. 2014; Crossley et al. 2016b.)

The syndrome seems to be more prevalent in physically active individuals and young adolescents. The peak prevalence is among youngsters aged 12 to 17, Thomas et al. (2010) specify the prevalence during childhood and adolescence at 19 %, while others describe a prevalence of 29 % for adolescents and 23 % for adults. The incidence among young adolescents is 9,2 %. (Davis & Powers 2010; Thomas, Wood, Selfe & Peat 2010; Witvrouw et al. 2014; Hall, Fass, Hewett & Myer 2015; Crossley et al. 2016a; Crossley et al. 2016b; Collins et al. 2018.)

Gender prevalence is not yet clarified without doubt, but it has been shown that in adolescents the prevalence is higher in women, which in earlier times led to a definition of PFP as a problem of female adolescence (Davis & Powers 2010; Powers, Bolgla, Callaghan, Collins & Sheehan 2012; Nunes, Stapait, Kirsten, de Noronha & Santos 2013; Witvrouw et al. 2014; Myer et al. 2015).

4.1.3 Etiology

The causes and risk factors of PFP are multifactorial and some authors suggest a likely mechanical reason for its initial onset, which is currently the primary theory for cause of PFP (Davis & Powers 2010; Harbaugh, Wilson & Sheehan 2010; Powers, Bolgla, Callaghan, Collins & Sheehan 2012).

Being specialized in a single sport as an adolescent raises the risk of suffering of PFP compared to multisport athletes. This may be due to repetitive loading of the PFJ. If the joint is overloaded repetitively it could increase patellar subchondral bone metabolic activity as well as patellar bone water content. It has been shown that in PFP caused by running, the pain fluctuates with changes in patellar water content. Additionally, a greater infrapatellar fat pad seems to be related to higher knee pain in individuals suffering from PFP. Its development can also be aided by generalized ligamentous laxity. (Davis & Powers 2010; Powers, Bolgla, Callaghan, Collins & Sheehan 2012; Hall, Fass, Hewett & Myer 2015; Crossley et al. 2016a; Powers, Witvrouw, Davis & Crossley 2017.)

Generalized quadriceps weakness or even atrophy is noticeable in idiopathic PFP, but it is not clear if this is a cause or consequence of the pain. On the other hand, a shortened quadriceps muscle seems to be a risk for PFP development. (Powers, Witvrouw, Davis & Crossley 2017.)

Navicular drop seems to be a risk-factor for the development of PFP as well. If there is little knee flexion during a jump-landing task it is a risk-factor for the development of PFP. For a long time, it was suspected that the static Q-angle would contribute to PFP, but this has been disproven. Other pathomechanical risk factors were described in section 3.2. The body mass index (BMI) and body composition, commonly regarded as a risk factor for PFP, are not associated with predisposition to PFP in young adolescent adults. (Witvrouw et al. 2014; Hall, Fass, Hewett & Myer 2015; Powers, Witvrouw, Davis & Crossley 2017.)

Other influences on PFP may be psychological, as it has been shown that somatization to pain can be present in female teenagers after possible physical or sexual abuse (Dye 2001).

4.1.4 Sequelae/Progression

Many individuals with PFP, about 70-90 %, suffer of recurrent or even chronic pain, which can lead to limitation in physical activities and less participation in sporting activities. Consequently, partaking in social life may decrease. (Davis & Powers 2010; Selfe et al. 2013; Selfe et al. 2015; Crossley et al. 2016a; Crossley et al.2016b; Selfe et al. 2016.)

If PFOA is a sequela of PFP has not yet been determined and is often discussed in literature (Davis & Powers 2010; Thomas, Wood, Selfe & Peat 2010; Dierks, Manal, Hamill & Davis 2011; Collins et al. 2013; Selfe et al. 2016).

The earlier described increased knee abduction during landing from a jump task (Section 3.2) also increases the risk for primary ACL rupture. Hip weakness could possibly develop as a consequence of PFP. (Myer et al. 2015; Powers, Witvrouw, Davis & Crossley 2017.)

Non-physical sequelae can include altered nociceptive and somatosensory processing, impaired sensorimotor function, and psychological factors like catastrophizing and kinesiophobia (Powers, Witvrouw, Davis & Crossley 2017).

4.2 Subgrouping of patellofemoral pain clients

Subgrouping has shown to be effective in other syndromes, for example low back pain. The current multimodal treatment approach is not effective enough, as 40 % of individuals after one-year follow-up from exercise intervention treatment did not recover fully or even moderately and 80 % of individuals still report pain five years after completion of a rehabilitation program. Other authors have reported that PFP persists in 50 % of cases, sometimes up to 20 years. (Davis & Powers 2010; Powers, Bolgla, Callaghan, Collins & Sheehan 2012; Witvrouw et al. 2014; Selfe et al. 2015; Selfe et al. 2016; Collins et al. 2018.)

In the consensus statement of the 2013 international patellofemoral pain research retreat subgrouping is declared as the “holy grail” of PFP research and is therefore an international priority (Witvrouw et al. 2014; Selfe et al. 2015).

4.2.1 Subgrouping system

There are several different ways to divide PFP clients into subgroups. Each division has its own perks and weakness. An older subgrouping approach was to divide clients into PFP causes related to the hip joint (proximal subgroup), knee joint (local subgroup), and ankle joint (distal subgroup). The subgrouping system I am describing has been developed and described by Selfe et al. (2013, 2015, 2016, 2018) and consists of three groups. One subgroup has high muscle strength, one is weaker with tight muscles, and the last one weak with pronated feet. (Davis & Powers 2010; Selfe et al. 2013; Selfe et al. 2015; Selfe et al. 2016; Selfe, Janssen, Drew & Dey 2018.)

It is important to note that individuals with PFP who suffer from recurrent patellar subluxation or dislocation form their own subgroup and are not considered further in this subgrouping system (Davis & Powers 2010).

4.2.2 How is subgrouping done so far?

Several high cost tests, like x-rays, MRIs, and six camera 3D analysis, have been proven useful in subgrouping. Admittedly, these tests are of no use to clinicians, as they are too expensive, and equipment is not available in a normal physiotherapy practice. (Selfe, Janssen, Drew & Dey 2018.)

Cheaper tests which were found to be useful are rectus femoris length, gastrocnemius length, maximum quadriceps strength, maximum hip abductor strength, total patellar mobility and foot posture index (Selfe et al. 2013; Selfe et al. 2015; Selfe et al. 2016; Selfe, Janssen, Drew & Dey 2018). There is no consistent use of tests for diagnosis or subgrouping of PFP (Cook, Hegedus, Hawkins, Scovell & Wyland 2010).

5 AIM AND OBJECTIVES OF THE THESIS

A mobile app sorting patellofemoral pain clients into subgroups is in development. Physiotherapists will be able to fill in client data, after which the app will determine the client's subgroup. The current study is supposed to identify if the 2D measured frontal plane projection angle can be used as one of the parameters used for discrimination between the subgroups.

The aim of this thesis is to establish a baseline set of data which can be compared to patellofemoral pain clients in later studies. To achieve this aim I will collect data from healthy individuals and analyze the range of measurements. I will then analyze the reliability of the different measurement methods.

6 FIRST TESTING PERIOD

6.1 Original process

The original testing process was created in Manchester in March/April 2018. As the testing is done across several countries, a rigorous testing procedure is needed.
The gathered personal data will include date of birth, height and weight, as height will influence the needed knee flexion to step down. The stance leg will be the preferred kicking leg. The step will be 20 cm high, as this is in-line with EU regulations for step height on stairs (European Comission 2011) as well as the usual height of a professional aerobic step. The placement of the camera was set at 3 m distance to the

participant, as this was the distance at which the participant's whole body excluding the face was caught on video. A trial with 2 m distance showed, that this would not be suitable for taller individuals. The camera will be placed at the height of the knee cap when standing on the step (i.e. height of knee cap + 20 cm). It was decided to do testing barefoot and assess the foot posture index (FPI), as foot kinematics can influence on patella tracking (Refer to section 3.2 for more information).

White sticky tape markers sized 2,54 cm^2 will be attached at the lateral and medial epicondyle of the femur, at the midpoint of the rectus femoris, at the insertion of the rectus femoris to the patellar tendon and at the midpoint between the lateral and medial malleolus (see fig. 4). The participant then practices a step-down five times, after which five trials are filmed. It is assumed that out of five at least three trials will be good enough for evaluation. The steps are performed with the arms crossed coffin-style in front of the chest to obviate excessive arms movements.

Fig. 4: Positioning of markers.

6.2 Pre-testing

During pre-testing with ten individuals it was observed that markers were sometimes not visible to the camera. To avoid this, two changes were made to the original testing protocol: One necessary change was to turn the step either 10° to the right or 10° to the left, if the markers could not be seen in a neutral position. The second change, a non-white background, is optional, but simplifies later analysis of the captured video material.

It was observed that participants were not consistent in touching the floor first with the heel or with the toe, which led to the conclusion that given instructions had to be clearer. It was agreed that participants will from now on perform five trials with heel touch and five trials with toe touch. The order of these will be randomly chosen by the participant from a sealed envelope.

6.3 Results of the first testing period in Manchester

The first 32 datasets (including the data of the first ten pre-testing subjects) showed high intertester reliability (high intraclass correlations with low standard error of measurement and low standard deviation), which raises hopes for high reliability in this study at SAMK as well (Callaghan 2018).

Some minor issues were faced during analysis of the dataset. The chosen analysis software cannot turn videos from landscape to portrait mode or vice versa, which is why all videos taken from now on will be in landscape mode. Not all subjects returned to the starting position after each step trial, which made it difficult to pinpoint the exact start/end of trials. From now on participants will be instructed to return to a standing position after each step trial.

7 METHODS

7.1 Recruitment

Advertisements were sent to all students of SAMK via e-mail (see Appendix 1). Additionally, I advertised personally in two physiotherapy study groups. The most effective way of recruitment was word of mouth, many participants were found by asking people walking by the room on the testing day. Subjects were asked to recommend the study to their classmates, which again increased the number of participants. Participants were asked to book a time for testing through Doodle.

7.2 Sample size

To mimic the trials in other countries, the aim was to recruit 10-25 participants. As the time frame for the study was limited, three dates were offered for testing. If someone wanted to participant outside of the official testing times, another meeting was agreed upon.

7.3 Test procedure

7.3.1 Preparation of test area

The whole testing area was comprised of three areas, including a separated area for participants to change their clothing, one sitting area with scale and height measure for consent taking, personal data collection and participant preparation, and the testing area comprised of a non-white wall, a 20 cm step with a white marking tape through the middle and a camera stand three meters apart from the step (see fig. 5). An assistant was standing next to the participants during testing to minimize the risk of falling.

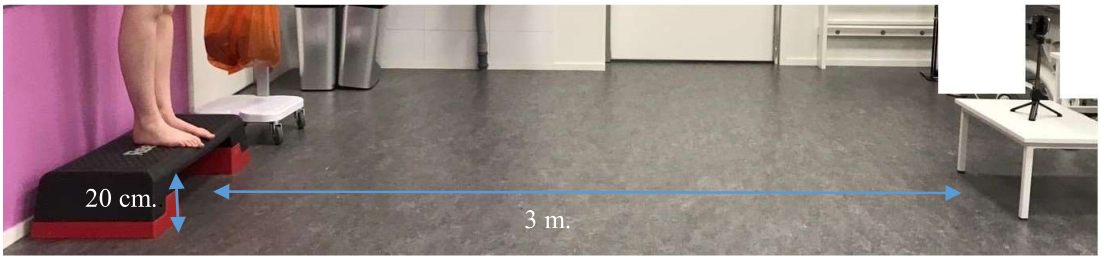


Fig. 5: Test area

7.3.2 Preparation of tests

The participants were asked to carefully read the patient information sheet (PIS) [dated 19.11.18] [version1.2] after which there was time for questions and consent taking. A copy of the consent form as well as the PIS was provided to participants. The participant then changed into shorts, these were either their own or provided by the researcher. Date of birth, height and weight were measured and the starting order (toe touch first or heel touch first) were randomized. In the next step the tape markers were placed on the preferred kicking leg.

Moving on to the testing area, the height of the camera was determined, and the equipment set up in place. The subject was explained and shown how to perform the step downs, including folding of the arms and line of sight. While the participant performed some practice step-downs (both toe touch and heel touch), the researcher checked that all markers can be seen on the smartphone-screen. If this was not the case, the step was adjusted with 10° rotation to the left or right.

7.3.3 Conduction of tests

On the count of three the participant performed five step-downs with either heel or toe touch, which were video-recorded. The second trial of five was performed with initial floor contact contrary to the first trial. The trials were recorded separately. After each step-down it was made sure the participant returned to a normal standing position and the arms stayed folded on the chest. After all trials were successfully completed, the FPI was assessed. The participant could then get dressed and the testing was over.

7.4 Statistical analysis

The frontal plane projection angle (FPPA) and the tibio-femoral rotation angle (TFRA) are measured at the initial floor contact of each step using the App. The data is compiled anonymously in an Excel sheet. Main focus is on the FPPA for two reasons. Firstly, it has been shown that the 2-D FPPA correlates well with the 3-D measures; and secondly evidence suggests that individuals suffering from PFP have an increased 2-D FPPA during one-leg squats (Davis & Powers 2010). The statistical software IBM SPSS statistics (subscription) is used for analysis.

8 RESULTS

8.1 Subjects

A total of 15 subjects were recruited, of which nine were female and six male. The age ranged from 19 years to 39 years with an average age of 26,7 years. Participants were between 147 cm and 188 cm tall, averaging at 162,3 cm. 14 participants preferred the right leg as kicking leg, one participant preferred the left leg. Four participants started with the toe-touch trial, the other eleven with the heel-touch trial. Of these 15 participants, one was excluded of the video analysis as the rectus femoris marker was hidden by pants sliding over it.

8.2 Data analysis

8.2.1 Statistical tools

Each set of data was analysed for general descriptives, including minimum (Min.), maximum (Max.), mean, variance (v.) and standard deviation (SD). As only one researcher performed analysis of the videos, data was tested for intratester reliability. The process of choosing the Intraclass correlation coefficient 2,k with absolute agreement can be followed from figure 6. The ANOVA (ANalysis Of VAriance) F test was performed along with the ICC, and the within people residual value was used to calculate the standard error of measurement (SEM), which is the square root of the within people residual. Knowing the SEM, the smallest detectable difference (SDD) $\sqrt{2} \times 1{,}96 \times SEM$ could be calculated. To change the SDD from degrees to percentage it was divided by the grand mean and multiplied by 100. The assumed confidence interval was 95 %. (Callaghan 2019.) Examples for the calculations and table outputs can be found from tables 1-4.

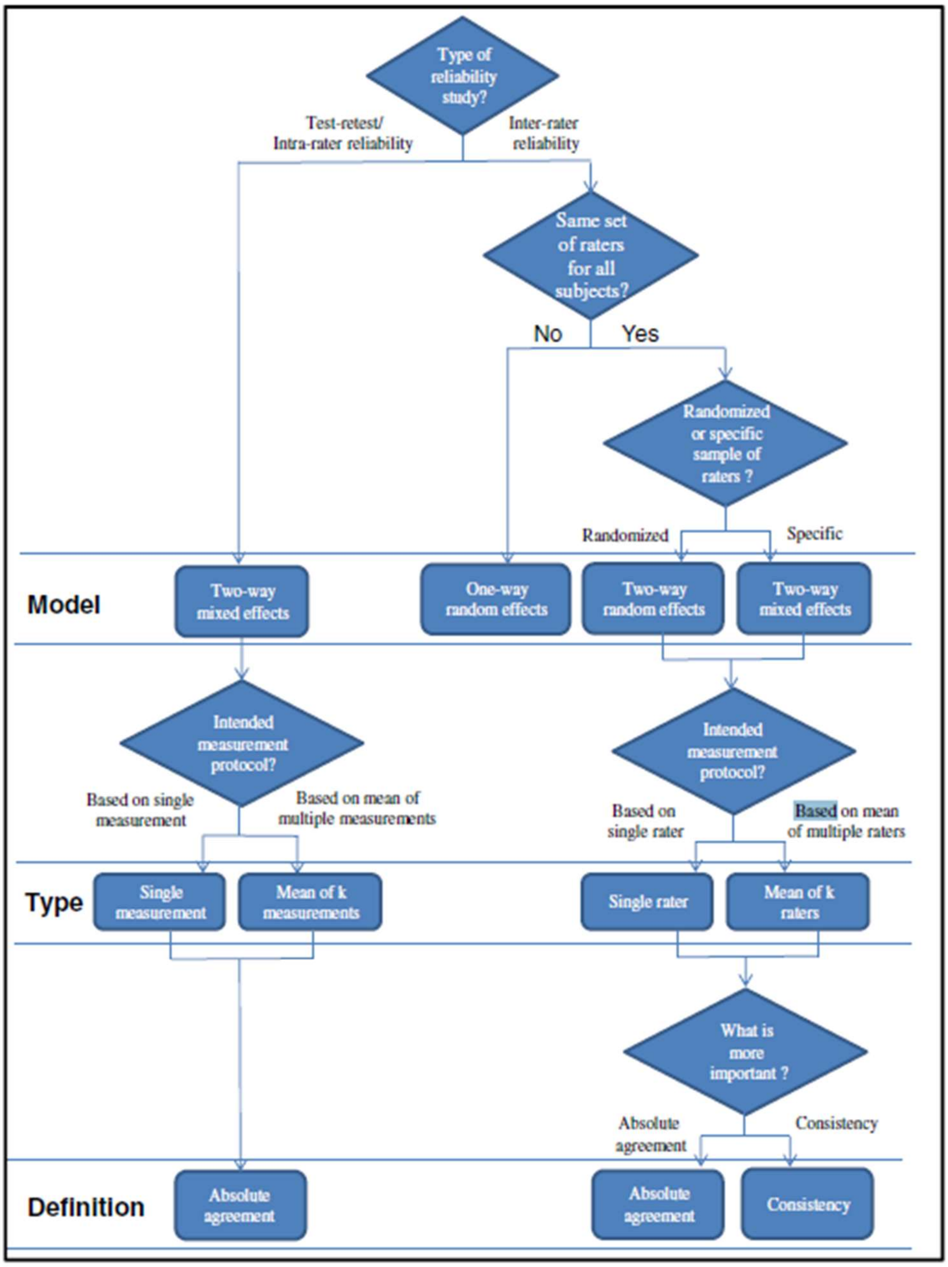


Fig. 6: Process of choosing the right ICC model (Koo & Li 2016).

8.2.2 FPPA toe touch

One case was missing a value for one trial. In order to still use the case for analysis, the missing value was replaced by the case's mean value.

The data ranged from Min. 157 degrees to Max. 180 degrees with a mean of 170,33 degrees and a SD of 6,69 degrees. The $ICC_{2,k}$ showed 0,823 for the single measures. The within people residue is 9,75 degrees, which leads to a SEM of 3,12 degrees. The SDD is 8,65 degrees or 5,08 %.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		2911.190	13	223.938		
Within People	Between Items	10.318	4	2.579	.265	.899
	Residual	506.832	52	9.747		
	Total	517.150	56	9.235		
Total		3428.340	69	49.686		

Grand Mean = 170,3321

Table 1: Example of ANOVA F calculations for the FPPA toe dataset.

8.2.3 FPPA heel touch

Two cases were missing a value for one trial, both were replaced by the specific case's average value.

The data ranged from Min. 151 degrees to Max. 179 degrees with a mean of 166,74 degrees and a SD of 8,31 degrees. The $ICC_{2,k}$ showed 0,865 for the single measures. The within people residue is 10,69 degrees, which leads to a SEM of 3,27 degrees. The SDD is 9,06 degrees or 5,43%.

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.865[a]	.741	.947	32.341	13	52	.000
Average Measures	.970[c]	.935	.989	32.341	13	52	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Table 2: Example of the $ICC_{2,k}$ calculations for the FPPA heel dataset.

8.2.4 TFRA toe touch

One case was missing a value for one trial. In order to still use the case for analysis, the missing value was replaced by the case's mean value.

The data ranged from Min. 73 degrees to Max. 136 degrees with a mean of 97,62 degrees and a SD of 15,9 degrees. The $ICC_{2,k}$ showed 0,969 for the single measures. The within people residue is 8,43 degrees, which leads to a SEM of 2,9 degrees. The SDD is 8,05 degrees or 8,24 %.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
TFRA1	14	79.00	131.00	98.1429	14.68048
TFRA2	14	75.00	136.00	97.5000	15.65862
TFRA3	14	76.00	134.00	97.3571	16.39234
TFRA4	14	73.00	136.00	97.6786	17.24887
TFRA5	14	74.00	130.00	97.4286	16.44438
Mean	14	76.40	133.40	97.6214	15.89747
Valid N (listwise)	14				

Table 3: Example of descriptive statistics for TFRA toe dataset.

8.2.5 TFRA heel touch

Two cases were missing a value for one trial, both were replaced by the specific case's average value.

The data ranged from Min. 73 degrees to Max. 131 degrees with a mean of 95,93 degrees and a SD of 14,93 degrees. The $ICC_{2,k}$ showed 0,939 for the single measures. The within people residue is 14,76 degrees, which leads to a SEM of 3,84 degrees. The SDD is 10,65 degrees or 11,10 %.

	Formula	Result
SEM	$\sqrt{14,76}$	3,84°
SDD	$\sqrt{2} \times 1,96 \times 3,84$	10,65°
SDD percentage	$10,65 \div 95,93 \times 100$	11,10 %

Table 4: Example of SEM and SDD calculations for the TFRA heel dataset.

9 CONCLUSION

Both toe touch datasets showed a higher mean value than their concurrent heel touch trial, which is presumably due to the lesser knee flexion needed during toe touch. The FPPA datasets had far lower standard deviations than the TFRA datasets, showing less variety between subjects.

In all trials the SDD was higher than the SEM, therefore any detectable difference in future trials can be assumed to be due to real change instead of measurement error. The FPPA toe touch trial had the percentually smallest detectable difference (5,08 %), therefore being the most sensitive of the measures.

All datasets have an $ICC_{2,k}$ of over 0,8, therefore all are reliable. The most stable measurement seems to be the TFRA toe touch dataset, as it has the highest ICC combined with the lowest SEM. Considering TFRA has not yet been proven to be combined to patellofemoral pain, future research needs to evaluate this aspect before the measure can be used.

Between the two main relevant measurements, FPPA heel and toe touch, there are only slight differences. The heel touch trial has a higher ICC, but also a higher SEM and SDD, while the toe touch trial has a lower ICC but also a lower SEM and SDD. In this case, as the measure is supposed to be used for classification rather than for testing of measurement change over time, it is presumably more reasonable to choose the FPPA heel touch measure. It has a higher reliability and detecting differences in future trials is not as important.

The high intratester reliability in all datasets could be explained by the researcher's experience in the testing, as well as the high intertester reliability in the previous study. It is for future studies to determine how much training a researcher would need in order to achieve the high reliability.

The answer to the original question of this thesis, "how reliable is it?", would simply be: The tests showed a high reliability, but further investigation is needed to extend this finding to other researchers and subject groups.

10 DISCUSSION

10.1 Limitations

One limitation was, that most studies on PFP so far have been either on athletes, military recruits or only on females. It is not possible to transfer these findings to the general population as it is.

Intratester reliability is less useful than intertester reliability, as findings cannot be generalized across researchers. Even though the reliability for the acting researcher was high, it cannot be concluded that this would be the case for every researcher.

The study was also limited to testing each participant only once, not showing any possible change between days of measurement. It could for example happen that participants significantly improve for a second testing day due to training of the movement.

Most of the participants were physiotherapy students, therefore representing a part of the population which is usually more physically active. Assumingly due to the fact that most participants were students, the average age was low, representing only a part of the target population.

10.2 Implementation for future research

Additional researchers should analyze the video-material for the same parameters to test for intertester reliability. Further research should also concentrate on testing the same subjects on different days, to check for test-retest reliability. During this, the training effect of trials are to be kept in mind.

The videos can be used to further analyze the lateral or medial patella displacement during step-down. This would allow to check for FPPA and TFRA at moments of highest lateral/medial displacement of the patella, to see if these points would be more effective to distinguish between subjects.

After a sufficient amount of data has been compiled from this research (along with the same tests done elsewhere), and the reliability has been proven to be sufficient, the next phase of the research can be started. The same test should then be performed with PFP subjects, to analyze any appearing differences between these two groups.

Mainly the FPPA heel touch trial should be performed with a larger set of subjects as well as with a subject set of PFP clients in order to further validate its reliability, sensitivity and specificity. This data would then have to be compared further with the subgroup classification system, to ensure usability of these tests for classification purposes.

10.3 My thesis process

The topic was offered to me during my work practice in Manchester, as I was involved with the testing period there. It was therefore only natural for me to carry on the study in Finland, as it is supposed to be done in several different countries. Getting ethical approval was more difficult than expected. As the study protocol had already been accepted by the ethical board of Manchester Metropolitan University, I assumed getting ethical approval in Finland would be a matter of handing in the study protocol. This was not the case, instead I had to write a full request for ethical approval. At first this was a misfortune, but during the process of writing it I learned so much about ethical boards, their decisions, confidentiality and handling of personal data that after all I consider myself lucky that I had the chance to educate myself on this topic while still supported by teachers. This will allow me to perform this task independently if needed later on in work life.

For safety reasons, and also to ease my workload, I recruited an assistant for the testing days. This was surprisingly easy and there were several students willing to help me. To be fair, I randomly chose one of them. It was a great help for me to have a student with me, as I could delegate some of the necessary preparations during the testing. This shortened the time required per participant. If the time needed would have been longer, some participants would not have taken part.

The main challenge for me was data analysis, as it was difficult to decide on the right models for statistical analysis. In this aspect I had help from Professor Michael Callaghan from Manchester Metropolitan University, he has answered to any questions I had about statistical analysis. Another issue during the statistical analysis was that the program, which was used during the previous studies, is not available at my university.

REFERENCES

Callaghan, M. RE: TIPPS-Thesis. Receiver: Uecker S. Sent 13.11.2018. Referred 14.12.2018

Callaghan, M. RE: Question about ICC model. Receiver: Uecker S. Sent 2-19.3.2019. Referred 19.3.2019

Collins N. J., Bierma-Zeinstra S. M. A., Crossley K. M., van Linschoten R. L., Vicenzino B. & van Middelkoop M. 2013. Prognostic factors for patellofemoral pain: a multicentre observational analysis. British Journal of Sports Medicine, v. 47, n. 4, p. 227-33

Collins N. J., Bouton C. J., van Middelkoop M., Callaghan M. J., Rathleff M. S., Vicenzino B. T., Davis I. S., Powers C. M., Maari E. M., Haut H. F., de Oliviera Silva D. & Crossley K. M. 2018. Consensus statement on exercise therapy and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th International Patellofemoral Pain Research Retreat, Gold Coast, Australia, 2017. British Journal of Sports Medicine, v. 52, n. 18, p. 1170-1178

Cook C., Hegedus E., Hawkins R., Scovell F. & Wyland D. 2010. Diagnostic accuracy and association to disability of clinical test findings associated with patellofemoral pain syndrome. Physiotherapy Canada, v. 62, n. 1, p. 17-24

Crossley K. M., Stefanik J. J., Selfe J., Collins N. J., Davis I. S., Powers C. M., McConnell J., Vicenzino B., Bazett-Jones D. M., Esculier J.-F., Morrisey D. &Callaghan M. J. 2016. Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome measures. British Journal of Sports Medicine, v. 50, n. 14, p. 839-43

Crossley K. M., van Middelkoop M., Callaghan M. J., Collins N. J., Rathleff M. S. & Barton C. J. 2016. Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). British Journal of Sports Medicine, v. 50, n. 14, p. 844-52

Davis I. S. & Powers C. M. 2010. Patellofemoral pain syndrome: proximal, distal, and local factors, an international retreat, April 30-May 2, 2009, Fells Point, Baltimore. Journal of Orthopaedic Sports Physical Therapy, v.40, p.A1-16

Desio S. M., Burks R. T. & Bachus K. N. 1998. Soft tissue restraints to lateral patellar translation in the human knee. American Journal of Sports Medicine, v. 26, n. 1, p. 59-65

Dierks T. A., Manal K. T., Hamill J. & Davis I. 2011. Lower extremity kinematics in runners with patellofemoral pain during a prolonged run. Medicine & Science in Sports & Exercise, v. 43, n. 4, p. 693-700

Dye S. F. 2001. Patellofemoral Pain Current Concepts: An Overview. Sports Medicine and Arthroscopy Review, v. 9, n. 4

European Commission 2011. Manual of standard building specifications. Brussels, Office for infrastructure and logistics

Hall R., Foss K. B., Hewett T. E. & Myer G. D. 2015. Sport specialization's association with an increased risk of developing anterior knee pain in adolescent female athletes. Journal of Sport Rehabilitation v. 24, n. 1, p. 31-5

Harbaugh C. M., Wilson N. A. & Sheehan F. T. 2010. Correlating femoral shape with patellar kinematics in patients with patellofemoral pain. Journal of Orthopaedic Research, v. 28, n. 7, p. 865-72

International knee documentation committee 2000. IKDC Subjective Knee Evaluation Form

Ittenbach R. F., Huang G., Foss K. D. B., Hewett T. E. & Myer G. D. 2016. Reliability and Validity of the Anterior Knee Pain Scale: Applications for Use as an Epidemiologic Screener. PloS one, v. 11, n. 7, p. e0159204-e0159204

Koo T. K. & Li M. Y. 2016. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. Journal of Chiropractic Medicine n. 15 p. 155-163

Loudon J. K. 2016. Biomechanics and pathomechanics of the patellofemoral joint. International Journal of sports physical therapy, v. 11, n. 6, p. 820-830

Myer G. D., Ford K. R., Di Stasi S. L., Foss K. D. B., Micheli L. J. & Hewett T. E. 2015. High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: is PFP itself a predictor for subsequent ACL injury? British Journal of Sports Medicine, v. 49, n. 2, p. 118-22

Nakagawa, T. H., Moriya E. T. U., Maciel C. D. & Serrão F. V. 2012. Frontal plane biomechanics in males and females with and without patellofemoral pain. Medicine & Science in Sports & Exercise, v. 44, n. 9, p. 1747-55

Naslund J., Naslund U.-B., Odenbring S. & Lundeberg T. 2006. Comparison of symptoms and clinical findings in subgroups of individuals with patellofemoral pain. Physiotherapy Theory and Practice, v. 22, n. 3, p. 105-18

Nunes G. S., Stapait E. L., Kirsten M. H., de Noronha M. & Santos G. M. 2013. Clinical test for diagnosis of patellofemoral pain syndrome: Systematic review with meta-analysis. Physical Therapy in Sport, v. 14, n. 1, p. 54-9

Powers, C. M., Bolgla L. A., Callaghan M. J., Collins N. & Sheehan F. T. 2012. Patellofemoral pain: proximal, distal, and local factors, 2nd International Research Retreat. Journal of Orthopaedic Sports Physical Therapy, v. 42, n. 6, p. A1-54

Powers C. M., Witvrouw E., Davis I. S. & Crossley K. M. 2017. Evidence-based framework for a pathomechanical model of patellofemoral pain: 2017 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester, UK: part 3. British Journal of Sports Medicine, v. 51, n. 24, p. 1713-1723

Rodolfo K. 2000. What is homeostasis? Scientific American.

Samuels M. E. & Campeau P. M. 2019. Genetics of the patella. European Journal of Human Genetics

Selfe J., Callaghan M., Witvrouw E., Richards J., Dey M. P., Sutton C., Dixon J., Martin D., Stokes M., Janssen J., Ritchie E. & Turner D. 2013. Targeted interventions for patellofemoral pain syndrome (TIPPS): classification of clinical subgroups. BMJ Open, v. 3, n. 9

Selfe J., Dey P., Callaghan M., Witvrouw E., Richards J., Sutton C., Stokes M., Martin D., Dixon J., Hogarth R., Baltzopoulos V., Ritchie E., Arden N., Turner D., Masters R., Polman R. & Janssen J. 2015. Targeted intervention for patellofemoral pain (TIPPS): identifying potential clinical subgroups. Physiotherapy, v. 101, p. e1365-e1366

Selfe J., Janssen J., Callaghan M., Witvrouw E., Sutton C., Richards J., Stokes M., Martin D., Dixon J., Hogarth R., Baltzopoulos V., Ritchie E., Arden N. & Dey P. 2016. Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs). British Journal of Sports Medicine, v. 50, n. 14, p. 873-880

Selfe J., Janssen J., Drew B. & Dey P. 2018. Anterior knee pain subgroups: the first step towards a personalized treatment. Annals of Joint v.3, n.32, p.1-9

Sports medicine NI 2019. Mechanisms of patellofemoral pain. Instagram Account of @sportsmedicineni. Referred 4.4.2019.
https://www.instagram.com/p/BuwbEVGhcTo/

Thomas M. J., Wood L., Selfe J. & Peat G. 2010. Anterior knee pain in younger adults as a precursor to subsequent patellofemoral osteoarthritis: a systematic review. BMC Musculoskeletal Disorders, v. 11, p. 201

Witvrouw E., Callaghan M. J., Stefanik J. J., Noehren B., Bazett-Jones D. M., Willson J. D., Earl-Boehm J. E., Davis I. S., Powers C. M., McConnel J. & Crossley K. M. 2014. Patellofemoral pain: consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013. British Journal of Sports Medicine, v. 48, n. 6, p. 411-414

Intranet/Internet Advert

STAFF OR STUDENTS NEEDED FOR A STUDY USING SMARTPHONES TO MEASURE LEG POSITION AND MOVEMENT

We are looking for healthy subjects to take part in a research study using smartphones to look at hip, knee and ankle movement during a squatting movement. To be eligible you need to:

- **Be healthy**
- **Be between 18 – 40 years of age**
- **Have no spine, hip, knee or ankle problems or injury.**
- **Be able to understand spoken and written English**

The study involves performing two sets of five single leg squatting tasks one after another. Each of these will be digitally filmed and recorded. The study session will last about 10-15 minutes in total. All procedures are safe and non-invasive. One of the research team will attach some sticky medical tape on the front of the thigh, knee and ankle.

The study will take place at the Pori campus of SAMK.

If you are interested please read through our information sheet. If you would like further information, or are interested in taking part please contact:

Sabrina Uecker: sabrina.uecker@student.samk.fi

APPENDIX 2

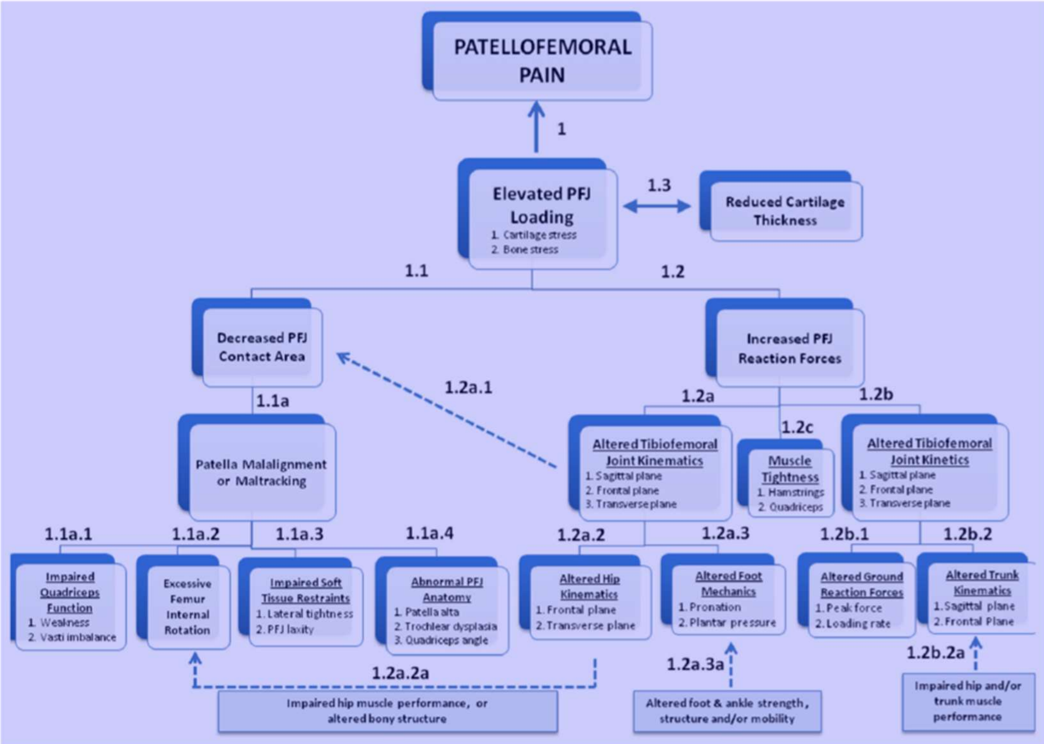
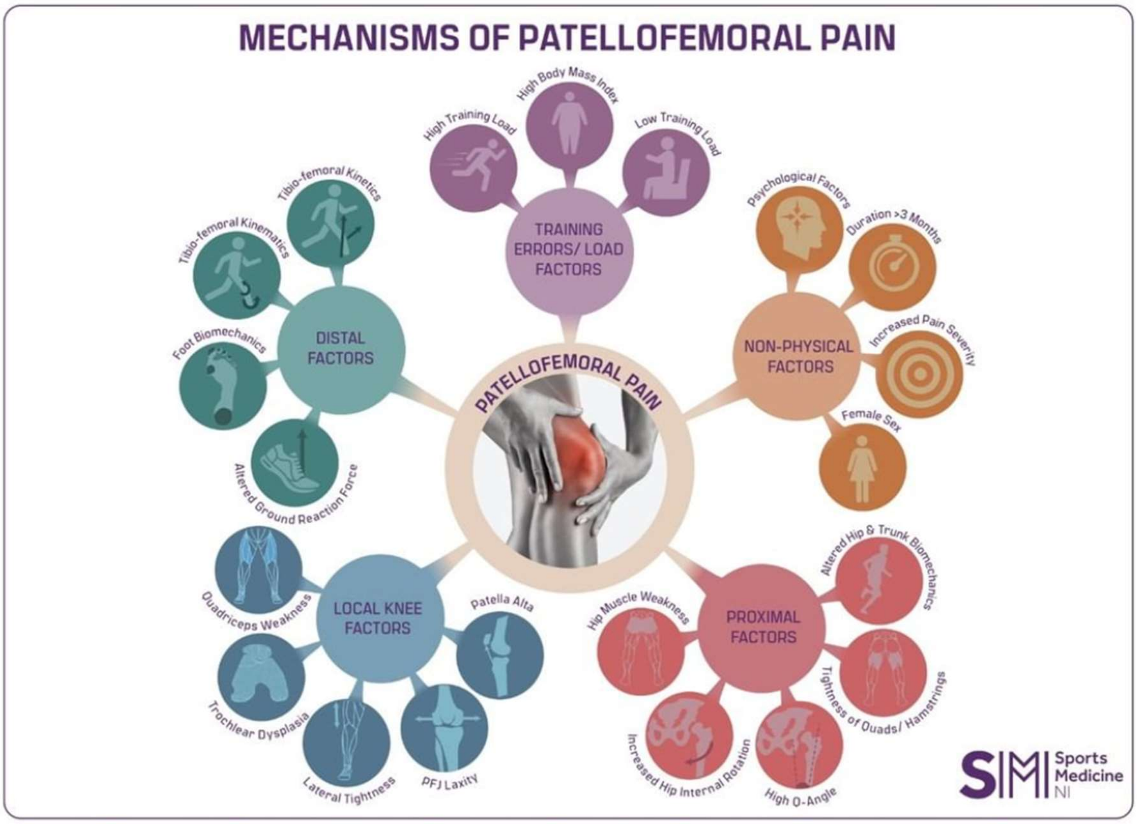


Figure 1 Schematic overview of potential pathways to elevated patellofemoral joint (PFJ) stress, a proposed contributor to patellofemoral pain.

Powers CM, *et al*. *Br J Sports Med* 2017;**51**:1713–1723. doi:10.1136/bjsports-2017-098717 1713

(Powers, Witvrouw, Davis & Crossley 2017)

APPENDIX 3



(Sports medicine NI 2019)

APPENDIX 4

FPPA Heel

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FPPA1	14	153,00	178,00	166,7857	7,04031
FPPA2	14	155,00	177,00	167,6429	7,76191
FPPA3	14	153,00	179,00	165,6429	9,35297
FPPA4	14	151,00	178,00	167,1429	9,96808
FPPA5	14	151,00	179,00	166,4821	9,57484
Mean	14	154,20	176,40	166,7393	8,31371
Valid N (listwise)	14				

Case Processing Summary

		N	%
Cases	Valid	14	100,0
	Excluded[a]	0	,0
	Total	14	100,0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
,969	5

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		4492,654	13	345,589		
Within People	Between Items	31,496	4	7,874	,737	,571
	Residual	555,654	52	10,686		
	Total	587,150	56	10,485		
Total		5079,804	69	73,620		

Grand Mean = 166,7393

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	F Test with True Value 0 Value	df1	df2	Sig
Single Measures	,865[a]	,741	,947	32,341	13	52	,000
Average Measures	,970[c]	,935	,989	32,341	13	52	,000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX 5

TFRA Heel

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
TFRA1	14	76,00	131,00	97,0714	15,72584
TFRA2	14	75,00	120,00	96,0714	15,17318
TFRA3	14	75,00	124,00	96,0000	15,01282
TFRA4	14	73,00	128,00	94,7143	14,85535
TFRA5	14	76,25	128,00	95,7857	15,81256
Mean	14	76,25	126,20	95,9286	14,93044
Valid N (listwise)	14				

Case Processing Summary

		N	%
Cases	Valid	14	100,0
	Excluded[a]	0	,0
	Total	14	100,0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
,987	5

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		14489,668	13	1114,590		
Within People	Between Items	39,571	4	9,893	,670	,616
	Residual	767,529	52	14,760		
	Total	807,100	56	14,412		
Total		15296,768	69	221,692		

Grand Mean = 95,9286

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	,939[a]	,875	,977	75,513	13	52	,000
Average Measures	,987[c]	,972	,995	75,513	13	52	,000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

FPPA Toe

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FPPA1	14	157,00	180,00	170,7857	6,99647
FPPA2	14	158,00	179,00	169,9286	8,06192
FPPA3	14	159,00	178,00	170,1429	7,02585
FPPA4	14	158,00	180,00	170,8036	7,28023
FPPA5	14	157,00	179,00	170,0000	6,82755
Mean	14	160,00	178,60	170,3321	6,69235
Valid N (listwise)	14				

Case Processing Summary

		N	%
Cases	Valid	14	100,0
	Excluded[a]	0	,0
	Total	14	100,0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
,956	5

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		2911,190	13	223,938		
Within People	Between Items	10,318	4	2,579	,265	,899
	Residual	506,832	52	9,747		
	Total	517,150	56	9,235		
Total		3428,340	69	49,686		

Grand Mean = 170,3321

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	,823[a]	,671	,929	22,976	13	52	,000
Average Measures	,959[c]	,911	,985	22,976	13	52	,000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

APPENDIX 7

TFRA Toe

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
TFRA1	14	79,00	131,00	98,1429	14,68048
TFRA2	14	75,00	136,00	97,5000	15,65862
TFRA3	14	76,00	134,00	97,3571	16,39234
TFRA4	14	73,00	136,00	97,6786	17,24887
TFRA5	14	74,00	130,00	97,4286	16,44438
Mean	14	76,40	133,40	97,6214	15,89747
Valid N (listwise)	14				

Case Processing Summary

		N	%
Cases	Valid	14	100,0
	Excluded[a]	0	,0
	Total	14	100,0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
,993	5

ANOVA

		Sum of Squares	df	Mean Square	F	Sig
Between People		16427,418	13	1263,648		
Within People	Between Items	5,557	4	1,389	,165	,955
	Residual	438,243	52	8,428		
	Total	443,800	56	7,925		
Total		16871,218	69	244,510		

Grand Mean = 97,6214

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	,969[a]	,936	,989	149,939	13	52	,000
Average Measures	,994[c]	,986	,998	149,939	13	52	,000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.