LOWER EXTREMITY VARIABLES AND EXTRINSIC FACTORS ASSOCIATED WITH PATELLOFEMORAL PAIN SYNDROME

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By

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LIST OF ABBREVIATIONS

ACL	anterior cruciate ligament
ADLS	Activities of Daily Living Scale
AIIS	anterior inferior iliac spine
AITFL	anteroinferior tibiofibular ligament
AKP	anterior knee pain
AKPS	anterior knee pain scale
ASIS	anterior superior iliac spine
ATFL	anterior talofibular ligament
ATTL	anterior tibiotalar ligament
BMI	body mass index
CFL	calcaneofibular ligament
CG	control group
COP	centre of pressure
CPM	continuous passive mode
EBG	elastic band exercise group
FFCP	forefoot contact phase
FFP	foot flat phase
FFPOP	forefoot push off phase
GRF	ground reaction force
HL	lateral heel
HM	medial heel
HO	heel off
IAAF	International Association of Athletics Federations
ICC	intraclass correlation coefficients
ICP	initial contact phase
IFC	initial foot contact
IFFC	initial forefoot contact
IKDC	International Knee Documentation Committee
IMC	initial metatarsal contact

LCL	lateral collateral ligament
LFC	last foot contact
LR	lateral retinaculum
LS	Lysholm Scale
M1	metatarsal head 1
M2	metatarsal head 2
M3	metatarsal head 3
M4	metatarsal head 4
M5	metatarsal head 5
MCL	medial collateral ligament
MR	medial retinaculum
P	patella
PCL	posterior cruciate ligament
PF	patellofemoral
PFJ	patellofemoral joint
PFJRF/PRF	patellofemoral joint reaction force
PFPS	patellofemoral pain syndrome
PTF	patellar tendon strain force
PTFL	posterior talofibular ligament
PTTL	deep posterior tibiotalar ligament
Q	quadriceps
QTF	quadriceps tendon strain force
R^2	coefficient of determination
RCT	randomised controlled trial
RCTs	randomised controlled trials
RF	rectus femoris
RMSE	root mean square error
ROM	range of motion
SD	standard deviation
SEG	sling exercise group
SERF	the stability through external rotation of the femur
STTL	superficial posterior tibiotalar ligament
T	tibia
TCL	tibiocalcaneal ligament

TFJ	tibiofemoral joint
TG	Tandem Gait
TNL	tibionavicular ligament
TSL	tibiospring ligament
TT	tibial tubercle
UK	United Kingdom
USA	The United States of America
USNA	The United States Naval Academy
VI	vastus intermedius
VL	vastus lateralis
VLL	vastus lateralis longus
VLO	vastus lateralis obliquus
VML	vastus medialis longus
VMO	vastus medialis obliquus

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ABSTRACT

Patellofemoral pain syndrome (PFPS) can affect the lower extremity as the hip, knee, and ankle work as a linkage to perform functional movements. There are several lower extremity variables and extrinsic factors that are related to PFPS. Not all variables and factors have been sufficiently investigated, especially in clinical populations. The main aim of this thesis, comprising of five studies, was to investigate some of the gaps identified in the literature regarding the prevalence of PFPS, selected lower extremity variables, and extrinsic factors associated with PFPS.

It is important to have an understanding of PFPS demographic before starting to investigate variables and factors associated with the syndrome. Therefore, the initial study explored the prevalence of PFPS in young Thai athletes and the relationship between PFPS and training duration per week. The overall prevalence of PFPS in young Thai athletes was 6% which was lower compared to previous studies. It was also presented that PFPS was significantly correlated with sports training duration and sum of general and sports training duration for the overall population.

Interventions that result from all studies on the lower extremity variables and extrinsic factors related to PFPS in this thesis may be a key to reduce the prevalence of PFPS. The second study evaluated the functioning of a stretch sensor, for the measurement of knee range of motion, a variable used to identify PFPS, during a passive non-weight-bearing movement and accessed the level of the measurement error. The main finding was that there was a strong relationship between the capacitance of the sensor and knee angles with high R^2 and root mean square error below 5 degrees. The equations generated from the participants' data were used individually to predict knee angles with a clinically acceptable level of error.

During knee flexion and extension, movements of the patellar, tibia, and femur occur. This results in changing of the Q-angle, another lower extremity variable believed to influence PFPS. The third study was a systematic review conducted to investigate the association between the Q-angle and PFPS and to examine the difference of the Q-angle between healthy individuals and individuals with PFPS. The main findings suggested that there were disagreements on the relationship between the Q-angle and PFPS and the difference of the Q-angle in individuals with and without PFPS.

According to the prevalence study of PFPS, one factor that varied between sports was playing surfaces. Different training surfaces have been shown to be an extrinsic risk factor for PFPS and result in changes of gait. Therefore, spatiotemporal and pelvic kinematic parameters of gait on 3 different training surfaces (natural grass, indoor multi-sport, and outdoor synthetic) during walking in healthy individuals were investigated in the fourth study. The main findings were that there were significant differences in cadence, speed, stride length, and pelvic tilts between the 3 training surfaces. These results provide an implication that rehabilitation should be progressed from the indoor multi-sport surface or outdoor synthetic surface. The natural grass should be the last surface to consider as it allows faster movements which is suitable for progressive rehabilitation and training.

In addition to the parameters in the study of training surfaces, foot loading patterns need to be further investigated as excessive foot pronation has been implicated with PFPS. The final study examined effects of McConnell taping and the stability through external rotation of the femur (SERF) strap on foot plantar loading patterns in healthy adults during walking and jogging. The application of the SERF strap has potentially resulted in more laterally directed pressure distribution at forefoot push off phase compared to no tape during walking.

In conclusion, the studies performed as part of this thesis have contributed the body of knowledge on the low prevalence of PFPS in young Thai athletes and the selected lower extremity variables and extrinsic factors associated with PFPS. The outcomes provided on the prevalence study, on the stretch sensor measuring knee ROM, on the three different training surfaces on gait, and on foot loading patterns with McConnell and SERF strap application may have impact on clinical practice and implications for clinicians and sport rehabilitation professionals. The disagreements of the relationship between the Q-angle and PFPS and the difference of the Q-angle between individuals with and without PFPS on the systematic review study may influence researchers for further investigations on the Q-angle.

CHAPTER 1

Introduction and literature review

1. INTRODUCTION

Knee pain influences population around 20-30% and is believed to be one of the most prevalent musculoskeletal disorders in active young populations (Callaghan & Selfe, 2007; Esculier et al., 2013; Myer et al., 2010; Nejati et al., 2011; Phillips & Coetsee, 2007; Roush & Bay, 2012; Erkocak et al., 2016). Patellofemoral pain syndrome (PFPS) is one of the most common diagnoses of knee pain in sports medicine clinics (Esculier et al., 2013). Typical clinical symptoms are pain behind or around the patella increased with running or other activities that require knee flexion including ascending and descending stairs and squatting (McKenzie et al., 2010; Vora et al., 2018; Ireland et al., 2003). PFPS does not only affect the knee but has been also shown to be multifactorial with various functional disorders of the lower extremity (Petersen et al., 2014; Liporaci et al., 2013). This is because the hip, knee, and ankle work as a linkage to perform functional movements for sports and activities of daily living (Rivera, 1994).

Even though PFPS is one of the most common diagnoses of knee pain in sports medicine clinics (Esculier et al., 2013), the studies of prevalence in PFPS only take place in Europe and USA mainly and they have only restricted to some groups of population such as military, young active adults, elite athletes, and adolescents (Smith et al., 2018). There are still limited evidences in most countries especially developing countries (Nejati et al., 2011). The latest review literature found that prevalence of patellofemoral pain in the general population was reported as 22.7%, adolescents as 28.9%, military as 13.5%, and elite athletes (cyclists) as 35.7% (Smith et al., 2018). Nevertheless, none of the results is from developing country populations. Training duration is an extrinsic factor that is proposed to influence PFPS (Halabchi et al., 2017). However, there is a lack of evidence demonstrating the relationship between PFPS and training duration.

There are several lower extremity variables that are believed to cause PFPS and to be affected by PFPS. Knee range of motion (ROM) has been used to objectively measure recovery after various knee surgeries (Harmer et al., 2009; Mook et al., 2009; Ritter et al., 2003) and as a clinical indicator of functional restrictions in activities, such as gait (Naylor et al., 2011). A variety of techniques and instruments have been developed to measure joint ROM. Universal goniometers have been popularly used in clinical practice (Bennett et al., 2009) whilst plain radiographs represent the gold standard for all ROM measurements but are high-cost (Phillips et al., 2012; Tajali et al., 2016). Several studies have demonstrated the accuracy, sensitivity, and reliability of knee ROM measurement and have presented that computer-assisted navigation goniometer, digital imaging, parallelogram goniometer, electrical digital inclinometer, radiographic goniometry, and visual estimation are reliable tools for measuring knee ROM (Naylor et al., 2011; Bennett et al., 2009; Austin et al., 2008b; Cleffken et al., 2007; Edwards et al., 2004; Brosseau et al., 1997). However, the main limitation of all these measuring methods is that they are static measures of knee ROM and not measures of knee ROM during functional dynamic activities. With a small wireless tool such as a stretch sensor, it may be more convenient to assess dynamic functional tasks.

Several previous studies have found that individuals with PFPS present with reduced hip abduction and external rotation strength compared to healthy individuals (Ireland et al., 2003; Robinson & Nee, 2007; Bolgla et al., 2008; Willson & Davis, 2009). The quadriceps (Q) angle is one of the variables of the lower extremity that is frequently examined (Sheehan et al., 2010). Traditionally, the Q-angle has been measured with subjects in a supine position, knee extended with the quadriceps relaxed. The Q-angle has also been assessed during standing (Smith et al., 2008). It has been hypothesised that greater Q-angle would increase the lateral force vector acting on the patella and may cause the patella to move laterally (Powers et al., 2002). Studies have shown that individuals with PFPS presented with greater Q-angle compared to healthy individuals (Emami et al., 2007; Herrington, 2013a; Lankhorst et al., 2013) and compared with the unaffected legs (Kaya & Doral, 2012). However, a conflict has been found as some studies demonstrated that there was no significant difference of the Q-angle between PFPS patients and healthy individuals (Kwon et al., 2014) and greater Q-angle was not associated with lateral displacement of the patella (Sheehan et al., 2010; Freedman et al., 2014) and was not a risk factor for PFPS (Park & Stefanyshyn, 2011). It is necessary to investigate if the Q-angle measurement can be used as a measurement tool to assess PFPS.

Gait parameters have the potential to predict lower extremity injuries including PFPS (Springer et al., 2016) and can be used to monitor healing process for patients (Tao et al., 2012; Steultjens et al., 2000; Kimmeskamp & Hennig, 2001). This is because the parameters: gait velocity, cadence, knee extensor moment, peak rearfoot eversion, and hip adduction angle are affected and changed during injuries (Arazpour et al., 2016). Gait parameters are not only affected by injuries but also extrinsic factors such as training surfaces (Fanchiang et al., 2016). However, only a few studies have investigated various training surfaces on gait parameters and some training surfaces have not been yet examined (Fanchiang et al., 2016; Menant et al., 2009). Natural grass, outdoor synthetic, and indoor multi-sport game surface are basic sports facilities, widely used, and comply with the rules of various sports (Meinel, 2008; Sport England, 1999). It may be useful for clinical use to investigate how these three surfaces affect gait.

Excessive foot pronation has been hypothesised to affect PFPS as it increases internal rotation of the tibia (Petersen et al., 2014; Powers, 2003; Barton et al., 2010b; Barton et al., 2009) and femur during gait, resulting in decreased patellofemoral contact area and increased patellofemoral joint stress (Willson et al., 2015). Individuals with PFPS were found to present with delayed peak rearfoot eversion and possessed more foot pronation during weight-bearing (Barton et al., 2010b; Barton et al., 2009). Foot pronation is difficult and costly to measure dynamically (Eichelberger et al., 2018; Souza, 2015). Plantar loading patterns provide an alternative option to access foot pronation during static and dynamic activities. Changes in the plantar pressure distribution may indicate functioning of the subtalar joint which is related to pronation of the foot (Santos et al., 2017).

Athletic taping is a temporary method mainly used as a preventive measure by athletes to protect an existing injury and served as post-injury rehabilitation (Bandyopadhyay & Mahapatra, 2012). The goals of taping in sports are to restrict and support injured parts of the body, protect injured parts from re-injury, accelerate healing process, compress soft tissues to decrease swelling, and serve as a soft splint (Birrer & Poole, 2004). There are several taping methods available with the corresponding needed materials along with common cases of injury, for instance, ankle taping for inversion sprains, turf toe taping for restricting toe extension, patellar taping for PFPS, hip spica for hip flexor muscle strains, thumb spica for jammed fingers, and wrist taping for carpal tunnel syndrome (Bandyopadhyay & Mahapatra, 2012). In addition to taping, limb support strapping is an alternative method that may be a potentially beneficial treatment for injuries (Wallace & Barr, 2012). When the usage is compared, strapping will last longer as it can be reused whilst taping is applied using a rigid tape that can be used once (Verma & Krishnan, 2012). However, tapping is less bulky and caters for unusual anatomy (Wallace & Barr, 2012).

From the evidence and knowledge above, there remain gaps about variables of the lower extremity that have not been investigated and need to be filled. The aim of this work was to investigate lower extremity variables and extrinsic factors associated with PFPS that had not been investigated to date with the overall focus on evaluation of accessible tools that could potentially be used in clinical settings.

2. OVERVIEW OF THE LOWER EXTREMITY

The lower extremity consists of three major areas of joint articulation: the hip, knee, and ankle and foot (Hang, 2013). It has the ability to support the body weight, adapt to the gravity, and is fundamental for locomotion (Cunningham et al., 2016). Understanding anatomy of the lower extremity makes it more understandable in advanced functional movements.

2.1 The hip

2.1.1 Anatomy and function

The hip joint, a diarthrodial ball and socket joint, is formed by head of the femur and acetabulum consisting of 3 bones: the ilium, ischium, and pubis (Ranawat & Kelly, 2005). There are several bony landmarks of the hip joint serving as attachment points for muscles (Figure 1.1) (Hang, 2013; Ranawat & Kelly, 2005). Anterior superior iliac spine (ASIS) and anterior inferior iliac spine (AIIS) provide attachment areas for hip flexors: sartorius on ASIS and rectus femoris on AIIS (Hang, 2013). Other primary hip flexors are iliacus, psoas, iliocapsularis, and pectineus (Ranawat & Kelly, 2005). Ischial tuberosity, greater trochanter, and lesser trochanter provide attachment areas for hip extensors: hamstrings, hip abductors (gluteus medius, gluteus minimus)/tensor fascia lata and iliotibial band, and hip adductor (adductor magnus) respectively (Hang, 2013; Ranawat & Kelly, 2005). Other hip extensors include gluteus maximus, biceps femoris (short and long heads), semimembranosus, semitendinosus, and adductor magnus (ischiocondyle part). Other hip adductors are adductor longus and brevis and gracilis (Ranawat & Kelly, 2005). Hip rotator muscles vary between hip flexion and extension positions (Bloom & Cornbleet, 2014; Bremner et al., 2015). The piriformis, gluteus maximus, medius, and minimus normally act as hip external rotators in hip extension. However, they switch to hip internal rotators in hip flexion (Bloom & Cornbleet, 2014). Other deep external rotators such as obturators and quadratus femoris perform external rotation at the range of hip flexion from 0-90° (Bloom & Cornbleet, 2014).

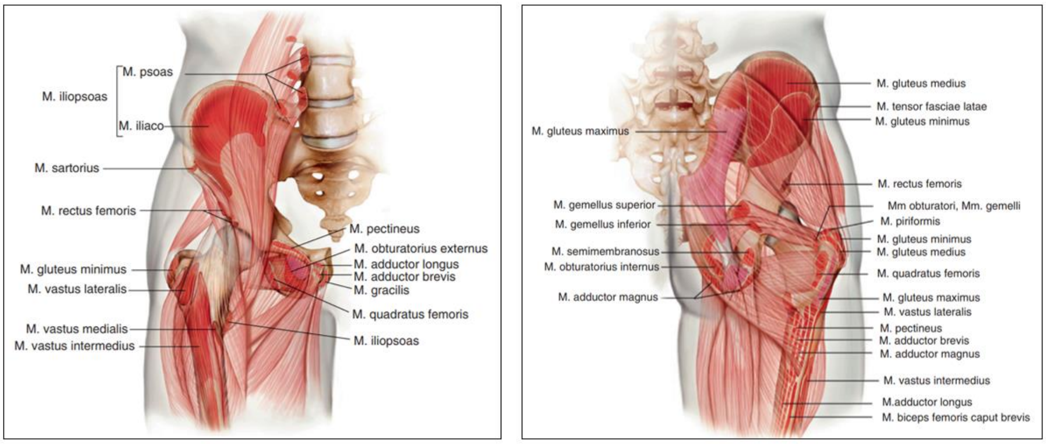


Figure 1.1 Muscles of the hip complex: anterior and posterior aspects (Pfeil & Siebert, 2010, p. 9).

Since the hip joint comprises of the pelvis and the femur, it is likely that movement of one segment may influence the other (Bagwell et al., 2016). Several studies have found that altered pelvis movement in the sagittal plane may influence transverse motion of the femur (Duval et al., 2010; Khamis & Yizhar, 2007; Pinto et al., 2008; Tateuchi et al., 2011). Internal rotation of the femur results in anterior pelvic tilt and external rotation of the femur results in posterior pelvic tilt (Duval et al., 2010; Khamis & Yizhar, 2007; Pinto et al., 2008; Tateuchi et al., 2011). Internal rotation of the femur causes the femoral head to posteriorly rotate into the posterior acetabulum which forces the pelvis into anterior tilt (Duval et al., 2010).

2.1.2 Range of motion

The hip joint consists of 3 degrees of freedom which are perpendicular to one another. Active range of motion (ROM) of hip flexion in healthy populations ranges from 120-135°, 15-30° for extension, 45-60° for abduction, 15-30° for adduction, 30-45° for internal rotation, and 45-60° for external rotation (Hang, 2013; Hallaceli et al., 2014; Yazdifar et al., 2013).

2.2 The knee

2.2.1 Anatomy and function

The knee complex provides strong stability and control under a high range of loading conditions of the human body (Abulhasan & Grey, 2017; Goldblatt & Richmond, 2003). It comprises 2 joints: 1) the tibiofemoral joint (TFJ); 2) the patellofemoral joint (PFJ) (Abulhasan & Grey, 2017; Goldblatt & Richmond, 2003; Flandry & Hommel, 2011). The TFJ is considered the largest joint in the human body. It consists of 2 condyloid articulations: the medial and lateral femoral condyles articulating with the tibial plateaus (Goldblatt & Richmond, 2003). The joint allows transmission of the body weight from the femur to the tibia whilst providing flexion/extension along with a small degree of tibial axial rotation (Flandry & Hommel, 2011). The medial and lateral menisci serve as shock absorbers to reduce force and to enhance the conformity of the joint (Makris et al., 2011). They also assist the rotation of the knee (Goldblatt & Richmond, 2003).

The patellofemoral joint is an articulation between the patella and the femoral trochlea. This joint plays an important role in stabilising the knee and in the extensor mechanism (Goldblatt & Richmond, 2003). The patella acts as a lever and increases the moment arm of the patellofemoral joint which assists the quadriceps tendon to exert on the femur by increasing the angle where it acts (Dixit et al., 2007). Stability of the patellofemoral joint includes static and dynamic stabilisers (ligaments and muscles) that control patellar movement within the trochlea groove (Goldblatt & Richmond, 2003; Dixit et al., 2007). The proximal tibiofibular joint is not included in the knee complex because the primary function of the joint is to dissipate torsional stresses applied at the ankle and lateral tibial bending moments rather than compressive weight-bearing (Sarma et al., 2015).

The knee complex is stabilised by both ligaments and muscles. Knee ligaments are considered primary passive stabilisers whilst muscles are secondary active stabilisers. The TFJ is reinforced by two collateral ligaments: medial collateral ligament (MCL) and lateral collateral ligament (LCL) and is prevented from excessive anterior and posterior, varus, and valgus translation of the tibia in relation to the femur by two cruciate ligaments: anterior cruciate ligament (ACL) and posterior cruciate ligament

(PCL) (Figure 1.2) (Abulhasan & Grey, 2017). MCL comprises the superficial and deep (mid-third capsular) ligaments (LaPrade et al., 2007). It provides stability for the medial part of the TFJ by preventing excessive valgus stress during knee external rotation (Abulhasan & Grey, 2017). LCL is originated from the lateral femoral condyle to the lateral aspect of the fibular head, providing stability to the lateral part of the TFJ by preventing excessive varus stress and external rotation of the knee at all positions (Abulhasan & Grey, 2017; Davies et al., 2004).

ACL is the main stabiliser of the TFJ, running from fossa of the medial surface of intercondylar notch of the lateral femoral condyle to the tibial plateau and serving as the primary resistant to anterior and rotational translation of the tibia on the femur. The ligament also secondarily stabilises valgus and varus translation in full extension (Abulhasan & Grey, 2017; Mall et al., 2013). PCL is considered the largest intraarticular ligament, running from lateral aspect of intercondylar notch of the medial femoral condyle to the posterior tibia (Stevens et al., 2015). The ligament plays an important role in preventing posterior translation of the tibia and secondarily stabilising varus, valgus, and external rotation of the knee (Costa et al., 2018).

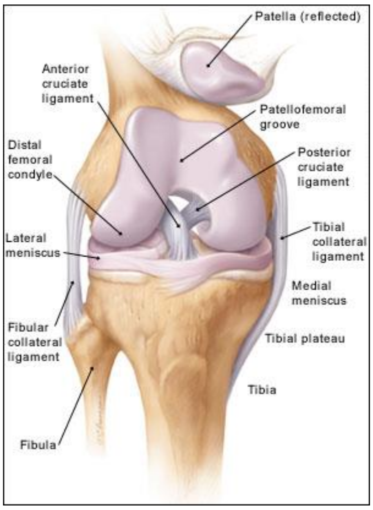


Figure 1.2 Ligaments of the knee (Tandeter et al., 1999, p. 2).

Knee flexion is predominately accomplished by the hamstrings (biceps femoris long head and short head, semimembranosus, and semitendinosus). The plantaris muscle, medial and lateral heads of the gastrocnemius muscle, and the soleus muscle act as secondary knee flexors (Figure 1.3). The iliotibial band and popliteus muscles also aid to flex the knee. Knee extension is predominately accomplished by the quadriceps muscles (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius). The semitendinosus also acts as a medial rotator of the knee. The biceps femoris and semimembranosus act as lateral rotators whilst the popliteus muscle rotates the knee both medially and laterally (Figure 1.3) (Abulhasan & Grey, 2017).

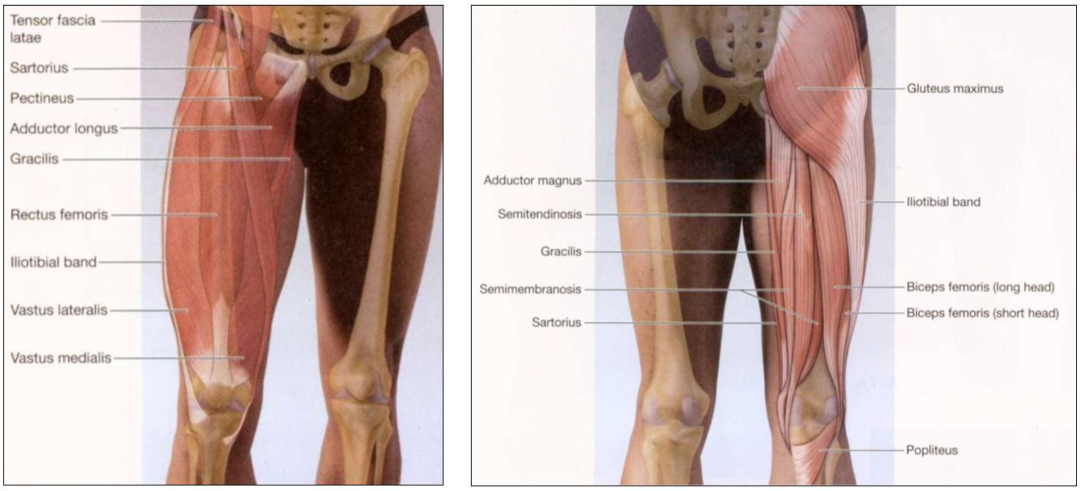


Figure 1.3 Muscles of the knee complex: anterior and posterior aspects (Cael, 2010, p. 320-321).

2.2.2 Range of motion

The knee includes 6 degrees of freedom ROM: 3 rotations (flexion/extension in sagittal plane, internal/external rotation in transverse plane, and varus/valgus translation in frontal plane) (Abulhasan & Grey, 2017; Komdeur et al., 2002) and 3 translations (anterior/posterior glide, medial/lateral shift, and compression/distraction) (Komdeur et al., 2002). However, only flexion and extension can be measured by a standard universal goniometer (Hallaceli et al., 2014; Lenssen et al., 2007; Dos Santos et al., 2017) and normal active ROM ranges between 0-140° from extension to flexion (Hang, 2013).

2.3 The ankle and the foot

2.3.1 Anatomy and function

The ankle complex, consisting of the lower leg and the foot, plays an important role in forming kinetic linkage allowing transmission of force between the lower extremity and the ground (Brockett & Chapman, 2016; Dawe & Davis, 2011). The ankle and the foot are comprised of 26 bones of the foot, the tibia, and the fibula to form 33 joints. The ankle joint complex includes the talocalcaneal (subtalar), tibiotalar (talocrural) (Brockett & Chapman, 2016), and transverse-tarsal (talocalcaneonavicular/midtarsal/ Chopart's) joints (Brockett & Chapman, 2016; Tweed et al., 2008). There are 12 muscles that perform most of the motion within the ankle and the foot (Brockett & Chapman, 2016). These muscles are divided into 4 compartments: anterior, lateral, superficial posterior, and deep posterior compartments (Figure 1.4) (Brockett & Chapman, 2016; Pechar & Lyons, 2016).

The anterior compartment involves tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus tertius. The tibialis anterior and the extensor hallucis longus perform ankle dorsiflexion and inversion whilst the extensor digitorum longus performs dorsiflexion and the peroneus tertius performs dorsiflexion and eversion. The lateral compartment includes peroneus longus and peroneus brevis with both muscles performing plantarflexion and eversion. The superficial posterior compartment comprises gastrocnemius, soleus, and plantaris acting as plantar flexors. The deep posterior compartment consists of tibialis posterior, flexor hallucis longus, flexor digitorum longus with all of these muscles performing plantarflexion and inversion of the ankle (Brockett & Chapman, 2016).

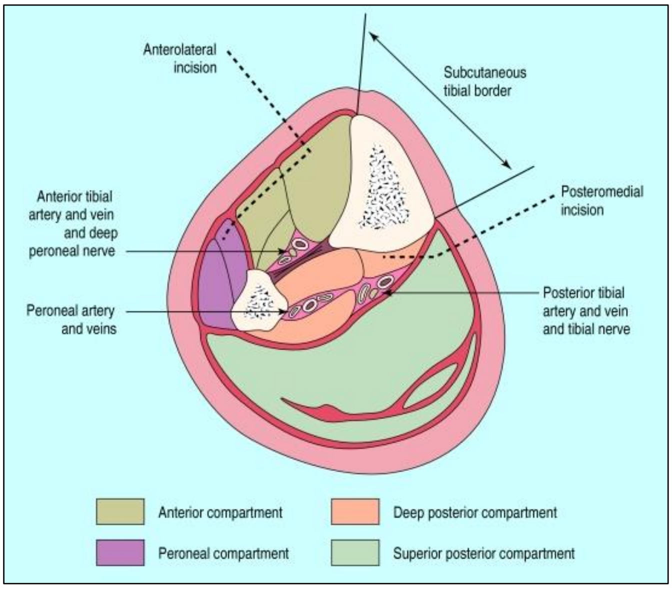


Figure 1.4 Compartments of the leg (Pearse et al., 2002, p. 558).

Ligaments at the ankle can be divided into 3 groups: lateral ligaments, medial (deltoid) ligaments, and the tibiofibular syndesmosis ligaments (Figure 1.5) (Dawe & Davis, 2011; Golano et al., 2016). The lateral ligaments complex is comprised of the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL) and posterior talofibular ligament (PTFL) (Dawe & Davis, 2011; Golano et al., 2016; Groth et al., 2010; Boonthathip et al., 2011). They provide stability for the lateral ankle by resisting inversion of the ankle (Dawe & Davis, 2011). The medial (deltoid) ligaments, the strongest ligaments stabilising the medial ankle, are divided into superficial and deep groups (Dawe & Davis, 2011; Golano et al., 2016; Lotscher & Hintermann, 2014).

The superficial ligaments include tibiospring ligament (TSL), tibionavicular ligament (TNL), superficial posterior tibiotalar ligament (STTL), and tibiocalcaneal ligament (TCL) whilst the deep ligaments are composed of deep posterior tibiotalar ligament (PTTL) and anterior tibiotalar ligament (ATTL) (Lotscher & Hintermann, 2014). The tibiofibular syndesmosis ligaments, supporting the stability between the distal part of tibia and the fibula and resisting axial, rotation, and translational forces that tend to take apart the tibia and the fibula, involve anteroinferior tibiofibular ligament (AITFL), posteroinferior tibiofibular ligament, and interosseous tibiofibular ligament (Dawe & Davis, 2011; Golano et al., 2016).

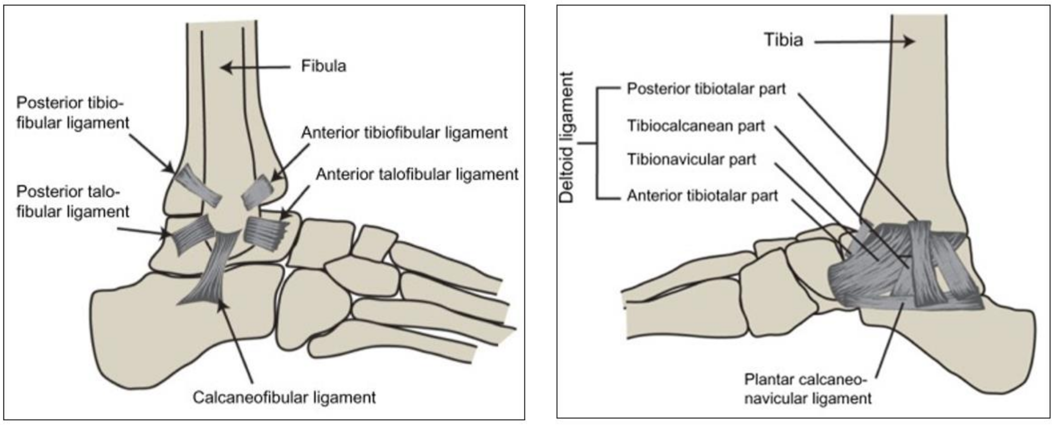


Figure 1.5 Lateral, medial, and syndesmosis ligaments of the ankle (Blalock et al., 2015, p. 19).

2.3.2 Range of motion

The ankle ROM varies between individuals and activities they perform. There are mainly 2 degrees of freedom for the ankle ROM: 1) the sagittal plane (plantarflexion/dorsiflexion) occurring predominantly at the tibiotalar (talocrural) joint with a few degrees at subtalar (talocalcaneal) joint; 2) the frontal plane (inversion/eversion) occurring predominantly at subtalar joint (Brockett & Chapman, 2016). The dorsiflexion ranges from 10 to 20° (Brockett & Chapman, 2016; Soucie et al., 2011) and 40 to 55° for the plantarflexion (Brockett & Chapman, 2016). The inversion and eversion is approximately 35° in total with 23° for inversion and 12° eversion (Brockett & Chapman, 2016; Butterworth et al., 2015).

2.3.3 Measurement of foot posture and arch index

Measurement of foot posture is widely considered as an important component of musculoskeletal examination in clinical practice and research and determinant in the function of the foot and lower extremity (Wearing et al., 2004; Menz et al., 2012). There are several methods used to classify foot posture: 1) visual observation (Redmond et al., 2008) 2) foot posture index (FPI) (Scott et al., 2007) 3) arch index (Scott et al., 2007; Cavanagh & Rodgers, 1987) 4) navicular height (Scott et al., 2007) and 5) angular measures derived from radiographs (Thomas et al., 2006).

Visual observation can be performed by having subjects standing in a line. They are instructed to stand with equal weight on both feet. Three examiners assessed the subjects' feet by observing them the anterior and posterior view. Feet are classified as pronated, supinated, or neutral. To be classified as pronated or supinated, the foot has to present with mandatory criteria deviating from the neutral foot and all the examiners must agree (Dahle et al., 1991).

Scott et al. (2007) described that the foot posture index (FPI) involved the rating of 6 criteria: 1) palpation of the talar head 2) observation of supra/infra malleolar curvature 3) inversion/eversion of the calcaneus 4) medial prominence of the talonavicular joint 5) congruence of the medial arch and 6) abduction/adduction of the forefoot on the rearfoot. Each of these criterion were scored on a five-point scale (range 2 to +2) and the summed score provided a single index of the degree of the pronated/supinated posture of the foot, with higher scores representing a more pronated (flatter) foot

Arch index has been measured originally following Staheli et al. (1987). Footprint parameters are often used in gait studies as indirect measures of arch index (Wearing et al. 2004). The width of the foot in the area of the arch (A) and the width of the heel (B) are measured, and the former number was divided by the latter one (A/B) to calculate the arch. After the middle stages of childhood, the arch index has a board normal range from about 0.3 to 1.0 through adulthood. The flexible flatfoot has the arch index of more than 1.0 and the high arch has the arch index less than 0.3 (Huang et al., 2004). In this thesis, this method was used to identify normal arch of foot for the participants following the inclusion criteria. This method is simple. The footprint can be obtained and measured by the RSscan pressure plate which was the equipment used in the thesis.

Navicular height is measured whilst the subject is fully weight-bearing. The navicular tuberosity is palpated and marked with an ink marking pen, and the height of the navicular tuberosity from the ground is measured in millimetres using a ruler (Menz et al., 2003).

Thomas et al. (2006) stated that angular measures derived from radiographs can be performed by having bilateral anteroposterior and lateral weight-bearing radiographs of the foot taken. All radiographs are obtained using a workstation. Radiographic reference lines and measurements are then obtained using a software. The digital radiograph is imported into a template that is designed for each study specifically. The software tools are then used to place reference lines and measure angles.

3. Lower extremity biomechanics related to the PFJ function

The musculoskeletal system consists of linked segments. For the lower extremity, it requires joints and muscles of hip, knee, ankle, and foot to work together to reproduce normal forces, loading patterns, and movement patterns in order to perform fundamental movements needed for sports and activities of daily living. The successively arranged skeletal links characterising hip, knee, ankle, and foot joints together comprise the lower extremity kinetic chain (Rivera, 1994). It has been recognised that the lower extremity may influence the patellofemoral joint (PFJ). Abnormal movement of the femur and tibia in frontal and transverse plans are believed to affect PFJ mechanics and cause PFPS (Powers, 2003). Lower extremity joint rotations are also associated with PFJ as it decreases retropatellar contact area and increases retropatellar stress during weight-bearing activities (Willson & Davis, 2008).

3.1 Patellofemoral joint reaction force

Patellofemoral joint reaction force (PFJRF) is a result from compression force acting in the PFJ and depends on knee joint angle and muscle tension (Loudon, 2016). With increased knee flexion, the angle between the patellar tendon and the quadriceps tendon becomes more acute resulting in increasing of the resultant force vector (Figure 1.6) (Schindler & Scott, 2011). High PFJRF together with a small contact area between the patella and the femur causes high PFJ stress and may harm the joint cartilage. This stress can be greater with poor positioning of the patella in the trochlea groove (Loudon, 2016).

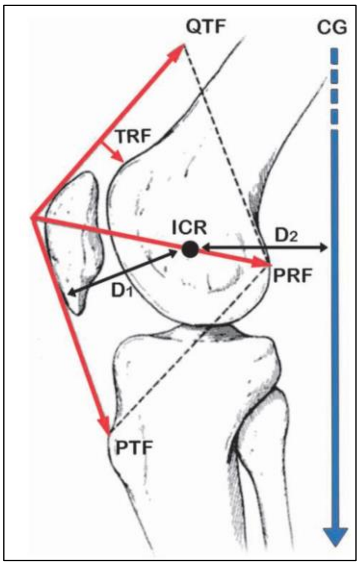


Figure 1.6 Patellofemoral joint reaction force (PRF) representing the resultant vector of the quadriceps tendon strain force (QTF) and the patellar tendon strain force (PTF) (Schindler & Scott, 2011, p. 425).

3.2 Quadriceps force vector

The quadriceps force vector or the quadriceps tendon strain force comprises forces from VL, vastus intermedius (VI), rectus femoris (RF), and VMO (Amis, 2007). In the frontal plane, the quadriceps force vector angles are created by vastus lateralis obliquus (VLO) at 35° and vastus lateralis longus (VLL) at 14° laterally, by the VI and RF at 0°, and by VMO at 47° and VML at 15° medially (Figure 1.7) (Amis, 2007; Waryasz & McDermott, 2008). The quadriceps force plays an important role in keeping the patella in the trochlear groove properly by pulling the patella in a sagittal direction (Waryasz & McDermott, 2008). When lateral patellar maltracking occurs, the lateral retinaculum is often released arthroscopically to alleviate the lateral displacement force (Calpur et al., 2005).

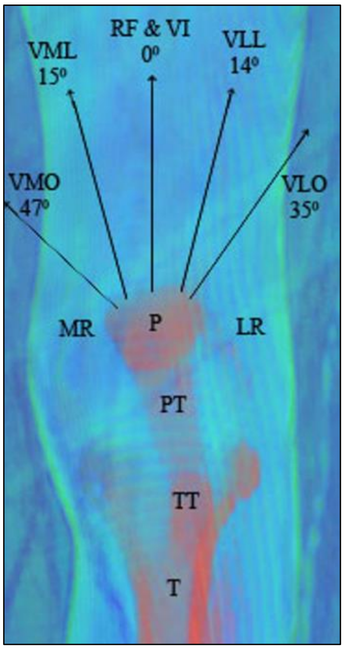


Figure 1.7 Quadriceps force vector diagram: VMO – Vastus medialis obliquus; VML – Vastus medialis longus; RF – Rectus femoris; VI – Vastus intermedius; VLL – Vastus lateralis longus; VLO – Vastus lateralis obliquus; P – Patella; TT – Tibial tubercle; T – Tibia; MR – Medial retinaculum; LR – Lateral retinaculum (Waryasz & McDermott, 2008, p. 4).

3.3 Patellofemoral contact area

The area of the patellar contact varies throughout ROM (Figure 1.8). When the knee is fully extended the patella is positioned proximal and slightly lateral to the trochlea (Andrish, 2015). As the knee begins to flex from 0°, the patellofemoral contact area progressively increases by degrees. The load and contact area firstly begin at the most distal surface of the lateral facet of the patella and the uppermost portion of the lateral femoral condyle (Loudon, 2016; Andrish, 2015). During 30° flexion, the contact area is distributed on both sides of the femoral condyles and the total contact is approximately 2 cm^2. At 60° flexion, the upper part of the patella contacts the femoral groove slightly inferior to the contact area of 30° flexion. The contact area between the patella and the femoral groove continues to increase as the knee reaches 90° flexion and is approximately 6 cm^2. At this degree, the upper part of the patella contacts the femoral groove above the notch (Loudon, 2016). During the midrange of the knee flexion between 50° and 90°, the quadriceps tendon starts to turn around the femoral trochlea and takes a load-sharing ability with the patella (Andrish, 2015). Between 90° and 120° flexion, the upper part of the patella contacts the femoral groove surrounding the intercondylar notch. After 120° flexion, there is only contact on the far medial and lateral edges of the patella as the patella bridges the span of the intercondylar notch in deep flexion. At the full flexion around 150°, the articulating contact between the patella and the lateral aspect of medial femoral condyle is the odd facet (Loudon, 2016).

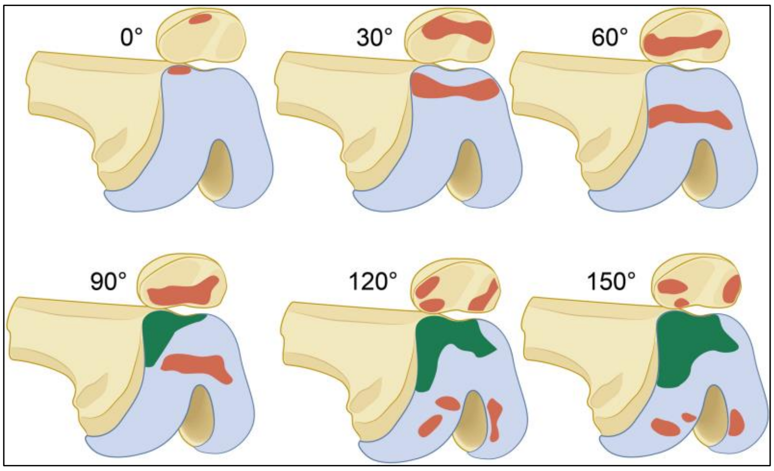


Figure 1.8 Contact areas between the patella and trochlea during different degrees of knee flexion with the red colour representing the patellar contact and the green colour representing the quadriceps tendon contact (Andrish, 2015, p. 65).

The contact area on the patella when getting close to full extension is small whilst the area is larger at 90° flexion. Therefore, PFJRF is small when it is close to the full extension and the articular cartilage pressure (force per unit area) may be relatively high. The forces increase during deep flexion and so does the contact area, resulting in less patellofemoral (PF) pressures than those near extension (Figure 1.9) (Andrish, 2015; Bellemans, 2003).

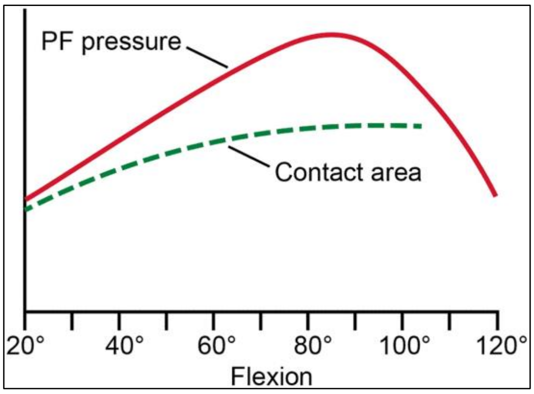


Figure 1.9 The relationship between patellofemoral pressure and patellofemoral contact area (Andrish, 2015, p. 66).

4. Patellofemoral pain syndrome

Patellofemoral pain syndrome (PFPS) is a term that is used to describe pain originating from the area of the patella and the femur (Oakes, 2005). PFPS is one of the most common disorders of the knee, accounting for 25% of all knee injuries that can be seen in sports medicine clinics (Fredericson & Powers, 2002). PFPS is also a common cause for "anterior knee pain" and mainly affects young women (Petersen et al., 2014). However, the cause of pain is not clearly understood (Fredericson & Powers, 2002; Peterson & Renstrom, 2005).

4.1 Aetiology

Articular surface damage of the patella normally occurs in individuals aged between 10 and 25 years and is related with pain, especially during uphill and downhill walking, stair climbing, and squatting (Peterson & Renstrom, 2005; Lowry et al., 2008). Several anatomic and congenital factors may also lead to a predisposition toward patellofemoral pain and/or instability. Tightness of the quadriceps, hamstrings and iliotibial band, and relative weakness of the quadriceps are probably the most common causes. Other factors that can cause this problem include femoral anteversion, tibial torsion, genu valgum, genu recurvatum, excessive pronation (Oakes, 2005; Labotz, 2004), quadriceps (Q) angle (Kaya & Doral, 2012), and patellar maltracking (Petersen et al., 2014). The tethering effect of tendons and ligaments adjacent to the patella are major determinants of forces across the PFJ. Overall lower extremity alignment and the relationship between the trochlea groove and the patella also produce forces across the

PFJ. In individual with PFPS, these factors often produce increased forces at the lateral joint surface and decreased forces at the medial surface (Labotz, 2004).

4.2 Pathophysiology

The pathophysiology of PFPS is not well understood. The syndrome normally occurs in young active population at the age of 18-35 years as it is assumed that the population at this age participate in several sports and activities (Roush & Bay, 2012). One possible mechanism of patellofemoral pain is increased stress at the cartilage-bone interface at the patellofemoral joint. This hypothesis is based on the assumption that localised stress transmitted through the cartilage has the potential to stimulate the sensation of pain called “nociceptors” in the subchondral bone (Pal et al., 2011). A potential mechanism of this elevated stress at the cartilage-bone area is laterally excessive maltracking of the patella within the trochlear groove (Grabiner et al., 1994). Normal patellar tracking requires balance of soft tissue structures that surround the PFJ. Unequal pull from one of the structures can result in increased force distribution between the patella and the femur leading to pain (Loudon, 2016). Delayed onset of VMO activity compared with that of VL may lead to medial-lateral force imbalance at the patella during the initial phase of knee extensor activity and subsequent maltracking of the patella (Cowan et al., 2002; Pal et al., 2011). Several studies have reported delays in VMO activity in individuals with PFPS compared with healthy controls (Cowan et al., 2002; Pal et al., 2011; Cowan et al., 2001; Cowan et al., 2002a; Cowan et al., 2002b).

The lateral retinaculum also plays an important role in patellofemoral pain. Chronic lateral patellar subluxation during knee flexion and extension may lead to retinaculum shortening which stimulates free nerve endings and breaks the ischemia-hyperinnervation-pain cycle (Sanchis-Alfonso et al., 2006).

4.3 Prevalence

Prevalence is defined as the number of cases of a condition existing in a population at a specific point or period of time divided by the number of individuals in the given population (Callaghan & Selfe, 2007; Roush & Bay, 2012). Not to be confused with the word “incidence” as it is defined as the number of new onsets within a population during a specified period of time (Callaghan & Selfe, 2007).

Researcher in United Kingdom, Europe, Australia, and USA have found that approximately 25% of general or sporting population present with PFPS (Callaghan & Selfe, 2007; Ireland et al., 2003; Brechter & Powers, 2002; Witvrouw et al., 2003). Individuals with the syndrome are most typically identified by ruling out other differential diagnoses (Roush & Bay, 2012; Naslund et al., 2006), by their history, as well as reporting the functional abilities as assessed by the Anterior Knee Pain Scale (AKPS) (Roush & Bay, 2012; Kujala et al., 1993). The AKPS questionnaire is a functional outcome tool that has been developed to evaluate symptoms of PFPS and chart progress in patients during their rehabilitation (Roush & Bay, 2012; Kujala et al., 1993). The tool includes 13 questions that query the patient about their ability to perform different activities, as well as a question about pain. It is considered a valid and reliable tool that is easy for patients or subjects to complete (Roush & Bay, 2012; Crossley et al., 2004; Watson et al., 2005).

4.4 Diagnosis

PFPS is usually known as a diagnosis of exclusion (Al-Hakim et al., 2012). Patients with PFPS often describe pain behind, underneath, or around the patella (Vora et al., 2018). The symptoms are usually gradual and pain in the anterior knee is the primary symptom of PFPS. It is also possible that some patients report instability and crepitation of the patellofemoral joint, specifically during loading of the joint and palpation of the patella. The pain increases after prolonged sitting, squatting, kneeling and stair climbing (Vora et al., 2018; Peterson & Renstrom, 2005). PFPS is defined as anterior knee pain or retropatellar pain after at least two of these activities: 1) ascending and descending stairs; 2) hopping; 3) jogging; 4) prolonged sitting; 5) kneeling; 6) squatting (Noehren et al., 2012). Table 1.1 presents the summary for PFPS diagnosis (Vora et al., 2018). PFPS excludes peripatellar tendonitis or bursitis, plica syndromes, Sinding-Larsen-Johansson syndrome (pain restricted to the lower pole of the patella and increases during knee flexion) (Chas et al., 2014), Osgood Schlatter disease (pain related with severe knee pain during physical exertion and can be reproduced by extending the knee against resistance) (Chas et al., 2014), and neuromas. However, patellar subluxation, dislocation, or prior surgery may lead to articular cartilage injury which also results in anterior knee pain (Vora et al., 2018). Dixit et al. (2007) have summarised the differential diagnosis of PFPS in Table 1.2.

Table 1.1 Summary of patellofemoral pain syndrome diagnosis.

PFPS	1) Retropatellar pain during stairs, hopping/jogging, prolonged sitting, kneeling, squatting 2) Negative findings on examination of knee ligament, menisci, bursa, synovial plica 3) Pain on palpation of patellar facets, femoral condyles

Table 1.2 Differential diagnosis of patellofemoral pain syndrome.

Articular cartilage injury	- May describe history of trauma; mechanical symptoms may occur if loose body present; may have effusion; may have tenderness of involved structure (e.g., femoral condyles, patella)
Bone tumors	- Pain may be insidious; may have tenderness of bony structures
Chondromalacia patellae	- Retropatellar pain; may have history of trauma; may have effusion on examination
Hoffa's disease	- Pain and tenderness localized to infrapatellar fat pad
Iliotibial band syndrome	- Typically presents with lateral pain and tenderness over lateral femoral epicondyle
Loose bodies	- Symptoms variable; may have intermittent sharp pain, locking, or effusion
Osgood-Schlatter disease	- Tenderness and swelling at insertion of patellar tendon at tibial tubercle in an adolescent
Osteochondritis dissecans	- Symptoms variable; may have intermittent pain, swelling, or locking
Patellar instability/subluxation	- Intermittent pain with sensation of instability or movement of patella; may have swelling; locking can occur with loose body formation; may have tenderness over medial retinaculum
Patellar stress fracture	- May have tenderness directly over patella
Patellar tendinopathy	- Tenderness of tendon; tendon may be thickened if chronic

Patellofemoral osteoarthritis	- May have crepitus or effusion; characteristic radiographic findings
Pes anserine bursitis	- Pain usually described as medial rather than anterior; tenderness over pes anserine bursa
Plica synovialis	- May be medial or lateral to patella; if symptomatic, tenderness can be demonstrated on examination
Prepatellar bursitis	- Characteristic swelling anterior to patella following trauma
Quadriceps tendinopathy	- Tenderness over tendon
Referred pain from the lumbar spine or hip joint pathology	- Symptoms depend on origin of pain; knee examination usually normal
Saphenous neuritis	- Pain usually medial but poorly localized; may have history of surgery
Sinding-Larsen-Johansson syndrome	- Tenderness at patellar tendon insertion at inferior pole of patella in an adolescent
Symptomatic bipartite patella	- May have tenderness directly over patella with characteristic radiographic findings

4.5 Treatment

Treatment for PFPS should focus on dispersing joint forces across a greater surface area including a combination of activity modification, taking anti-inflammatory medication, stretching, and strengthening program (Labotz, 2004). Surgical intervention is rarely necessary and is generally reserved for cases of chronic instability that cannot be corrected or malalignment of the lower leg. For patellofemoral symptoms that are caused by a change in activity level or exacerbated by specific activity, activity modification is the main focus for treatment (Oakes, 2005). Treatment of acute onset of patellofemoral pain syndrome from a specific event, such as long-distance running or initiating a new exercise program, is straightforward. In general, this would include an initial period of rest and ice (Dixit et al., 2007; Oakes, 2005).

Chronic PFPS is more complicated to treat. The main treatment is a combination of quadriceps strengthening exercises in addition to quadriceps, hamstring, and iliotibial band stretching exercises (Dixit et al., 2007; Oakes, 2005; Lowry et al., 2008). It is often helpful to receive physiotherapy treatment for one or two sessions of hands-on instruction in the appropriate exercise program (Oakes, 2005). However, there is no best program that will be effective for all individuals (Dixit et al., 2007) but it needs to be planned individually from information gathered from assessment of a patient (Labotz, 2004). Occasionally, electric stimulation and biofeedback are useful for the pain (Oakes, 2005). Braces, sleeves, and straps are other options for treating PFPS as they may provide modest symptomatic relief in selected cases (Dixit et al., 2007; Oakes, 2005).

4.5.1 McConnell taping

Application of medial patellar taping (McConnell's technique) was originally developed by Jenny McConnell (Cowan et al., 2006). This method is widely used by clinicians during the treatment of PFPS (Keet et al., 2007). Several hypotheses for the mechanism of action of the McConnell taping have been proposed, including decreasing pain (Cowan et al., 2006), improving alignment of the patella in the trochlear groove with a resultant decreased load on the PFJ (Dixit et al., 2007), and improving quadriceps function by altering muscle recruitment with regard to timing of onset of the VMO relative to the VL (Keet et al., 2007).

Multiple studies have supported that patellar taping can decrease pain (Cowan et al., 2002b; Crossley et al., 2004; Herrington & Payton, 1997) and improve patellar tracking by changing vastus medialis obliquus (VMO) timing (Cowan et al., 2002; Cowan et al., 2001; Cowan et al., 2002a; Cowan et al., 2002b; Crossley et al., 2004) with functional tasks. Verma and Krishnan (2012) compared effects of McConnell taping along with VMO exercises and conventional physiotherapy treatment (Short wave diathermy and VMO exercises) on pain and functional improvement in the management of PFPS. It was presented that the McConnell group showed highly significant values for both pain relief and functional improvement. Therefore, McConnell taping along with VMO exercises improved patellar tracking thought soft tissue adaptations and muscle re-education resulting in decreasing the PFJRF and pain (Crossley et al., 2000).

Although several outcomes have been measured following the application of McConnell taping, some outcomes still remain unclear and need to be investigated.

PFPS is not only associated with patellar malalignment locally but also distally with excessive and prolonged foot pronation during stance phase of walking (Bek et al., 2011). Since McConnell taping has the ability to improve the alignment of the patella (Campolo et al., 2013), changing of the patellar alignment should also alter foot pronation. However, there is a lack of evidence demonstrating effects of McConnell taping on foot pronation.

4.5.2 The Stability Through External Rotation of the Femur (SERF) strap

The SERF strap (Don Joy Orthopaedics Inc, Vista, CA) was developed with the purpose of assisting the lower extremity kinematics, decreasing knee valgus through supporting femoral abduction and external rotation (Herrington, 2013b). Individuals with PFPS have been found to present with increased hip adduction and internal rotation (Meira & Brumitt, 2011). Increasing of hip adduction and internal rotation influences the greater Q-angle by increasing the relative valgus of the lower extremity. The greater Q-angle increases the peak lateral contact pressure on the PFJ (Lee et al., 2003). An increase of 10° in the Q-angle can increase patellofemoral contact pressure by 45%. Internal rotation of the femur also increases patellofemoral contact pressure (Meira & Brumitt, 2011; Lee et al., 2003).

There is a lack of evidence investigating effects of the SERF strap. Only one study examined an effect of the SERF strap on pain and knee valgus angle during unilateral squat and step landing in individuals with PFPS. It was found that the application of the SERF strap significantly reduced pain and knee valgus during both tasks (Herrington, 2013b). There is still a need of investigating effects of the SERF strap on other outcomes related with PFPS such as foot pronation as it is accepted as influencing the kinematic pattern of the lower extremity. From a clinical standpoint, it is proposed that increased foot pronation results in excessive internal rotation of the tibia and femur (Reischl et al., 1999).

Table 1.3 presents the summary of PFPS treatment options between surgical and non-surgical (Vora et al., 2018).

Table 1.3 Patellofemoral pain syndrome treatment options.

Surgical	Non-surgical
• Lateral retinacular release • Proximal realignment procedures • Distal realignment procedures • Elevation of tibial tubercle • Anteromedial tibial tubercle transfer & elevation • Articular cartilage procedures • Patellectomy	• Relative rest • Physical therapy • Proximal strengthening • Gait retraining • Analgesics • Bracing • Patellar taping

5. The lower extremity variables and extrinsic factors associated with PFPS

Altered lower extremity movement patterns has been implicated in pathogenesis of PFPS. It has been reported that altered hip, knee, foot, and ankle kinematics result in excessive medial collapse of the lower extremity during various functional activities (Rabin et al., 2014). Understanding of lower extremity variables that may affect PFPS is very important as interventions to control abnormalities of lower extremity mechanics are not mainly focused on the pain area but on the other parts such as segments and joints that are located proximal and distal to the patellofemoral joint instead (Powers, 2003; Loudon, 2016). These variables such as femoral anteversion, genu valgus/recurvatum, internal tibial rotation, foot pronation, ankle deformity, quadriceps strength, and hip muscles strength may be useful for clinical assessment for individuals with PFPS (Al-Hakim et al., 2012) as well as prescribing rehabilitation programmes (Loudon, 2016). However, not all variables have been investigated how they have effects on PFPS.

Extrinsic factors associated with PFPS are factors outside of the human body that can influence PFPS such as types of sports activities, environmental conditions, training characteristics, training surfaces, and equipment used (Halabchi et al., 2013). In this thesis, the lower extremity variables investigated were spatiotemporal and pelvic kinematic parameters of gait, plantar loading patterns, the Q-angle, and knee ROM. Extrinsic factors were training duration and training surfaces.

5.1 Spatiotemporal and pelvic kinematic parameters of gait

In orthopaedics and rehabilitation, gait analysis is used to monitor the patient healing progress (Steultjens et al., 2000; Hadizadeh et al., 2016). There is a study demonstrating changes in gait kinematics, kinetics and symmetry in ACL reconstructed athletes during rehabilitation programs. It was presented that the gait analysis was able to measure progression of the rehabilitation programs in these athletes (Hadizadeh et al., 2016). In health diagnostics, gait analysis can be applied between asymptomatic subjects and patients. One study investigated kinematic and kinetic gait patterns of individuals with PFPS compared to healthy individuals. It was hypothesised that individuals with PFPS would modify their gait patterns in order to reduce loading on the painful patellofemoral joint. The results supported the hypothesis that the modifications were found in the knee and hip angles during the gait patterns (Nadeau et al., 1997). Gait analysis can also evaluate gait parameters in healthy individuals for their activities of daily living as there is a study investigating gait parameters (ground reaction force (GRF) and spine related signals) for the various asymmetric loads carried by healthy individuals during walking. The results showed that an increase in the carrying weight resulted in changing of the spine dynamics and vibrations (Berceanu et al., 2016).

Spatiotemporal parameters of gait represent time-distance variables during stance and swing phases of gait (Hollman et al., 2011) whilst pelvic kinematic parameters are defined as pelvic tilts or pelvic motions (Hertel et al., 2004). The gold standard definition of pelvic tilt is a position-dependent parameter defined as the angle created by a line between the sacral end plate midpoint to the centre of the bifemoral heads and the vertical axis (Ellenbogen et al., 2018). Hollman et al. (2011) have provided operational definitions of spatiotemporal parameters of gait in Table 1.4.

Table 1.4 Operational definitions of spatiotemporal parameters of gait.

Parameters	**Definitions**
Spatial parameters	
Step length (cm or m)	- Anterior-posterior distance from the heel of one footprint to the heel of the opposite footprint
Stride length (cm or m)	- Anterior-posterior distance between heels of two consecutive footprints of the same foot
Step width (cm or m)	- Lateral distance from heel centre of one footprint to the line of progression formed by two consecutive footprints of the opposite foot
Temporal parameters	
Cadence (steps/min)	- Number of steps per minute
Step time (s)	- Time elapsed from initial contact of one foot to initial contact of the opposite foot
Stride time (s)	- Time elapsed between the initial contacts of two consecutive footfalls of the same foot
Stance time (s)	- Time elapsed between the initial contact and the last contact of a single footfall
Swing time (s)	- Time elapsed between the last contact of the current footfall to the initial contact of the next footfall of the same foot
Single support time (s)	- Time elapsed between the last contact of the opposite footfall to the initial contact of the next footfall of the same foot
Double support time (s)	- The sum of the time elapsed during two periods of double support in the gait cycle
Spatiotemporal parameters	
Gait speed (cm/s or m/s)	- Calculated by dividing the distance walked by the ambulation time
Stride speed (cm/s or m/s)	- Calculated by dividing stride length by the stride time

Spatiotemporal parameters of gait is one of the lower extremity variables related to PFJ load. There is a study investigating effects of step length on PFJ stress in female runners with and without PFPS during running. The results presented that a longer step length resulted in increasing of peak PFJ stress and a shorter step length resulted in decreasing of peak PFJ stress for both groups (Willson et al., 2014). Another study investigated the effect of cadence and shoes on PFJ kinetics in runners with PFPS and found that running in minimalist shoes or regular running shoes at an increased cadence reduced PFJ stress and joint reaction force (Bonacci et al., 2018). Gait can also be used as a treatment for PFPS as there is a study using gait retraining in runners with PFPS and presented that pain was significantly reduced after the retraining sessions (running with a forefoot strike pattern) (Roper et al., 2016).

Apart from spatiotemporal parameters, pelvic kinematics could also play an important role in PFPS. Normally, at the initial contact of gait, the pelvis is tilted anteriorly approximately 7°, rotated forward approximately 5°. During the loading response, the pelvis tilts upward on the stance limb side to a maximum of 5°, then it regains neutral tilt at the next initial contact of the swing limb. During stance phase, the pelvis rotates backward on the stance limb side and tilts anteriorly.(Nordin & Frankel, 2001) An anterior pelvic tilt posture may cause femoral internal rotation resulting in patellar maltracking, decreased patellofemoral contact area, and therefore increased patellofemoral stress (Mullaney & Fukunaga, 2016).

5.2 Training surfaces

Besides intrinsic factors, extrinsic factors also influence gait. Various training surfaces might have different effects on changes in spatiotemporal parameters of gait (Fanchiang et al., 2016) that might result in lower extremity injuries including PFPS (Halabchi et al., 2017). Synthetic playing surfaces are widely used for court and field sports. Artificial turf surfaces are commonly used as an alternative to natural grass surfaces whilst outdoor surfaces like clay and acrylic are also prevalent (Dragoo & Braun, 2010). Dragoo and Braun (2010) conducted a systematic review investigating the effect of playing surfaces on injury rates by presenting data from peer-reviewed studies. It was found that playing surfaces affected injury rates. First-generation (short-pile fibres without infill) and second-generation (longer fibres with sand infills) turf surfaces were generally related with significantly higher injuries rates. It was also presented that the overall rate of injury on third-generation (infills with mixtures of sand and granules of recycled rubber) artificial turf surfaces was similar to that of the natural grass surface. There also appeared to be fewer injuries on wood and clay compared with artificial court surfaces. Another study compared injury risks in pivoting indoor sports between two playing surfaces which were artificial floors and wooden floors. The results presented that the risk of traumatic injury in pivoting indoor sports was higher when playing on the artificial floors than on the wooden floors (Pasanen et al., 2008).

Only a few studies have assessed effects of different surfaces on spatiotemporal parameters of gait. One study investigated effects of different walking surfaces on spatiotemporal parameters of gait in children with idiopathic toe walking compared with typically developing children aged 4-10 years. The surfaces included vinyl tile, carpet, and pea gravel. Velocity, cadence, step length, and step width were recorded along with early heel rise during walking sessions. The results showed that all children presented with lowest velocity, cadence, and shortest step length on gravel and greatest velocity and cadence on vinyl tile. Children with idiopathic toe walking had significantly less toe-walking on the gravel walkway. It can be concluded that walking surfaces played an important role in altering spatiotemporal parameters of gait in the children (Fanchiang et al., 2016). Menant et al. (2009) examined effects of walking surfaces (control, irregular, and wet) and shoe features on spatiotemporal parameters of gait (velocity, cadence, step length, step width, double-support time, toe clearance, shoe-floor angle, and heel velocity) in young and older individuals. It was found that all subjects significantly exhibited decreased walking velocity, cadence, step length, double-support time, heel velocity as well as greater step width and toe clearance when walking on the irregular versus the control surface. The subjects significantly produced reduction in walking velocity, step length, shoe-floor angle as well as increased step width when walking the wet versus the control surface. The older individuals exhibited a more conservative walking pattern especially on the irregular and wet surfaces compared to the young individuals. From the previous studies, there is still limited evidence on effects of walking or training surfaces on spatiotemporal parameters of gait. Effects of more types of training surface on spatiotemporal parameters still need to be investigated as well as different groups of population.

5.3 Plantar loading patterns

Foot posture is a risk for some lower extremity injuries. Systematic reviews that focused on specific lower extremity pathologies have found significant relationships between planus foot posture (low medial longitudinal arch) and PFPS (Buldt et al., 2018). Excessive foot pronation and subsequent rotation of the lower extremity has been hypothesised as being implicated with PFPS (Powers et al., 2002; Noehren et al., 2012;

Rathleff et al., 2014). It is considered as one of the intrinsic factors that may increase lateral PFJ stress and subsequent PFPS development (Lee et al., 2017). During normal gait, the subtalar joint begins to pronate straight away after the initial contact and reaches the maximum value of 4° to 6° by 14% of the gait cycle. During pronation, the calcaneus everts whilst the head of the talus translates medially and inferiorly causing medial rotation of the talus. Subsequently, the tibia internally rotates and reaches a maximum value of 6° to 10° by 10% of the gait cycle. In late midstance, the subtalar joint reverses its function and starts to supinate causing external rotation of the tibia (Powers et al., 2002). A previous study reported that excessive foot pronation during stance phase of the gait may result in increased internal rotation of the tibia and femur and increased hip adduction and the dynamic Q-angle (Lee et al., 2017). It can be concluded that excessive or prolonged foot pronation has been shown to lead to PFPS (Willson et al., 2015).

The predominant techniques that have been used to investigate the interaction between foot posture and the lower limb biomechanics are kinematics, electromyography, and plantar pressure analysis (Landorf & Keenan, 2000). Plantar pressure analysis is defined as the measurement of the magnitude and distribution of force that is applied to the plantar surface of the foot during walking (Buldt et al., 2018). This measurement is important as variations in pressure are related with alterations to moments acting on proximal joints to the foot such as the ankle (Saraswat et al., 2014). A number of physiotherapists have used plantar pressure as a tool to evaluate abnormalities of the foot and the lower extremity to provide appropriate interventions and treatments for patients (Koh et al., 2015). Moreover, additional advantages of conducting pressure data are lower price and less time-consuming setting up the equipment compared to the gold standard laboratory-based 3-dimentional (3D) motion capture system (Schurr et al., 2017).

In PFPS research , most previous studies focused on investigating pain and quadriceps functions (Campolo et al., 2013; Verma & Krishnan, 2012; Christou, 2004; Khuman et al., 2012; Brantingham et al., 2009; Clifford & Harrington, 2013; Salsich et al., 2002) and there is only a few evidence reporting investigations of plantar loading patterns. A previous study demonstrated plantar pressure distribution in individuals with and without PFPS during the support phase of stair descent using Pedar-X insoles. Six plantar areas (medial, central and lateral rearfoot, midfoot, medial, and lateral forefoot) were investigated. It showed that people with PFPS developed greater contact areas at the medial rearfoot and midfoot compared to healthy people suggesting a more medially-directed support at ground contact (Aliberti et al., 2010). A study (Aliberti et al., 2011) investigated the influence of PFPS on plantar pressure distribution during the foot rollover process (initial contact, midstance, and propulsive phases) in individuals with and without PFPS. It was found that patients with PFPS had larger contact areas on the medial and central rearfoot at the initial contact and a lower peak pressure on the medial forefoot during propulsion compared to control subjects. A plantar contact that is medially oriented in the rearfoot has been associated with an everted rearfoot and could to excessive medial rotation of the tibia. This rotation could induce a compensatory medial rotation of the femur and a lateralization of the patella in relation to the femur, increasing the PFJ stress (Aliberti et al., 2011). Similarly, two studies investigated that there was increased pronation, accompanied with more pressure on the medial side of the rearfoot in healthy people who developed exercise-related lower leg pain during barefoot running (Willems et al., 2006; Willems et al., 2007). Based on the review and evidence that are currently presented and on the rehabilitation purposes, more studies of plantar loading patterns with some methods applied that could possibly affect the loading patterns are required to provide more evidence for healthcare professionals in treatments of PFPS.

5.4 The quadriceps (Q) angle

The normal alignment of the lower extremity affects the patella to directed forces laterally. This is described as “the law of valgus” and occurs because the 2 primary forces acting on the patella, the resultant quadriceps force vector and the patellar tendon force vector, are not on the same straight line. As a result, the quadriceps contraction creates a lateral force vector acting on the patella (Figure 1.10) (Powers, 2003). This offset in force vectors is clinically defined by “the Q-angle”, measured as the angle formed by the intersection of 2 lines crossing on the midpoint of the patella: one line beginning from ASIS to the midpoint of the patella and the other line beginning form the tibial tuberosity to the midpoint of the patella (Figure 1.10) (Powers, 2003; Ebeye et al., 2014; Almeida et al., 2016; Stensdotter et al., 2009).

Degrees of the Q-angle between 8° and 10° are considered normal for males and up to 15° for females. The values higher these degrees may indicate abnormality (Ebeye et al., 2014). The explanations of the difference of the Q-angle between males and females are that females present more lateral shift of the patella during the quadriceps contraction because they have wider hip and shorter femur which could increase the valgus of the lower extremity (Ebeye et al., 2014; Jaiyesimi & Jegede, 2009).

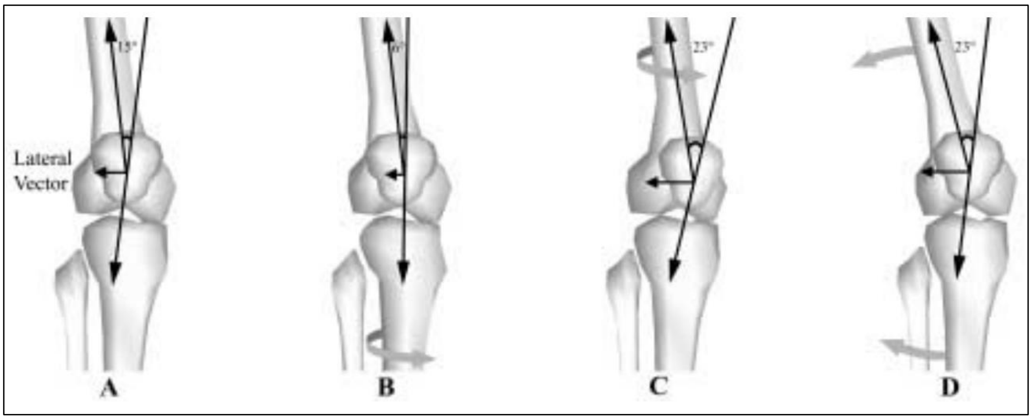


Figure 1.10 The Q-angle with the lateral force vector acting on the patella: A) normal lateral vector B) tibial internal rotation decreases the Q-angle and the magnitude of the lateral vector; C) femoral internal rotation increases the Q-angle and the lateral vector; D) knee valgus increases the Q-angle and the lateral force vector (Powers, 2003, p. 640).

The Q-angle is believed to be an important variable of patellofemoral function and dysfunction (Jaiyesimi & Jegede, 2009). It is widely used to evaluate individuals with PFPS (Almeida et al., 2016) as it is believed that a greater Q-angle is likely to produce a greater lateral vector and may have potential to result in lateral patellar tracking and increased patellofemoral contact pressures (Powers, 2003; Waryasz & McDermott, 2008). There are several studies presenting that individuals with PFPS had greater Q-angle compared to healthy individuals and the Q-angle and PFPS were associated. Emami et al. (2007) measured the Q-angle in individuals with PFPS and healthy individuals in a standing position using a universal goniometer and found that the mean Q-angle for the PFPS group was 18° and the control group was 14.9° with greater Q-angle in females for both groups. This study only provided the mean and not the standard deviation. Similarly, Liporaci et al. (2013) evaluated the frequency of signs and symptoms of PFPS including the Q-angle on a functional assessment of the lower extremity in individuals with and without PFPS. The results showed that individuals with PFPS presented increased Q-angle more often than ones without PFPS. Kaya and Doral (2012) also found a significant difference of the Q-angle between the affected side (19.61±4.35) and unaffected side (17.63±4.29) in individuals with unilateral PFPS measured by a universal goniometer in a standing position. Herrington (2013) generated an equation model from bilateral stance Q-angle and unilateral stance Q-angle in individuals without PFPS to predict the Q-angle in individual with PFPS. All Q-angle measurements were obtained from images taken by a digital photography. It was found that the individuals with PFPS presented higher actual Q-angle than those predicted with the mean difference of 2.3°.

Conversely, Kwon et al. (2014) evaluated the correlation between intrinsic PFPS and lower extremity biomechanics in young adults. This experiment was carried out with sixty (24 men and 32 women) individuals, who were normal university students. All subjects underwent 3 clinical evaluations. For distinguishing the intrinsic PFPS from controls, the Modified Functional Index Questionnaire (MFIQ), Clarke’s test, and the eccentric step test were used. Based on the results of the tests, subjects who were classified as positive for 2 more tests were allocated to the bilateral or unilateral intrinsic PFPS. Static and dynamic Q-angle were measured during standing and descending from the step on one leg respectively and it was presented that both angles were not significantly different between the 2 groups. These results are in line with Erkocak et at. (2016) who investigated the effects of rotational deformities in PFPS and the validity of certain related radiological patellofemoral alignment parameters including the Q-angle in individual with unilateral PFPS and healthy individuals. It was presented that there was no significant difference between the symptomatic and asymptomatic knees for the Q-angle. Similarly, Stensdotter et al. (2009) investigated the Q-angle in 3 methods: manual measurement by a standard goniometer in a supine position, whole body kinematics by five high speed cameras in supine and standing positions, and a radiograph image in a standing position in women with and without PFPS. The results demonstrated that there were no significant differences of the Q-angle between the both groups for all measurements, except the goniometer measurement which presented that the Q-angle was greater in the PFPS group.

Freedman et al. (2014) and Sheehan at al. (2010) found that increased Q-angle was not associated with lateral displacement of the patella but medial displacement instead. From this conflict, there is no strong evidence supporting if the Q-angle is larger in individuals with PFPS and the association between the Q-angle and PFPS still remains unclear. Further investigations are needed to present the fact about the Q-angle and PFPS.

5.5 Knee ROM

Knee ROM is more complex than only simple flexion/extension as this modified hinge joint consists of the PFJ and the TFJ and unlocks during the initial degrees of flexion and the femur rotates laterally on the tibia. However, flexion/extension is still a key component when measuring knee ROM (Peters et al., 2011). Knee ROM has been used to objectively measure recovery after various knee surgeries (Harmer et al., 2009; Mook et al., 2009; Ritter et al., 2003) and as a clinical indicator of functional restrictions in activities, such as gait (Naylor et al., 2011). It is also used for physical examination to identify if a patient presents with PFPS (Manske & Davies, 2016) and to monitor effectiveness of treatments and progression in individuals with PFPS as these individuals normally present less knee flexion than healthy individuals (Harshitha et al., 2014).

Goniometry is commonly used as instruments to measure joint ROM. There are several types of instruments and methods developed for measuring joint ROM with advantages and limitations of those (Bennett et al., 2009; Edwards et al., 2004). In clinical practice, knee ROM is usually assessed either visually or with a universal goniometer (Bennett et al., 2009). Plain radiographs have been used to measure pre- and postoperative knee flexion in research studies (Bennett et al., 2009) and computer-assisted navigation has been used to analyse knee ROM during orthopaedic surgery (Austin et al., 2008b). Radiography currently represents the gold standard for all ROM measurements (Phillips et al., 2012; Tajali et al., 2016; Herrmann, 1990) but this method is expensive, has potentially harmful effects on humans (Herrmann, 1990), and can only measure static ROM (Phillips et al., 2012). There have been many studies that have investigated the accuracy, sensitivity and reliability of knee ROM measurement (Naylor et al., 2011; Bennett et al., 2009; Austin et al., 2008b; Cleffken et al., 2007; Edwards et al., 2004; Brosseau et al., 1997; Peters et al., 2011; Wood et al., 2006).

The main limitation of these measuring methods is that they are static measures of knee ROM and not during functional dynamic activities. Research investigating dynamic ROM assessment is limited and the reliability and validity of dynamic ROM assessment methods remains unclear (Cronin et al., 2006). Measurement of dynamic movement is often quantified as a static measure where a universal goniometer is used to measure the final ROM at the end of the dynamic movement (Roberts & Wilson, 1999). In terms of validity, estimating a dynamic movement using a static measure is problematic and may not accurately reflect full functional ROM (Cronin et al., 2006). A method for measuring dynamic knee ROM or a method that can lead to dynamic knee ROM measurement needs to be focused on in the future research.

5.6 Training duration

Training duration is an extrinsic risk factor for overuse injuries that is believed to also influence PFPS (Halabchi et al., 2017). Most overuse injuries of the lower extremity cause by training errors or too much training (Buist et al., 2007). Several studies have suggested a number of factors that may increase the risk of lower limb injuries and training duration is one of those factors (Van Middelkoop et al., 2008). A previous study reported 7.4 and 6.9 running-related injury per 1000 hours of running among marathon runners who ran 204 and 162 minutes per week over a 1-year period (Jakobsen et al., 2013). Similarly, Buist et al. (2008) found an average of 33 running-related injury per 1000 hours of running in 2 groups of novice runners. One group performed running at an average of 52 minutes per week over a 13-week period (30 running-related injury/1000 hours) whilst the other group performed running at an average of 59 minutes per week over an 8-week period (38 running-related injury/1000 hours). Hespanhol Junior et al. (2013) also demonstrated that training duration was identified as a risk factor for running-related injury in a cohort study of predicting running-related injury in a recreational runners.

From the previous research, it is concluded that training duration could influence lower extremity overuse injuries including PFPS (Hespanhol Junior et al., 2013). Taking any history about recent alterations in sporting activities, training program including any changes in the frequency, intensity and duration of training is very important in athletes presenting with PFPS (Halabchi et al., 2017; Dixit et al., 2007). However, there is no evidence demonstrating relationship between PFPS and this extrinsic risk factor, so evidence is required to investigate this suggestion.

6. Aims and outline of the thesis

The thesis comprises five studies. The overall aim was to investigate lower extremity variables (spatiotemporal and pelvic kinematic parameters of gait, plantar loading patterns, the Q-angle, and knee range of motion) and extrinsic factors (training duration and training surfaces) associated with PFPS with the overall focus on evaluation of accessible tools that could potentially be used in clinical settings. Each study has a specific aim as presented in the next paragraph.

The initial study explored the prevalence of PFPS in young Thai athletes and examined the relationship between PFPS and training duration hours per week. The second study evaluated the functioning of a stretch sensor directly attached on the skin for knee range of motion (ROM) measurement and assessed the level of the measurement error. The stretch sensor was used to measure knee flexion in a laboratory environment during passive non-weight-bearing. The third study was a systematic review investigating the association between the Q-angle and PFPS and investigating the difference of the Q-angle between healthy individuals and individuals with PFPS as prior evidence about these have remained unclear. Various walking surfaces might have different effects on changes in spatiotemporal parameters of gait and pelvic kinematic parameters. However, there is a lack of studies assessing effects of different surfaces on gait patterns. Therefore, the fourth study investigated spatiotemporal and pelvic kinematic parameters of gait on different training surfaces during walking in healthy individuals. Three surfaces in the study included: 1) indoor multi-sport game surface; 2) outdoor synthetic surface for track and field; 3) natural grass surface. The final study examined the effect of McConnell taping and the stability through external rotation of the femur (SERF) strap on foot plantar loading patterns in healthy adults during walking and jogging. These two applications were chosen because McConnell taping is an effective treatment option in reducing pain after its immediate application in individuals with PFPS and SERF strap has been developed to pull the femur into external rotation to stabilise the PFJ, to reduce pain, and to improve lower limb kinematics during dynamic activities. It is proposed that the application of the SERF strap should alter plantar loading patterns by pulling the femur externally resulting in a reduction in medial tibial rotation and foot pronation. Although McConnell taping has become very popular for PFPS management, relatively little knowledge is known regarding its effect on foot pressures. Figure 1.11 provides the diagram of 5 studies in this thesis beginning from the first to the last study.

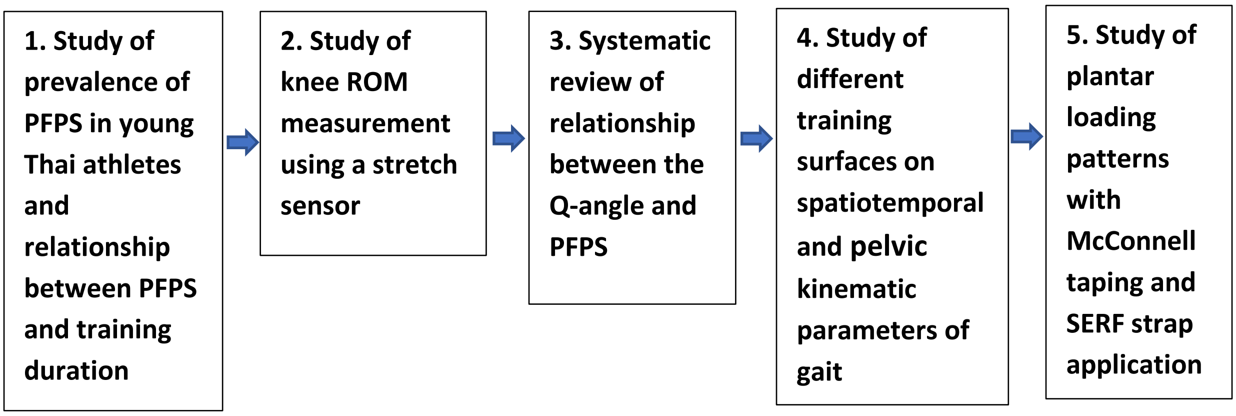


Figure 1.11 The diagram of 5 studies in the thesis: Extrinsic factors (training duration and training surfaces) are included in the 1st and 4th study; Lower extremity variables (knee ROM, the Q-angle, spatiotemporal and pelvic kinematic parameters of gait, and plantar loading patterns) are included in the 2nd, 3rd, 4th, and 5th study.

Chapter 2: Study 1

Prevalence of patellofemoral pain syndrome in young Thai athletes

1. ABSTRACT

Introduction: Patellofemoral pain syndrome (PFPS) is usually related with sports and activities of daily living and the condition may affect up to 25% of males and females who participate in sporting activities. However, only researchers in Europe, Australia, USA, and a few Asian countries have conducted studies of prevalence of PFPS. There is still a lack of good epidemiological evidence studying incidence or prevalence of PFPS in most countries including Thailand. PFPS is also often related to overuse so recent changes in activities and changes in duration of training should be considered. Therefore, the primary aim of the study was to estimate the prevalence of PFPS in young Thai athletes and the secondary aim was to investigate the relationship between PFPS and training duration. ***Methods:*** 362 Thai athletes (12-18 years) were recruited in the study. The participants completed a self-reported questionnaire known as "Anterior Knee Pain Scale (AKPS)" for the initial screening process. Participants who provided a score of less than 100 underwent further physical examination for PFPS. Details of their training schedule according to training duration per session, training frequency per week, and types of training were given by sports coaches at school. ***Results:*** 310 participants completed the AKPS questionnaire. There were 51 participants who reported a questionnaire score of less than 100 and 19 of those presented with PFPS with a greater prevalence in females but no significant difference of PFPS was found between males and females. The overall prevalence of PFPS was 6% (19 out of 310). PFPS was significantly related to sports training duration (p = 0.004) and sum of general and sports training duration (p = 0.015) for the overall population. When genders were considered, PFPS was significantly related to general training duration (p = 0.032) in males, sports training duration ($p < 0.001$) and sum of both training duration (p = 0.001) in females. ***Conclusion:*** The overall prevalence of PFPS in young Thai athletes was 6% which was a lower rate compared to previous studies. Sports training duration and sum of both training duration were associated with PFPS. The results of the current study may have implications for coaches or sports teachers for planning the schedule of sports training duration for the young Thai athletes.

Keywords: prevalence, patellofemoral pain syndrome, training duration, knee

2. INTRODUCTION

Patellofemoral pain syndrome (PFPS) is one of the most common knee pain diagnoses in sports medicine clinics (Esculier et al., 2013). Anterior knee pain (AKP) is a symptom that most commonly results from PFPS so the terms AKP and PFPS are often used synonymously to describe the same syndrome (Roush & Bay, 2012; Dixit et al., 2007). The disorder is usually related to sports and activities of daily living and the condition may affect up to 25% of males and females who participate in sporting activities (Phillips & Coetsee, 2007). The major complaint is pain around or behind the patella (retropatellar pain) usually during running, inclined walking, stair climbing, prolonged sitting with the knee in a flexed position, and squatting (Fredericson & Powers, 2002; Verma & Krishnan, 2012; Christou, 2004; Anloague, 2011). As a result, a large number of children and adolescents may be restricted in activities or perform submaximally on the sports field (Phillips & Coetsee, 2007). Limitation of physical activities can lead to a negative effect on physical development, motor skill and psychosocial development (Phillips & Coetsee, 2007; Barber Foss et al., 2012), and can also increase risk of becoming over-weight and obese adults (Hills et al., 2011).

Researchers in Europe, Australia, and USA have found that 25% of the general or sporting population present with PFPS (Phillips & Coetsee, 2007; Ireland et al., 2003; Brechter & Powers, 2002; Witvrouw et al., 2003; Anderson & Herrington, 2003). Callaghan and Selfe (2007) conducted a literature review to investigate incidence or prevalence of PFPS in the United Kingdom. Only 40 out of 136 articles cited rate or ratio for incidence or prevalence of PFPS and of these 15 out of 40 papers found a PFPS prevalence of 25% or 1:4 ratio in general population. However, there is still a lack of good epidemiological evidence studying incidence or prevalence of PFPS in general population in the United Kingdom. Other studies found different prevalence of PFPS. Barber Foss et al. (2012) reported that prevalence of AKP was 26.6% in the middle and high school-aged female athletes who were followed up over 3 years in USA which was believed to be associated with patellofemoral pain syndrome. Roush and Bay (2012) also found that the prevalence of APK in 18-35-year-old non-sporting females in USA was 12-13%. However, there is still a lack of studies assessing prevalence of PFPS in most countries and Thailand is one country where prevalence of PFPS has not previously been evaluated in any populations. Thai National Statistical Office stated that in 2011, 26.1% of the Thai population at the age of 11 years and above participated in exercise and sporting activities. When investigating rate of exercise in each age group, it was found that the 11-14-year age group had the highest exercise participation rate which was 60.1% (3:5). The second highest rate was found in the 15-24-year age group at 40% (2:5). The 60+ year age group was 23.6% and the 25-59-year age group was the lowest rate at 19% (National Statistical Office Ministry of Information and Communication Technology, 2012). Whilst the young Thai population have a high exercise participation rate and there is a lack of knowledge of the prevalence of PFPS in Thailand.

The anterior knee pain scale (AKPS), also known as Kujala scale, was designed to evaluate patellofemoral pain (Kujala et al., 1993). Esculier et al. (2013) conducted a systematic review of 5 self-reported questionnaires used to assess the level of symptoms and disability in people with PFPS. The questionnaires included Activities of Daily Living Scale (ADLS), International Knee Documentation Committee (IKDC), Lysholm Scale (LS), Functional Index Questionnaire (FIQ), and AKPS. It was found that AKPS presented excellent test-retest reliability (intraclass correlation coefficients (ICC) > 0.80) and minimal detectable change was only 9%. Myer et al. (2010) also used AKPS as an initial tool to screen middle and high school female athletes in USA if they had a score of less than 100 to investigate the prevalence and incidence of PFPS during their competitive basketball season. The results showed that the prevalence of PFPS was 16.3 per 100 athletes (16.3%) at the beginning of the season. The cumulative incidence risk and rate were 9.66 per 100 athletes and 1.09 per 1000 athletes. AKPS has also been translated into other languages which are Turkish, Chinese, Persian (Esculier et al., 2013), Dutch (Kievit et al., 2013), and Thai versions (Sakunkaruna et al., 2015). All translated versions appeared to be reliable and valid similar to the original English version.

The causes of PFPS are still under investigation (Fredericson & Powers, 2002; Anloague, 2011) but one of the most common factors in orthopaedic sports medicine is overuse (Fulkerson, 2002). As PFPS is often related to overuse, recent changes in activities and changes of training characteristics should also be considered (Dixit et al., 2007). Overuse injuries occur when training characteristics exceed the body’s ability to repair itself and are common in athletes or individuals starting an overzealous exercise program (Manske & Davies, 2016). Overuse injuries are also found in low-contact sports where the same movements are repeated multiple times, often within long training sessions (Yang et al., 2012). However, there is a lack of studies investigating the relationship between PFPS and training duration so the need for an investigation of this relationship is required. Therefore, the primary aim of the study was to estimate the prevalence of PFPS in young Thai athletes. The secondary aim was to investigate the relationship between PFPS and training duration hours per week. The prevalence of PFPS taken from the previous studies was 25% (Callaghan & Selfe, 2007). However, Thailand is a developing country where sports science and technology and training strategies may not be as established as in developed countries (The Ministry of Tourism and Sports Thailand, 2017). It was therefore hypothesised that the prevalence of PFPS in young Thai athletes would be more than 25%. The second hypothesis was that there would be a significant positive relationship between PFPS and longer training duration hours per week based on the proposal that overuse injuries including PFPS are associated with long training sessions (Yang et al., 2012).

3. METHODOLOGY

Participants

This survey study was an observational descriptive research (cross-sectional) that recruited students in Phitsanulok Provincial Administrative Organization Sports School, Thailand. The total number of students enrolled in the school was 362 and ages ranged from 12 and 18 years. This age range was selected as the survey on population behaviour in playing sport or physical exercise and mental health from the Thai National Statistical Office showed that this age range has a high rate of exercise participation (National Statistical Office Ministry of Information and Communication Technology, 2012). Every student in the school trained and engaged in one type of sport differently. Baseline characteristics of the participants are shown in Table 2.3.

The study was approved by the School of Sport & Exercise Sciences Research Ethics and Advisory Group (REAG), University of Kent at Medway (Ethics reference: Prop 53_2015_2016). The assent form for participants under 16 years, consent form for their guardians, consent form for participants at age 16 to 18, and participant information sheet were all translated into Thai. All participants and their guardians whose children were under 16 gave written informed consent prior to the participation. The guardians were provided with a one-week period to decide if they allowed their children to participate the study. A total of 362 written informed consents and 228 assents were given to teachers who were responsible for each classroom. The informed consent forms were divided into 3 types: 1) one for participants under 16 (228 forms provided); 2) one for guardians of participants under 16 (228 forms provided); 3) one for participants aged between 16 and 18 (134 forms provided).

Inclusion criteria

1. Students (boys and girls) who studied in Phitsanulok Provincial Administrative Organization Sports School, Thailand.
2. Ages ranged from 12 to 18 years.

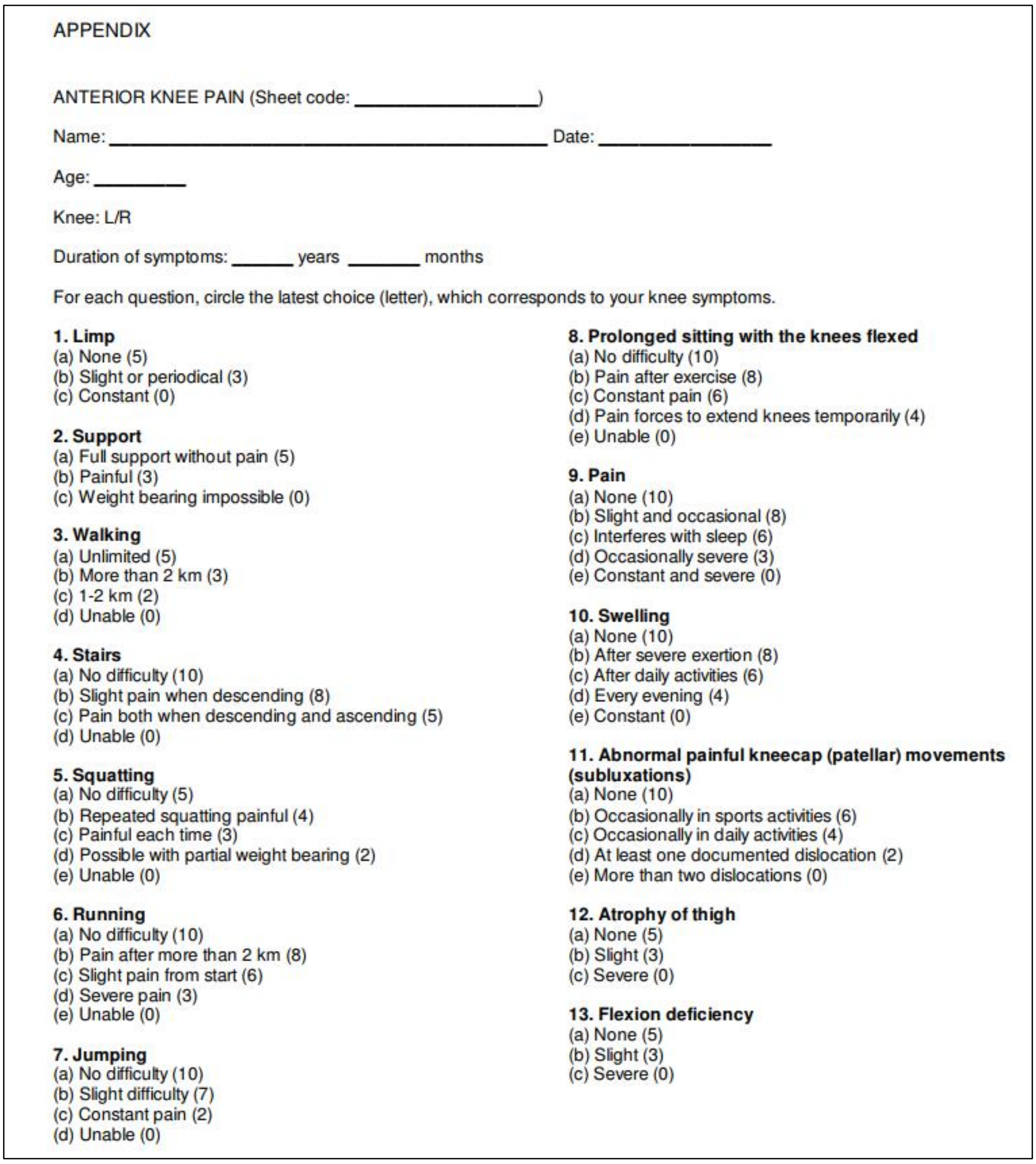
Exclusion criteria

1. Students who did not receive permission from their guardians to participate in the study.
2. Younger than 12 or older than 18 years.
3. Anyone who was not at school during the study period.

Anterior knee pain scale (AKPS)

The AKPS is a self-report questionnaire consisting of 13 items (Figure 2.1) that evaluates subjective responses to specific activities and to assess the symptoms and the level of disability of patients with PFPS (Esculier et al., 2013; Myer et al., 2010; Kujala et al., 1993; Barber Foss et al., 2012; Myer et al., 2016). The scale responds to 6 activities believed to be related with anterior knee pain (walking, running, jumping, stair climbing, squatting, and prolonged sitting with both knees bent) along with symptoms such as limp, weight-bearing inability on the affected limb, maltracking of the patella, muscle atrophy, swelling, and knee flexion limitation. It also asks about limb affected and duration of symptoms (Singer & Singer, 2009). The score of the questionnaire runs from a minimum of 0 to a maximum of 100 points. Lower scores represent greater pain and lack of ability. Participants who have no sign of AKP will have a score of 100 (Esculier et al., 2013; Myer et al., 2010; Kujala et al., 1993; Barber

Foss et al., 2012; Myer et al., 2016). It is considered a valid and reliable tool and easy to understand and complete ((Roush & Bay, 2012; Myer et al., 2016).



APPENDIX

ANTERIOR KNEE PAIN (Sheet code: ________________)

Name: ____ Date: ________________

Age: ________

Knee: L/R

Duration of symptoms: ______ years _______ months

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

1. Limp
(a) None (5)
(b) Slight or periodical (3)
(c) Constant (0)

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

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

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

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

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

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

8. Prolonged sitting with the knees flexed
(a) No difficulty (10)
(b) Pain after exercise (8)
(c) Constant pain (6)
(d) Pain forces to extend knees temporarily (4)
(e) Unable (0)

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

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

11. Abnormal painful kneecap (patellar) movements (subluxations)
(a) None (10)
(b) Occasionally in sports activities (6)
(c) Occasionally in daily activities (4)
(d) At least one documented dislocation (2)
(e) More than two dislocations (0)

12. Atrophy of thigh
(a) None (5)
(b) Slight (3)
(c) Severe (0)

13. Flexion deficiency
(a) None (5)
(b) Slight (3)
(c) Severe (0)

Figure 2.1 Anterior knee pain scale consisting of 13 questions (Kujala et al., 1993, p. 162).

Anterior knee pain scale translation

The AKPS questionnaire was translated from English into Thai to fit the local participants and tested for reliability in 40 participants which were similar population of the sample group on 2 occasions with a 30-minute time interval (Sakunkaruna et al., 2015). The Thai version of the questionnaire was then analysed by the intraclass correlation coefficient (ICC) 95% CI for test-retest reliability. To identity the reliability of the questionnaire, the correlation value between 0.9 and 1.00 was considered very strong, strong if the value was between 0.7 and 0.9, moderate if the value was between 0.5 and 0.7, and weak if the value was below 0.5 (Kievit et al., 2013). The result showed that the translated version of the AKPS questionnaire presented very strong test-retest reliability of 0.97.

Procedure

The initial screening process was that participants completed the Thai version of AKPS questionnaire which was given to the participants at school. They were provided with 1 hour to complete the questionnaire. Participants who provided a score of 100 presenting that they had no pain and disability related to PFPS (Barber Foss et al., 2012) did not need to go through further assessment. Participants who provided a score of less than 100 underwent further investigation which was a physical examination for PFPS performing by the researcher who was an experienced physiotherapist in a separate room providing by the school. (Table 2.1) (Dixit et al., 2007; Fredericson & Yoon, 2006; Hattam & Smeatham, 2010). Details of their training schedule per week according to training duration, frequency, and types (Ellapen et al., 2013) were given by sports coaches at school. The training consisted of general training and sports training. All participants performed the same general training which was speed, agility, power, and strength training 3 or 4 days a week depending on sports they participated. Sports training was different in each sport with the training including specific skills and game-based training 6 or 7 days a week.

Table 2.1 Key components and findings of physical examination for PFPS.

Components and finding	Comment
Inspection	
Lateral patellar tracking (“J” sign)	Patellar misalignment as a result of tight lateral structures or weak vastus medialis obliquus (VMO)
Poor VMO tone	Could be seen in PFPS
Palpation	
Effusion	Very rare in PFPS
Tenderness of:	
Patellar retinaculum (medial and lateral)	Common in PFPS; having pain in some portion of the lateral retinaculum

Facets (medial and lateral)	Could be seen in PFPS
Patella	Usually not tender in PFPS
Quadriceps and patellar tendon	Suggestive of tendinopathy or tear if injury is acute
Joint line	Suggestive of meniscus injury
Measurement	
Q-angle	May show a relationship between a higher Q-angle and PFPS
Range of motion (ROM)	ROM of knee and hip usually normal in PFPS
Crepitus	May occur with PFPS or osteoarthritis
Popping/clicking	May happen when palpating during passive or active ROM; could be a sign of patellar maltracking
Special test	
Patellar apprehension test	To detect instability/pain emanating from the patellofemoral articulation; positive if a patient experiences pain and/or apprehension in anticipant of patella subluxation and attempts to contract the quadriceps to prevent further excursion
Patellofemoral grind test	To elicit pain and/or apprehension emanating from the patellofemoral joint; positive if a patient feels pain
Muscle flexibility	An association between tight quadriceps and development of PFPS
Muscle strength	Quadriceps muscle weakness commonly seen in patients with PFPS

Diagnosis of PFPS

Determining the best tests for PFPS diagnosis is still limited (Roush & Bay, 2012; Cook et al., 2010; Crossley et al., 2016). In the present study, PFPS was diagnosed following the criteria in the Table 2.2.

Table 2.2 PFPS diagnosis criteria.

Criteria	Comment	Study
- Pain behind or around the patella following prolonged sitting with knee flexed, rising from sitting, or pain during activities such as ascending or descending stairs, squatting, kneeling, or running	- Most common symptom seen in PFPS	Dixit et al., 2007; Crossley et al., 2016; Cook et al., 2010
- Tenderness on palpation of medial or lateral retinaculum	- Common in PFPS: imbalance between VL and VMO cause the retinaculum to be stretched	Dixit et al., 2007
- Full range of motion of the knee joint	- Common in PFPS: knee and hip ROM usually normal in PFPS	Dixit et al., 2007; Crossley et al., 2016
- No knee effusion	- Sign of articular cartilage injury, chondromalacia patellae, loose bodies, patellofemoral osteoarthritis	Dixit et al., 2007; Crossley et al., 2016
- No locking of the knee joint	- As locking suggests a meniscal tear or loose bodies in the joint.	Dixit et al., 2007
- No localised pain at the inferior patellar pole	- This suggests patellar tendinopathy.	Crossley et al., 2016
- No localised tenderness and swelling around the tibial tuberosity	- This suggests Osgood Schlatter disease.	Crossley et al., 2016
- No morning stiffness, involvement of multiple joints or tendons, and joint swelling	- This refers to systemic joint disease.	Crossley et al., 2016

Statistical analysis

Age, weight, and height were expressed as mean±SD using Microsoft Excel. The differences of age, weight, and height between males and females were analysed by independent T-test as all the data was normally distributed. The difference of the questionnaire score between males and females was analysed by independent T-test following normal distribution of the data. The data were checked for normal distributions using Kolmogorov-Smirnov (K-S) test. The prevalence was calculated as the number of PFPS cases divided by the total number of participants that completed AKPS questionnaire in the study. The relationship between PFPS and general training duration and sports training duration per week were analysed by Pearson Chi-square. The relationships between PFPS and age, weight, and height were analysed by Pearson correlation (Point biserial). The statistics (Kolmogorov-Smirnov (K-S) test, independent T-test, and Pearson correlation (Point biserial)) were analysed using SPSS 24.0 (Norusis/SPSS Inc., Chicago, IL, USA). An Alpha level of $p \leq 0.05$ was used to test statistical significance.

4. RESULTS

The total number of students enrolled in the school was 362. Three hundred and forty-one consent forms were returned 1 week after they were handed out. Three hundred and ten AKPS questionnaires were distributed to the participants as 15 out of 341 participants did not give permission to participate and 16 of them did not present on the day that the questionnaires were completed. A total number of participants that did not participate in the study were 52 (Figure 2.2). All the questionnaires were returned within the day that they were provided to the participants, so this gave a return rate of 100%. Baseline characteristics of the participants are shown in Table 2.3. There were 51 participants who reported the questionnaire score of less than 100. No participants who met any of the criteria for AKP (Table 2.2) scored the maximum of 100. When gender sub-groups were considered, 35 out of 213 males (16%) and 16 out of 97 females (16%) scored less than 100 on the questionnaire (Table 2.4).

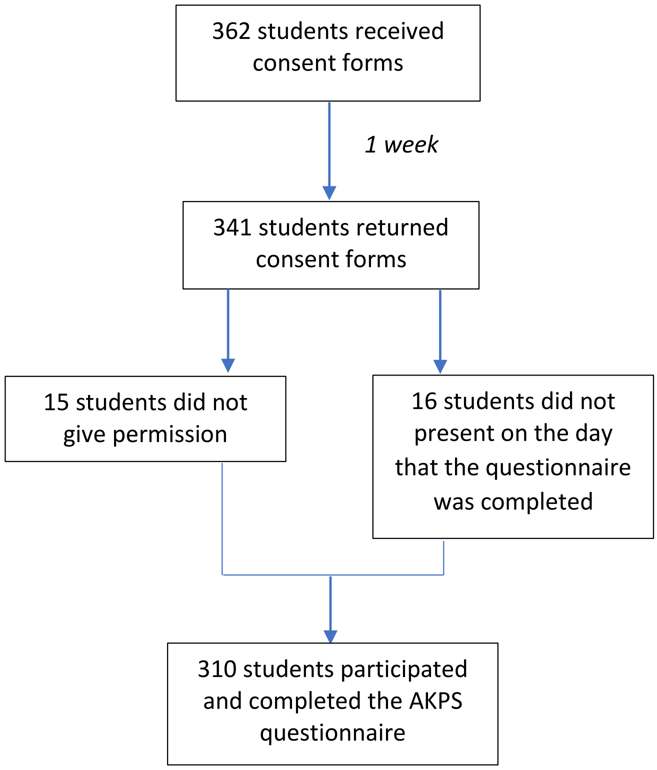


Figure 2.2 Flow chart representing the number of participants participating in the study.

Table 2.3 Baseline characteristics of the participants.

	Male (N = 213)		**Female (N = 97)**		***p*-value**	**Total (N = 310)**	
	Mean±SD	Max:Min	Mean±SD	Max:Min		Mean±SD	Max:Min
Age (year)	15±2	18:12	15±2	18:12	0.645	15±2	18:12
Weight (kg)	52.3±9.4	85:28	51.4±8.6	82:32	0.471	52.0±9.1	85:28
Height (cm)	165.9±9.0	185:136	160.7±6.9	178:145	< 0.001*	164.3±8.7	185:136

**p*-value < 0.001

Table 2.4 Number and percentage of participants who had the questionnaire score of 100 and less than 100.

Score	**Number of participants (N = 310)**	**Percentage**	**Male**		**Female**	
			N = 213	**%**	**N = 97**	**%**
< 100	51	16	35	16	16	16
100	259	84	178	84	81	84

Table 2.5 Number and percentage of participants whose scores were less than 100 and were diagnosed with or without PFPS.

PFPS	Number of participants (N = 51)	Average AKP score	Percentage	Male		Female	
				N = 35	%	N = 16	%
Positive	19	81±10	37	12	34	7	44
Negative	32	82±9	63	23	66	9	56

Table 2.5 indicates that 19 out of 51 participants (37%) who had the questionnaire score of less than 100 had signs and symptoms commensurate with a diagnosis of PFPS. There was no significant difference of average AKP scores between the positive and negative group (*p*-value = 0.740). When gender sub-groups were considered, 12 out of 35 males (34%) and 7 out of 16 females (44%) had signs and symptoms commensurate with a diagnosis of PFPS indicating a higher prevalence of PFPS in females but a significant difference between these 2 proportions was not found (*p*-value = 0.521). Overall, the prevalence of PFPS in young athletes registered at Phitsanulok Provincial Administrative Organization Sports School, Thailand who participated in this study was 6% (19 out of 310).

Table 2.6 Number, percentage, general training duration, sports training duration, and sum of both training duration of participants who were diagnosed with PFPS divided by sport played.

Sport played	Number of participants with PFPS (n = 19)	PFPS in percentage for each sport (%)	General training duration (hours/week)	Sports training duration (hours/week)	Sum of both training duration (hours/week)
Football (n = 87)	4	5	6	10.5	16.5
Volleyball (n = 65)	6	9	8	10.5	18.5
Athletics (Track) (n = 34)	6	18	6	9	15
Futsal (n = 40)	3	8	6	10.5	16.5

Table 2.6 presents a number of participants who were diagnosed with PFPS, percentage, general training duration, sports training duration, and sum of both training duration divided by sports that they played. Participants who performed the same sport had the

same training duration and frequency. Football, athletics, and futsal had the same general training duration which was 6 hours per week while volleyball was 8 hours per week. Football volleyball, and futsal had longer sports training duration which was 10.5 hours per week compared to athletics that was 9 hours per week.

Table 2.7 Relationships between PFPS and general training duration, sports training duration, age, weight, and height.

	General training duration (hours/week)	**Sports training duration (hours/week)**	**Age (year)**	**Weight (kg)**	**Height (cm)**
***p*-value**	0.108	0.004*	0.217	0.549	0.257

* Relationship is significant at 0.05

Table 2.7 shows the relationships between PFPS and general training duration, sports training duration, age, weight, and height. PFPS was significantly related to sports training duration (*p* = 0.004) showing that individuals with PFPS (100%) engaged in 9-hour and 10.5-hour sports training duration more often than individuals without PFPS (70.8%). This result suggests that longer sports training duration could be a factor in the development of PFPS. Significant relationships were not found between PFPS and general training duration, age, weight, and height.

Table 2.8 Relationships between PFPS and general training duration, sports training duration, age, weight, and height divided by genders.

	General training duration (hours/week)		**Sports training duration (hours/week)**		**Age (year)**		**Weight (kg)**		**Height (cm)**	
	M	F	M	F	M	F	M	F	M	F
***p*-value**	0.032*	0.124	0.197	< 0.001*	0.118	0.983	0.822	0.489	0.232	0.998

* Relationship is significant at 0.05
M = males, F = females

Table 2.8 presents relationships between PFPS and general training duration, sport straining duration, age, weight, and height when the gender sub-groups were analysed. PFPS was significantly related to general training duration (*p* = 0.032) in male participants presenting that individuals with PFPS (100%) engaged in 6-hour and 8-

hour general training duration more often than individuals without PFPS (85.5). There was a significant relationship between PFPS and sports training duration ($p < 0.001$) in females. Individuals with PFPS (100%) engaged in 9-hour and 10.5-hour sports training more often than individuals without PFPS (65.6%). Age, weight, and height were not associated with PFPS in both males and females.

Table 2.9 Relationships between PFPS and sum of general and sports training duration.

	Sum of general and sports training duration (hours/week)		
	Both genders	Males	Females
***p*-value**	0.015*	0.163	0.001*

* Relationship is significant at 0.05

Table 2.9 presents the relationships between PFPS and the sum of general and sports training duration. There were significant relationships between PFPS and sum of both training duration in all participants and in females when the gender sub-groups were divided. Male participants did not show a significant relationship between PFPS and sum of both training duration. Individuals with PFPS (100%) engaged in 15-hour, 16.5-hour, and 18.5-hour sum of both training duration more often than individuals without PFPS (62.5%). When the gender sub-groups were divided, females with PFPS (100%) engaged in 15-hour, 16.5-hour, and 18.5-hour sum of both training duration more often than females without PFPS (66.7%).

5. DISCUSSION

The prevalence of PFPS in young Thai athletes registered at Phitsanulok Provincial Administrative Organization Sports School, Thailand was found to be 6% (19/310). The initial hypothesis that prevalence of PFPS would be higher than 25% was therefore rejected. The prevalence in the present study was found to be lower than reported in previous studies. Evidence from the Europe, USA, and Australia have reported levels of prevalence of PFPS of 25% for general or sporting populations (Callaghan & Selfe, 2007). Barber Foss et al., (2012) found that AKP was presented in 26.6% of adolescent female athletes screened over 3 years whilst Roush and Bay (2012) stated that the estimated prevalence of AKP in 18-35-year-old females was 12%. Nejati et al. (2010) also investigated prevalence of PFPS in Iranian female athletes and it was found that the prevalence was 16.74%. Moreover, the latest systematic review that included 23 studies of prevalence in PFPS reported that annual prevalence for PFPS in general population was reported as 22.7% and adolescents as 28.9% (Smith et al., 2018). Similarly, a study found that the prevalence of PFPS in Chinese population was 20.7% for overall, 20.3% for males, and 21.2% for females (Xu et al., 2018) which is still higher compared to the current study. Callaghan and Selfe (2007) stated that most PFPS prevalence studies recruited university athletes, competitive athletes, and male military. A possible reason for the low prevalence of PFPS found in this present study may be that these young Thai athletes were still at the beginning level of sports training and competition compared to those in the previous studies, so their training schedule and intensity may not be as high as competitive athletes or from the military.

Table 2.5 shows that 32 of 51 participants presented with the questionnaire score of less than 100 but were not diagnosed with PFPS. AKPS questionnaire was not only developed to respond to six activities associated with AKP but also symptoms such as inability to weight bear through the affected limb, swelling, abnormal patellar movement, muscle atrophy, and knee flexion limitation (Singer & Singer, 2009). It is possible that these 32 participants may have presented with these symptoms.

The prevalence of PFPS in the present study was found to be higher in the female participants (44%) compared with the male participants (34%) but no significant difference of PFPS prevalence was found between males and females. However, several previous studies found significantly greater prevalence of PFPS in females compared to males (Myer et al., 2010; Nejati et al., 2011; Phillips & Coetsee, 2007; Roush & Bay, 2012; Barber Foss et al., 2012; Boling et al., 2010). Boling et al. (2010) found the prevalence of PFPS in females and males was 15.3% and 12.3% respectively. The incidence rate in females was 33/1000 person-years whilst 15/1000 person-years was found in males. Similarly, Phillips and Coetsee (2007) investigated the incidence of AKP in 11-17-years-olds school males and females. Their results showed that AKP was common among children between 11-17 years with a peak during 12-15 years in females.

There are anatomical and biomechanical factors that may lead to higher prevalence of PFPS in the females compared to the males (Boling et al., 2010). One of those factors includes the difference in quadriceps angle (Q-angle) (Boling et al., 2010) as females have greater Q-angle than males (Horton & Hall, 1989) and a greater Q-angle is a risk for PFPS (Kaya & Doral, 2012). Theoretically, a greater Q-angle increases the lateral pull of the quadriceps muscle and potentiates patellofemoral joint disorders (Emami et al., 2007; Horton & Hall, 1989). Lower extremity muscle strength is believed to be another risk factor for PFPS. Females have been reported to be significantly weaker than males on measurements of hip abduction, hip extension, hip lateral rotation, and quadriceps strength (Leetun et al., 2004; Barber-Westin et al., 2006). This muscle weakness places the females at a higher risk of joint pain and injuries, including PFPS (Phillips & Coetsee, 2007). However, the current study did not find a significant difference of PFPS prevalence between male and female participants. The possible reason can be explained by the small amount of PFPS cases diagnosed in the study especially in female participants. This may result in type II error (false-negative) where a null hypothesis that is false is accepted. A larger sample size can reduce this type II error (Banerjee et al., 2009).

The current study only investigated point prevalence of PFPS, and period prevalence and incidence rate were not investigated. For a chronic condition such as PFPS, the manifestation is often intermittent. As a result, point prevalence, based on a single assessment at one point of time, is likely to underestimate the prevalence of PFPS in the Thai athletes (Callaghan & Selfe, 2007; Roush & Bay, 2012). As period prevalence and incidence rates include a specific period of time (Callaghan & Selfe, 2007; Roush & Bay, 2012), reporting period prevalence or incidence rates helps to normalise for the time factor. Nevertheless, point prevalence is useful to find if a number of cases increase or decrease the next time that another point prevalence is investigated (Callaghan & Selfe, 2007; Roush & Bay, 2012).

Participants who engaged in athletics (track/running) demonstrated highest prevalence of PFPS which was 18% whilst volleyball, futsal, and football presented with 9%, 8%, and 5% respectively (Table 2.6). These results support the literature that most running injuries are located in the knee with PFPS being the most prevalent injury (Thijs et al., 2008). A retrospective case-control analysis of running injuries found that PFPS was the most common injury among patients with running related injuries. Injury breakdown with respect to anatomical location yields the knee as the most commonly injured site (42.1%) with 46% of these injuries being PFPS (Taunton et al., 2002).

Similarly, other two studies reported that 50-60% of all knee injuries was due to PFPS (Pinshaw et al., 1984; Clement et al., 1981). A possible reason may be that the runners performed more running distance especially during sports training compared to the other sports. Therefore, this caused a development of PFPS (Nielsen et al., 2013).

The secondary aim of this study was to investigate the relationship between PFPS and training duration per week. The second hypothesis of PFPS being significantly related to training duration per week was only partially supported. There were no significant relationships between PFPS and general training duration, age, weight, and height for the overall group of participants. However, PFPS was found to be significantly related to sports training duration ($p = 0.004$) and sum of both training duration ($p = 0.015$) which supported the second hypothesis. This finding supports the literature that PFPS is more common among physically active population (Callaghan & Selfe, 2007; Esculier et al., 2013; Myer et al., 2010; Nejati et al., 2011; Phillips & Coetsee, 2007; Roush & Bay, 2012; Erkocak et al., 2016; Pappas & Wong-Tom, 2012). In individuals with PFPS, training error such as changes in frequency, intensity, and duration of training can contribute to PFPS (Dixit et al., 2007).

Importantly, when gender sub-groups were considered, the male participants presented with a significant relationship between PFPS and general training duration ($p = 0.032$) whilst the female participants presented with a significant relationship between PFPS and sports training duration ($p < 0.001$) and sum of both training duration ($p = 0.001$). Small numbers of participants diagnosed with PFPS may result in type II error which caused differences of the significant relationships between PFPS and training duration in male and female participants. Training duration per week in the present study was acquired from a number of training hours per day multiplied by a number of training days per week (frequency). Jones et al. (1994) conducted a review of exercise, training, and injuries and found that runners and other physically active groups had consistently demonstrated that greater duration and frequency of training are associated with higher risks of injuries. On the other hand, the sports medicine literature presented little association between exercise intensity and injuries. This is the reason why training intensity was not evaluated in the present study. However, it is possible that training intensity could be another reason that the relationships between PFPS and training duration varied between males and females as it is one of the training characteristics that influences PFPS (Dixit et al., 2007). In the present study, it may be possible that the participants were controlled by training duration, but the training intensity was not monitored.

However, PFPS and the sum of general and sports training duration showed a significant relationship in all participants with individuals with PFPS (100%) engaged in 15-hour, 16.5-hour, and 18.5-hour training duration (Table 2.6) more often than individuals without PFPS (62.5%). On the basis of these results, it can be concluded that long training duration may be a factor in the development of PFPS. There were no significant differences of age ($p = 0.645$) and weight ($p = 0.471$) between male and female participants in the present study but a significant difference of height was found ($p < 0.001$) (Table 2.3). However, this significant difference of height should have no effect on the result as Lankhorst et al. (2012) and Pappas and Wong-Tom (2012) conducted a systematic review on risk factors and prospective predictors for PFPS and concluded that anthropometric variables including age, weight, and height were not associated with PFPS.

6. LIMITATIONS

There were several limitations of the current study, firstly the data collection only took place at one school and this limits the generalisation of the findings to a general Thai population of this age group. Future studies of prevalence of PFPS in other groups of Thai population or in other schools with the same age range are required to clarify if the results will be similar to the present study. Secondly, there were only a few PFPS cases diagnosed in the present study. This may be one of the reasons that relationships between PFPS and training duration varied between male and female participants. Statistical power calculation for the sample size is required to reduce type II error. Thirdly, the current study was a point prevalence study and a specific period of time was not included. This could underestimate a number of individuals diagnosed with PFPS (Callaghan & Selfe, 2007; Roush & Bay, 2012). Period prevalence and incidence rates should be considered in the future to normalise the time factor.

7. IMPLICATIONS

This current study of PFPS prevalence provides useful information for health professionals that can be used to aid the planning of treatment and rehabilitation interventions for PFPS patients. The results of this study also has implications for coaches or sports teachers at the school in the for planning of training programmes for the athletes. For example, it has been known from the results of the present study that long training duration could influence PFPS so training duration shortening, or frequency of training cut offs may help to reduce the prevalence of PFPS. The study provides research implications on the need to investigate prevalence of PFPS in other Thai schools and compare if the prevalence is similar to the school in the current study. If the prevalence is high, it then should be evaluated what the reason of low prevalence in the present school is. The training schedule may be related and should be investigated further in detail.

8. CONCLUSION

The overall prevalence of PFPS in young Thai athletes was found to be 6%, which is lower than previously reported levels of prevalence. PFPS was significantly related to sports training duration and the sum of general and sports training duration in the overall population. With the low prevalence of PFPS in the young Thai athletes in the present study, future data collection of the other lower extremity variables was not performed in this group of Thai population. However, prevalence of PFPS on other groups of population from the previous studies across the world were still high. Therefore, other variables of the lower extremity associated with PFPS still need to be investigated in the other studies.

Chapter 3: Study 2

Measuring knee range of motion using stretch sensors in healthy adults

1. ABSTRACT

Introduction: Knee flexion and extension ROM is a key component for normal knee function. A variety of techniques and instruments have been developed to measure knee ROM. However, the main limitation of all these measuring methods is that they were static measures and not during functional dynamic activities. Moreover, in terms of validity, estimating a dynamic movement using a static measure such as a goniometer is problematic and may not accurately reflect full functional ROM. The development of a valid and reliable method to assess dynamic knee ROM during free-living activities would be a valuable measure for monitoring and progressing knee rehabilitation. Therefore, the aim of this study was to evaluate the functioning of a stretch sensor, attached directly to the skin, measuring through capacitance, for the measurement of knee ROM and to assess the level of the measurement error. ***Method:*** Nine healthy participants aged 18-40 years were included in the study. Three stretch sensors were attached on the participants' right knees (middle, medial, and lateral sides) by the Kinesiotape. The participants were fastened to the dynamometer in a sitting position. The dynamometer was set to continuous passive mode (CPM). Data collection started when the knee was in an extended position and finished when the knee was fully flexed. Data was recorded through the StretchSense™ application. Knee angles were obtained from the video clips recorded during the testing and were analysed by MaxTraq® 2D motion analysis software. The knee angles were then synchronised with the sensor capacitance through R programme. ***Results:*** The middle sensor was chosen for the analysis and the results showed that seven of nine participants presented high coefficient of determination (R^2) (> 0.98) and low root mean square error (RMSE) (< 5°) which means there was strong relationship between sensor capacitance and knee angle. The equations generated from the 7 participants' data can be used individually to predict knee angles. ***Conclusion:*** It is possible to use the stretch sensors to measure knee ROM in healthy adults with a clinically acceptable level of error. Further research is now needed to establish the validity and reliability of the methodology under different conditions before it can be considered to have potential within a clinical setting.

Keywords: stretch sensor, flexible sensor, silicone sensor, knee range of motion, range of motion measurement

2. INTRODUCTION

The chapter 2 found that the prevalence of PFPS in the young Thai athletes from the previous chapter was low, investigating other lower extremity variables related with PFPS is necessary as the prevalence of PFPS in other groups of population elsewhere including the UK is still high (Callaghan & Selfe, 2007). Interventions that are resulted from improved understanding of the lower extremity variables related to PFPS may be able to reduce the prevalence of PFPS. Therefore, the improve understanding of the related lower extremity variables is essential. In order to achieve this understanding, reliable objective measures are needed. There is a limitation from assessing knee ROM using a universal goniometer during the physical examination in the previous prevalence study as the landmarking may result in substantial measurement error. The need for a more accurate measurement of knee ROM is required.

Measurement of joint ROM is established practice within sports and orthopaedic rehabilitation (Naylor et al., 2011; Bennett et al., 2009). Knee flexion and extension ROM is a key component for normal knee function with a mean functional arc of 96° and full passive ROM of 135° to 140° (Peters et al., 2011). Knee ROM is a lower extremity variable that is frequently used to objectively measure recovery after various knee surgeries (Harmer et al., 2009; Mook et al., 2009; Ritter et al., 2003) and as a clinical indicator of functional restrictions in activities, such as gait (Naylor et al., 2011). The measurement of knee ROM is standard practice within the physical examination and can be used to identify if a patient presents with PFPS (Manske & Davies, 2016). Importantly, knee ROM is also used to monitor effectiveness of treatments and progressions in individuals with PFPS as these individuals often present with reduced knee flexion compared with healthy individuals (Harshitha et al., 2014).

A variety of techniques and instruments have been developed to measure joint ROM. In clinical practice, knee ROM is usually assessed either visually or with a universal goniometer (Bennett et al., 2009). Plain radiographs have been used to measure pre- and postoperative knee flexion in research studies (Bennett et al., 2009) and computer-assisted navigation has been used to analyse knee ROM during orthopaedic surgery (Austin et al., 2008b). Radiography currently represents the gold standard for all ROM measurements (Phillips et al., 2012; Tajali et al., 2016; Herrmann, 1990) but this method is expensive, has potentially harmful effects on humans (Herrmann, 1990), and can only measure static ROM (Phillips et al., 2012). There have been many studies that have investigated the accuracy, sensitivity and reliability of knee ROM measurement (Naylor et al., 2011; Bennett et al., 2009; Austin et al., 2008b; Cleffken et al., 2007; Edwards et al., 2004; Brosseau et al., 1997; Peters et al., 2011; Wood et al., 2006). Peters et al. (2011) compared 3 methods of measuring knee ROM in 21 healthy male participants: visual estimation by physicians, hand goniometry by physiotherapists, and radiographic goniometry. Intra-rater and inter-rater reliability were found to be satisfactory for all 3 methods. However, inter-rater reliability across the methods was not found to be satisfactory, possibly due to variations in technique among physicians and physiotherapists. Bennett et al. (2009) demonstrated a method of recording and measuring knee ROM using digital imaging in patients who had undergone knee replacement surgery. The results presented high inter-observer reliability ($r > 0.948$) and intra-observer repeatability ($r > 0.906$) for the digital imaging. However, the main limitation of all these measuring methods is that they were static measures of knee ROM and not during functional dynamic activities. Research investigating dynamic ROM assessment is limited and the reliability and validity of dynamic ROM assessment methods remains unclear (Cronin et al., 2006). Measurement of dynamic movement is often quantified as a static measure where a universal goniometer is used to measure the final ROM at the end of the dynamic movement (Roberts & Wilson, 1999). In terms of validity, estimating a dynamic movement using a static measure is problematic and may not accurately reflect full functional ROM (Cronin et al., 2006).

Laboratory based equipment such as a dynamometry can be used to collect data regarding angular motion. Even though this type of research yields valuable information, the results only remain valid in conditions where there is no anticipation or reaction to the real environment (Bergmann et al., 2013). Data collection is often in non-weight-bearing positions such as sitting and supine that do not reflect functional activities. Laboratory equipment is expensive and not practical in a clinical and rehabilitation scenario (Bergmann et al., 2013).

The normal active ROM of the knee is from 0° of extension to 140° of flexion. Full extension is required for normal function (Nordin & Frankel, 2001), but many daily activities require less than 140° of flexion, dependent on the activities performed. Tying shoes (sitting and bringing the foot up from the floor) requires 106° of knee flexion;

sitting (without touching the chair with the hands) 93°; ascending and descending stairs 83°-105° and 86°-107° respectively; walking 60°; and fast running (faster than 7.5-minute mile) 103° (Clarkson, 2005). The development of a valid and reliable method to assess dynamic knee ROM during free-living activities would be a valuable measure for monitoring and progressing knee rehabilitation.

Stretch or flexible sensors are one of the methods that have been used to measure joint ROM (Austin et al., 2008b; Bergmann et al., 2013; Chiang et al., 2017; Hirata et al. 2015; Kumar et al., 2015; Tognetti et al., 2015). A wide range of materials have been used as stretch sensors to measure human movement range, including thin films of aligned single-walled carbon nanotubes; ZnO nanowire/polystyrene hybridized flexible films; electrogoniometers; a mixture of rubber and carbon (Bergmann et al., 2013); conductive rubber; conductive fabrics; polyvinylidene fluoride; and nanocomposites (Huang et al., 2017). A stretch sensor network that consists of wireless sensors attached to the patient could, potentially, provide an easy method to collect clinically relevant information about knee function in everyday situations (Bergmann et al., 2012).

Bergmann et al. (2013) applied stretch sensors integrated into clothing around the knee joint during non-weight-bearing movement on a Cybex dynamometer in healthy individuals with the aim of finding a way to measure knee joint kinematics that could be potentially used to detect and manage osteoarthritis (OA). They found an average root mean square error of ∼1°, a mean absolute error of ∼3° with a coefficient of determination (R^2) above 0.99 between the obtained angles and reference angles. These initial results demonstrated the potential of the sensors to measure dynamic knee ROM in patients with OA that could be used improve patients' quality of life. Feldhege et al. (2015) also evaluated a stretch sensor system against an electro-mechanical goniometer for knee ROM in healthy subjects and patients with multiple sclerosis during physical activities. The sensor system in this study demonstrated high validity for knee joint angle measurement with a root mean square error of less than 5° for the calculated flexion-extension angle of the knee joint compared with the result obtained using the reference goniometer. More recently, Papi et al. (2018) demonstrated that a flexible sensor attached to leggings was able to measure peak sagittal knee angles with small margins of error. However, these previous studies have all used sensor systems that were either attached to clothing or orthoses (Bergmann et al., 2013; Feldhege et al., 2015) and not directly onto the skin surface of the joint.

StretchSense™ (Auckland, New Zealand) have developed a stretch sensor that combines the ultra softness of silicone with the robustness of a fabric stretch sensor. Each sensor contains an integrated printed circuit board is soft and flexible, allowing the device to conform to the natural curves of the human body. The manufacturers state that the sensor can stretch to up to 3 times (200% strain extension) it’s original length, meaning the sensor should not restrict movements (Stretchsense, n.d.b). The capacitance of the sensor changes as the sensor is stretched or compressed (Stretchsense, n.d.d). In clinical settings, it would be useful to be able to adopt stretch sensors for knee ROM evaluation as the sensors are small, portable, easy to manage, and cheaper than lab-based equipment such as a Cybex dynamometer. They also allow a continuous measure of knee flexion within the maximum ROM (Saggio et al., 2014). This would allow evaluation of knee ROM during activities of daily living (Papi et al., 2018) as there is a lack of information regarding knee ROM during free-living activities. This would even provide benefits in terms of time and money saving for both healthcare professionals and patients as the patients can easily use the tool to measure themselves at home (Saggio et al., 2014) and knee ROM measures are currently taken at discrete points during clinical visits (Biggs & Shelbourne, 2006).

Currently, there are no published studies that have investigated the functioning of a stretch sensor, attached directly on the skin, measuring through capacitance, for the measurement of knee ROM. The aims of this study were to evaluate the functioning of a stretch sensor for the measurement of knee ROM during passive non-weight-bearing movement and to assess the level of the measurement error. From the previous studies of validating stretch sensors on knee ROM measurement, it has been found that the sensors demonstrated high validity and low level of error (Bergmann et al., 2013; Feldhege et al., 2015; Papi et al., 2018). Therefore, the hypotheses of the study were that the stretch sensors could be used to measure knee ROM during passive non-weight-bearing movement with a level of the measurement error less than the 5° that is considered as a clinically acceptable level of error in knee angle measurement (Unver et al., 2009; Wilken et al., 2012; Allseits et al., 2018). Moreover, the maximum error of human joints for the majority of requirements of motion capture is acceptable at not more than 5° (Huang et al., 2017).

3. METHODOLOGY

Participants

Simulation studies of prediction models have suggested minimum events per variable (EPV) values of between 5 and 20 for reliable results (Ogundimu et al., 2016). According to the previous studies in sensor systems for measuring knee ROM, eight to ten participants were recruited in the studies (Bergmann et al., 2013; Chiang et al., 2017; Saggio et al., 2014; Lee et al. 2016; McGinnis et al. 2016).

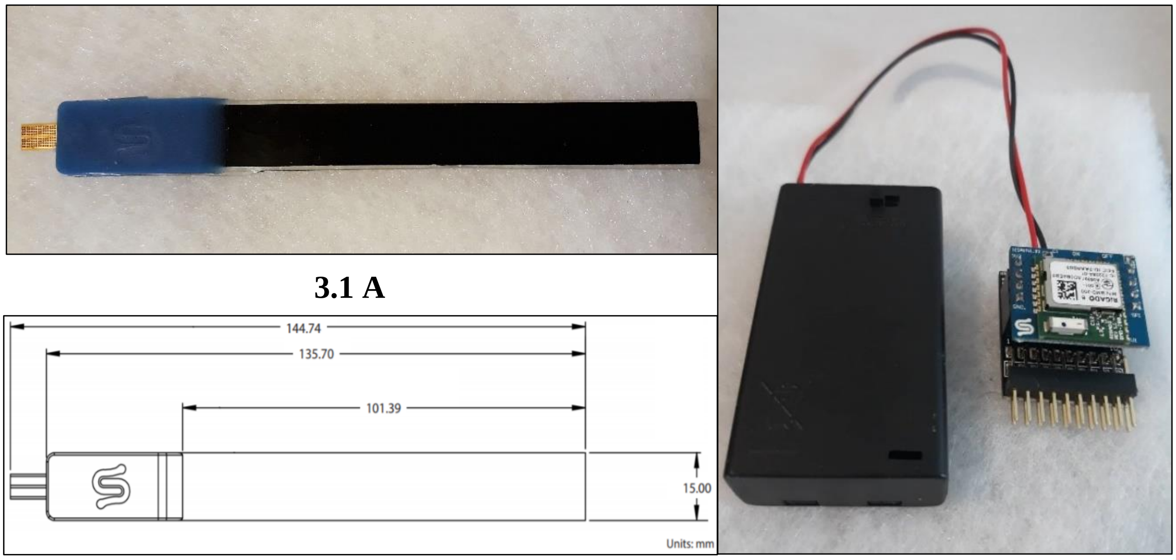
Inclusion criteria

1. Healthy individuals aged 18-40 years (both males and females).
2. No knee pain with any activities (Aliberti et al., 2010).
3. No history of a surgery involving the lower leg, ankle or foot in the last 12 months (Willems et al., 2006).
4. No history of an injury to the lower leg, ankle or foot within 6 months (Willems et al., 2006).
5. Adequately understand verbal explanations or written information given in English.
6. Not allergic to silicone and Kinesiotape.

Stretch sensor system

The stretch sensor (StretchSense™, Auckland, New Zealand) (Figure 3.1 A) consists of thin layers of silicone rubber, a non-conducting dielectric material, carbon filled, and silicone electrodes. The dimensions of the sensor are also shown in Figure 3.1 B. The sensor has maximum extension of 200% strain, average capacitance of 365 pF, average sensitivity of 2.8 pF/mm, and noise level of 0.67 pF (Stretchsense, n.d.e). When it is stretched, the ability to hold an electric charge at a given voltage changes. This charge-holding capability, capacitance is the ratio of the charge stored on the sensor divided by the voltage across its dielectric (Xu et al., 2015).

The stretch sensor is connected to a 10-channel SPI sensing board (#0CTX) (Figure 3.1 C) which gathers stretch sensing data simultaneously. It has output data rate of up to 1 kHz per channel, sensing channels of 10, Bluetooth 4.0 for digital communication, range of 0-65536 pF, 3-sigma (noise) of 0.46 pF (Stretchsense, n.d.a).



3.1 A

3.1 B

3.1 C

Figure 3.1 The stretch sensor system: 3.1 A) sensor; 3.1 B) sensor dimension; 3.1 C) 10-channel SPI sensing board and Bluetooth communicator.

Pilot testing session for sensors

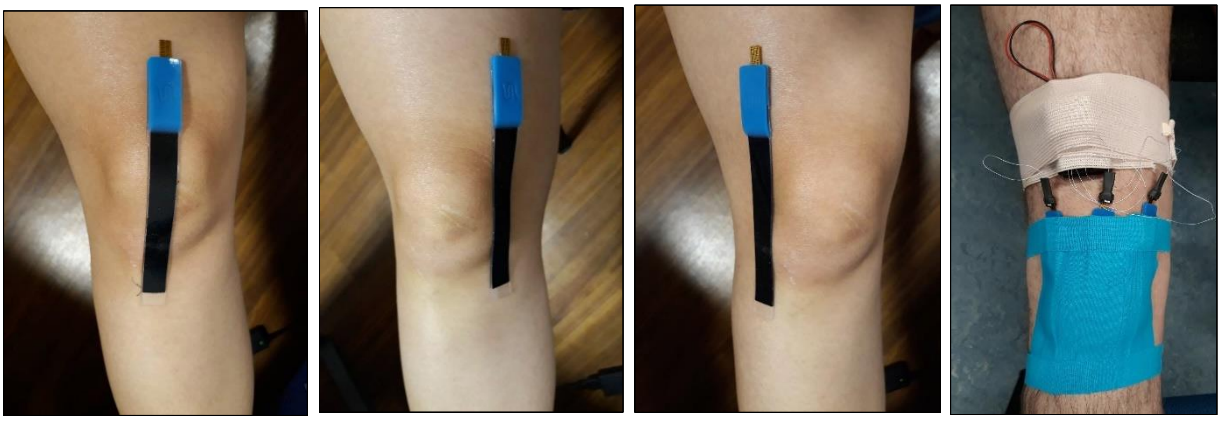
The stretch sensor placement was tested on 3 areas of the knee: middle of the patella over the patellofemoral join and tibiofemoral joint; the medial side of the patella over the tibiofemoral joint; and the lateral side of the patella over the tibiofemoral joint. The sensors were covered by Kinesiotape to ensure that the sensors were attached to the skin without any space between the sensors and the skin. Each participant then sat on an isokinetic dynamometer (Cybex HUMAC NORM model 770) with the dynamometer moving the right knee automatically. The sensor capacitance was recorded by the StretchSense™ application on a tablet connected to the sensor system by Bluetooth signal. Measurements were repeated 1 hour after the first test (Unver et al., 2009). The results of this pilot testing showed that the all three sensors demonstrated excellent test-retest reliability (intraclass correlation coefficient (ICC) = 0.853 for the capacitance of the middle placement, 0.832 for the capacitance of the medial placement, and 0.884 for the capacitance of the lateral placement).

Reliability test for MaxTraq® 2D motion analysis software

MaxTraq® 2D is a motion analysis software that allows users to track and analyse human movements from video clips that are opened by the software. The MaxTraq® 2D software was used to obtain knee angles in the present study. An intraclass correlation coefficient (ICC) was used to estimate intra-rater reliability of the researcher for using MaxTraq® 2D software to identify knee angles for participants. The researcher calculated knee angles from a video clip played by MaxTraq® 2D. The same process was performed again with a separation of 2 days (Tucker et al., 2007). The testing results demonstrated a correlation of 0.99. This was considered a high level of correlation as a correlation above 0.7 indicates acceptable reliability (Remigio et al., 2017).

Testing procedure

The study was approved by the School of Sport & Exercise Sciences Research Ethics and Advisory Group (REAG), University of Kent at Medway (Ethics reference: Prop 60_2017_18). All participants gave written informed consent prior to the participation. The participants attended the laboratory on one occasion. The Kinesiotape was used to attach the sensors to the skin in this study. The tape is a non-restrictive elastic adhesive tape selected for use in this study as it can stretch an additional 20-40% of its original length. Importantly, it has been designed to have the same amount of stretch as human skin and to provide support and stability to muscles and joints without restricting ROM (Drouin et al., 2013). Participants had a small patch of Kinesiotape applied over their skin on the knee area for 30 minutes prior to the data collection as a patch test (Parreira Pdo et al., 2014). All sensors were attached to the participant's right knee with the knee in an extended position. The first sensor without the connector was placed on the tibial tuberosity indicated by palpation and the rest of the sensor was attached over the midpoint of the patella with no tension (Figure 3.2 A). The second sensor was placed on the medial side of the knee next to the patella (Figure 3.2 B) and the third sensor was placed on the lateral side (Figure 3.2 C) with the middle of both sensors on the tibiofemoral joint line as the ends without the connectors were on the tibia and the other ends were on the femur. Each sensor was directly attached to the skin using a 5-cm-wide Kinesiotape that was placed over the sensor without tension. Two anchor strips (2.5-cm-wide) were placed without tension around the thigh and shank to prevent the sensors from displacing during knee movement (Figure 3.2 D). The Bluetooth communicator was placed on the right thigh and fixed by an elastic bandage (Figure 3.2 D).



3.2 A **3.2 B** **3.2 C** **3.2 D**

Figure 3.2 Sensor placement for 3 areas: 3.2 A) middle sensor; 3.2 B) medial sensor; 3.2 C) lateral sensor; 3.2 D) the sensors attached on the right knee by Kinesiotape with the Bluetooth communicator fixed by an elastic bandage.

A Cybex dynamometer was used to standardise movement speed of the knee joint (Bergmann et al., 2013). Participants were fastened to the dynamometer in a sitting position with 3 sensors on the right knee. A mobile phone was set up on a tripod and placed on the medial side of the right leg as a camcorder to record the knee movement. A tablet was used to record sensor capacitance through the StretchSense™ application. For standardisation, the right medial malleolus and the right medial femoral epicondyle were identified and marked by the researcher for knee angle measurement (Brosseau et al., 1997) and rechecked by an experienced physiotherapist. The midpoint of the medial side of the femur was marked as a reference for the hip joint as the greater trochanter could not be identified on the medial side (Figure 3.3). The dynamometer was set to continuous passive mode (CPM) for a self-selected ROM determined by the participants (Bergmann et al., 2013). To determine ROM, the participants were advised to straighten and bend their knees as much as they could, and those angles were recorded by the Cybex. The participants were given 5 minutes to perform 3 sets of 10 repetitions to familiarise themselves with the dynamometer and to learn to relax their quadriceps when the dynamometer moved. Data collection started when the knee was in an extended position and finished when the knee was fully flexed. The participants repeated the same process 3 times. Data was recorded through the StretchSense™ application when the record button on the tablet screen was pressed and ended when the record button was pressed once again.

Knee angles were obtained from the video clips recorded during the testing and were analysed by MaxTraq® 2D motion analysis software (Innovision Systems Inc). The software provided raw data at the rate of 30 frames per second (FPS). Capacitance from the sensors was recorded through the StretchSense™ BLE application installed on the tablet at the rate of 25 FPS. The raw data from both the MaxTraq® and StretchSense™ application were used. Due to the difference in sampling rates between the MaxTraq® and StretchSense™ application, drop frame method was used to reduce the sampling rate to 25 FPS for the MaxTraq® data. The knee angles were then synchronised with the sensor capacitance through R programme.

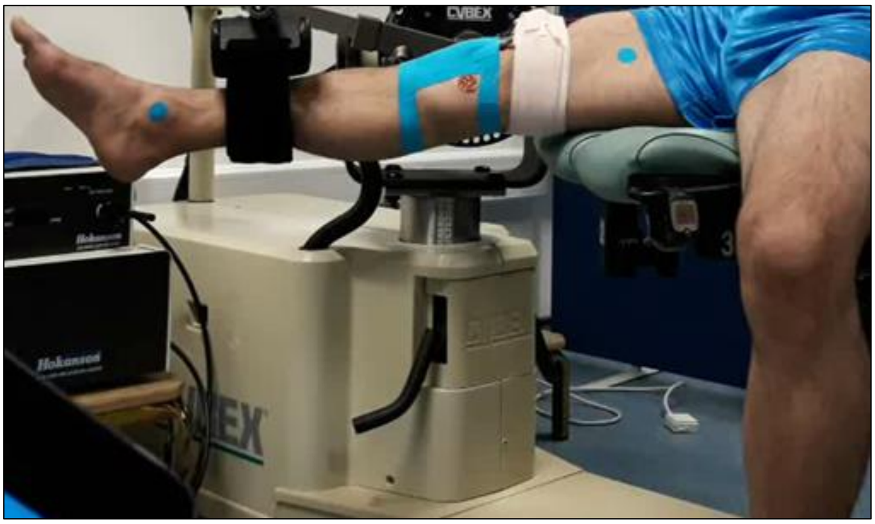


Figure 3.3 Three markers used for knee angle measurement: the medial malleolus, the medial epicondyle, and the midpoint of the medial side of the femur.

Statistical analysis

Baseline characteristics of the participants (age, weight, and height) were expressed as mean±standard deviation (SD) by Microsoft Excel. The average of 3 synchronised data sets of knee angles and sensor capacitance from each participant and the average of synchronised data sets from all participants were analysed using JMP® Statistical

Software trial version (© SAS Institute Inc.). A plot was created from the average synchronised data set in Microsoft Excel and RMSE and R^2 were generated by JMP®. A trend line was created using a second order polynomial for the curve fit (Saggio et al., 2014; Sbernini et al., 2016).

4. RESULTS

Baseline characteristics of the participants are presented in Table 3.1. Sample size calculations indicated ten participants for the study, however, 9 participants were able to be tested due to changes to the StretchSense™ application.

Table 3.1 Baseline characteristics of the participants.

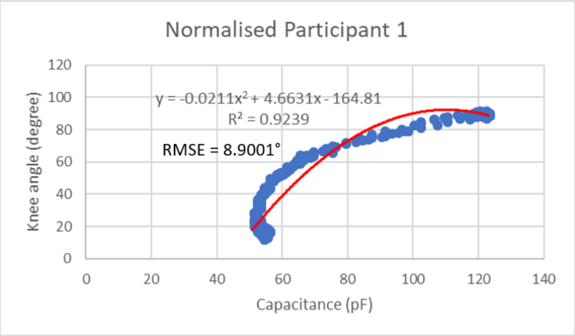
	Male (N = 6)		Female (N = 3)		Total (N = 9)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Age (year)	36±5	26-40	34±5	29-38	35±5	26-40
Weight (kg)	84.3±13.5	70-102	64.0±5.6	59-70	77.6±15.0	59-102
Height (cm)	182.0±5.8	176-190	162.3±3.1	159-165	175.4±10.9	159-190

The capacitance of the sensors was normalised for all participants as they had different starting values. The coefficient of determination (R^2) and Root Mean Square Error (RMSE) were calculated to determine the robustness of the relationship between the capacitance and the knee angles. The middle sensor demonstrated the highest R^2 and lowest RMSE for seven of the participants (Table 3.2) and the results from the middle sensor were therefore selected for further analysis.

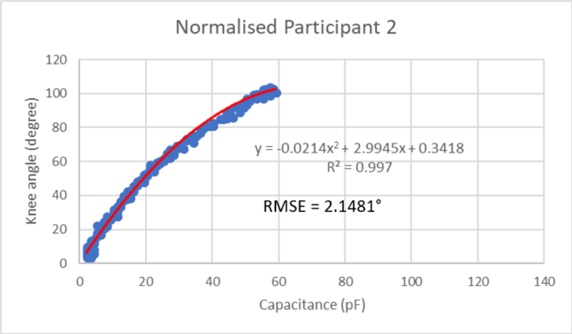
Table 3.2 The coefficient of determination (R^2) and Root Mean Square Error (RMSE) for each sensor from 9 participants.

Participant	R square			Root Mean Square Error		
	Middle sensor	Medial sensor	Lateral sensor	Middle sensor	Medial sensor	Lateral sensor
1	0.9239	0.9705	0.9717	8.900	5.5435	5.4373
2	0.9970	0.9743	0.9837	2.1481	6.2643	4.9680
3	0.9983	0.9762	0.9473	1.8486	6.9732	10.3893
4	0.9935	0.9781	0.9375	3.5152	6.4382	10.8646
5	0.9978	0.9942	0.9944	1.4744	2.4229	2.3608
6	0.9969	0.9866	0.9771	1.9893	4.1426	5.4154
7	0.9897	0.9830	0.9639	3.3396	4.3009	6.2501
8	0.9844	0.9545	0.9527	5.4047	9.1917	9.3726
9	0.9823	0.9934	0.9645	4.3248	2.6512	6.1339

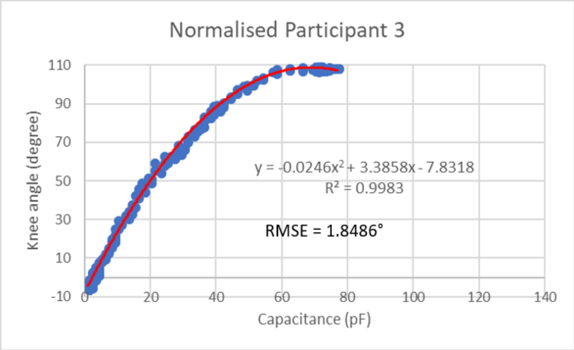
The middle sensor plots for each participant with trend lines are shown in Figure 3.4. A nonlinear model was chosen as it had the best fit for the data (Figure 3.4).



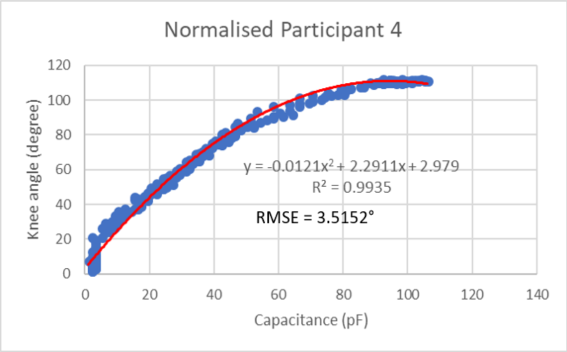
3.4 A



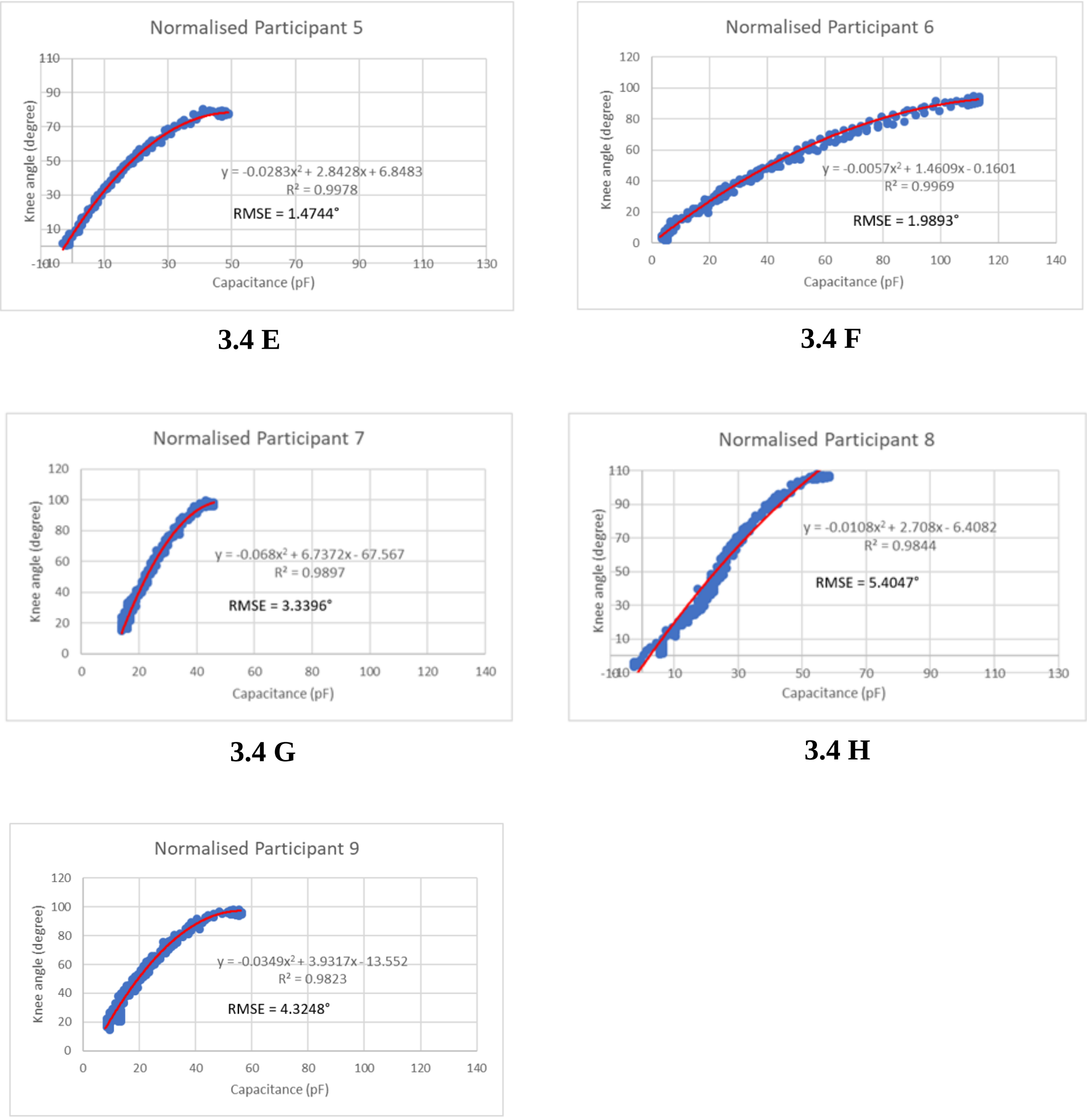
3.4 B



3.4 C



3.4 D



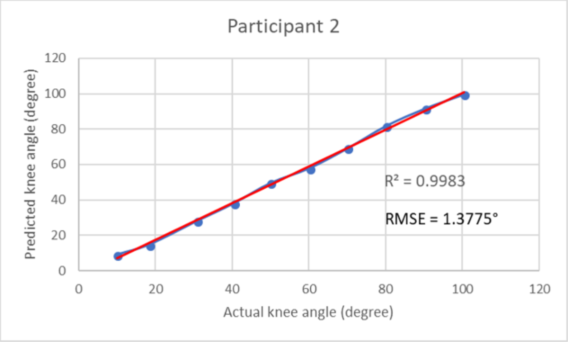
3.4 E **3.4 F**

3.4 G **3.4 H**

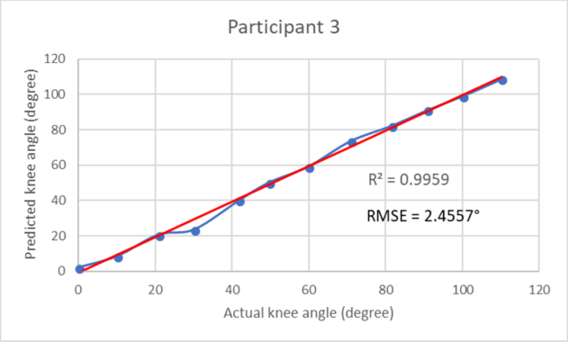
3.4 I

Figure 3.4 Plots of sensor capacitance and knee angles of each participant with the blue dots representing actual relationship between capacitance and knee angles and the red line representing theoretical ideal fit.

Participant 1 (Figure 3.4 A) and participant 8 (Figure 3.4 H) presented high RMSE so it did not confirm good accuracy of the sensor on these two participants. Their data were removed from the analysis as the equations generated from their data would not be good models to predict knee angles. The equations from participants 2 to 7 and participant 9 were used to calculate predicted knee angles to compare with actual knee angles as shown in Figure 3.5. When the mean data set for the 9 participants was analysed, it was not found to be a good fit for nonlinear regression ($R^2 = 0.7864$ and RMSE = 17.9555°).



3.5 A



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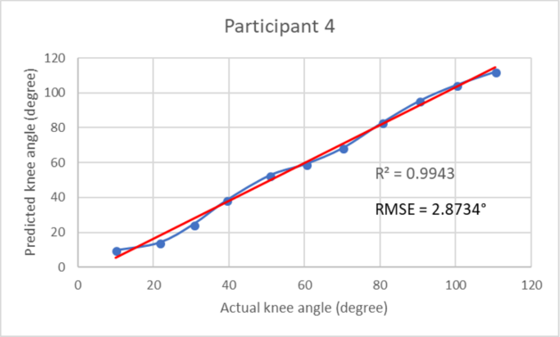
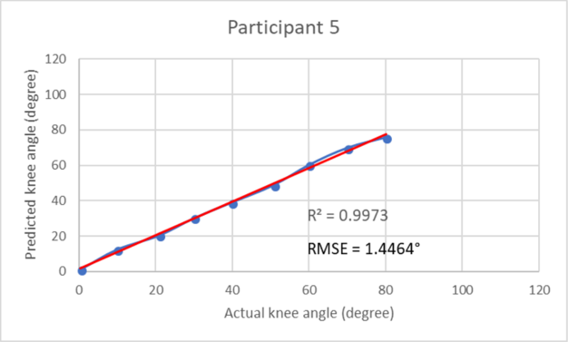


3.5 C



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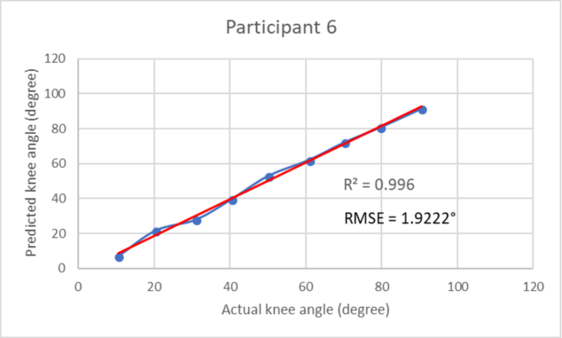
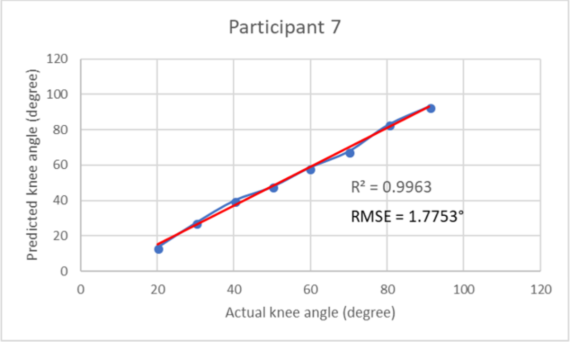
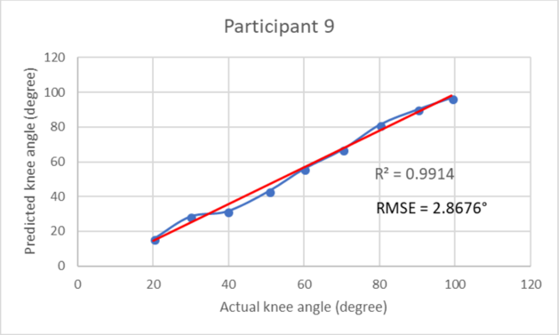


3.5 E



3.5 F



3.5 G

Figure 3.5 Plots of actual knee angles and predicted knee angles with the blue line representing relationship between actual knee angles and predicted knee angles and the red line representing theoretical ideal fit.

5. DISCUSSION

The aim of this study was to evaluate the potential use of a stretch sensor attached to the skin for the measurement of knee range of motion. The main finding of this study was that there was a strong relationship between the capacitance and knee angles (Figure 3.4) for seven out of the nine participants with high R^2 and a RMSE below 5 degrees. This is clinically important as 5 degrees is considered as a clinically acceptable level of error in knee angle measurement (Unver et al., 2009; Wilken et al., 2012; Allseits et al., 2018). A study investigated a minimal detectible change during gait kinematics and kinetics in healthy individuals and found that changes in gait kinematics during knee flexion could be identified only if the angle was greater than 5 degrees (Wilken et al., 2012). However, participant 1 (Figure 3.4 A) and participant 8 (Figure 3.4 H) presented high RMSE greater than 5°. It is proposed that the reason for the increased RMSE in these two participants was due to the stretch of the sensor (Bergmann et al., 2013; Saggio et al., 2014). Figures 3.4 A and 3.4 H show how, at the beginning of knee flexion, the capacitance decreased whilst the knee angle increased which was not expected. This pattern is likely to have been the result of the synergic actions of bending and stretching forces of the sensor (Saggio et al., 2014) as it was built from stretchable material (Bergmann et al., 2013) together with the noise level that occurred when the sensor was placed on the skin and covered by the Kinesiotape. Another possible reason may due to the sensor being stretched at the width of it during the passive movement which complicates the relationship between the knee angle and sensor capacitance (Stretchsense, n.d.e).

Figure 3.5 shows a strong linear relationship between actual knee angles and predicted knee angles with $R^2 > 0.99$ and RMSE < 3° for the 7 participants. On the basis of the relationship for these seven participants, there is support for the measurement of knee ROM using a stretch sensor attached to the skin on an individual basis. However, it was not possible to produce an overall model for the 7 participants due to the considerable inter-participant variation in the nonlinear regression model for each individual (Figure 3.4). Anatomical and functional differences could explain the variation in results between participants. Amis et al. (2006) found that when the knee was flexed, the patellar translated medially 4 mm to engage the trochlear groove at 20° knee flexion then translated to 7 mm laterally by 90° knee flexion. The patella also tilted progressively to 7° laterally by 90° knee flexion and patellar medial-lateral rotation was usually less than 3°. If there was variation in the distances and degrees of translation and tilting of the patella between individuals, this would have altered the capacitance of the sensor at different points in knee range of motion. This would result in the finding of consistent, but varied, nonlinear models for individuals (Saggio et al., 2014). The implications of this finding is that it may be necessary to calibrate the sensor for every participant before knee angles can be calculated.

Three stretch sensors were placed on different areas of the right knee which were middle, medial, and lateral sides. The medial ($R^2 = 0.7393$; RMSE = 19.8030°) and lateral sensors ($R^2 = 0.6193$; RMSE = 23.9226°) did not show a strong relationship between sensor capacitance and knee angles. It is likely that the positioning of the sensors on the sides of the patella and over the tibiofemoral joint line resulted in asymmetry between the borders of the sensors as the knee was flexed. That resulted in minimal change in sensor capacitance (Bergmann et al., 2013).

This study demonstrated a consistent, strong relationship between knee angle and capacitance during a passive, non-weight-bearing movement in the majority of individuals tested. However, this was for a single application in healthy adults. Future studies need to consider the repeatability of the individual nonlinear regression models and dynamic weight-bearing movements.

6. LIMITATIONS

The limitations of the current study were that it was a lab-based study which limited the application of the results to non-lab based dynamic functional activities at present and this was for a single application during a passive, non-weight-bearing movement. Moreover, this was the first study using silicone stretch sensors directly attached on the skin measuring through capacitance so the results outside the laboratory have not yet been investigated. Another limitation was the knee angles being measured by MaxTraq® 2D without validating this method against the gold-standard of a motion analysis system. Some photogrammetric devices, such as the Vicon, are able to guarantee the most accurate and reliable motion analysis (Saggio et al., 2014). Nevertheless, their high performances are high-cost and require trained staff and dedicated rooms (Saggio et al., 2014) which were not available for the current study.

Further studies are required to consider repeatability of the test for the nonlinear regression model by applying the stretch sensor on each individual with multiple testing during passive non-weight-bearing in order to know whether recalibration is necessary for every individual who applies the stretch sensor or not. After the repeatability for passive non-weight-bearing is performed, several further steps are needed, and each step needs to be evaluated for reliability, validity, and sensitivity: 1) active non-weight-bearing in a laboratory 2) active weight-bearing in a laboratory 3) active functional free-living activities such as walking or running and 4) in clinical populations. Once the reliability, validity, and sensitivity are performed, the stretch sensor may be used during dynamic weight-bearing movements such as walking in individuals with PFPS to monitor progression of knee ROM during rehabilitation programmes.

7 IMPLICATIONS

This study has highlighted the necessity for calibrating the sensor for each participant before knee angles can be calculated. The need for calibration resulted from the findings of considerable inter-participant variation in the nonlinear regression model for each individual. With the strong relationship between the sensor capacitance and knee angles and the small size of the sensor, it may be possible that the stretch sensors can be used to measure dynamic knee ROM during free-living activities. The ability to monitor these kinematic changes would provide clinically important and relevant information to further understanding of the syndrome progression as well as inform rehabilitation practice (Papi et al., 2018).

8. CONCLUSION

This study was an initial validation study that considered the functioning of stretch sensors attached to the skin to measure knee ROM through capacitance. The sensors demonstrated consistent, strong relationships between knee angle and capacitance with less than 5 degrees of error for the majority of participants. On an individual basis in a laboratory situation, it has been shown that it is possible to use the stretch sensors to measure knee range of motion in healthy adults with a clinically acceptable level of error. Further research is now needed to establish the validity and reliability of the methodology under different conditions before it can be considered to have potential within a clinical setting.

The measurement of knee ROM has been proposed as a standard measurement within the physical examination and can be used to identify if a patient presents with PFPS. During knee flexion and extension, movements of the patellar, tibia, and femur occur. This results in changing of the Q-angle, another lower extremity variable are believed to influence PFPS. However, there is still a conflict whether greater Q-angle is associated with the development of PFPS or not.

Chapter 4: Study 3

Association between the Q-angle and patellofemoral pain syndrome: A systematic review of the current literature

1. ABSTRACT

Introduction: The Quadriceps (Q) angle is frequently used as an indicator of patellofemoral pain syndrome (PFPS). An angle that is larger than 20 degrees is assumed to influence PFPS by translating the patella laterally and increasing retropatellar pressure. Traditionally, the Q-angle is typically a static measurement evaluated with individuals in the supine position, knee extended with the quadriceps muscle relaxed. It is also assessed in the standing position. However, there is still some conflict about the relationship between the Q-angle and PFPS. Therefore, the primary purpose of this systematic review was to investigate the association between the Q-angle and PFPS and the secondary purpose was to investigate the difference of the Q-angle between individuals with and without PFPS. ***Methods:*** Case-control or cross-sectional or cohort or randomised controlled studies writing in English and publishing between 2013 and 2016 were eligible for the review. Search strategy was conducted in PubMed, Web of Science, Scopus, and CINAHL. Quality of the papers was assessed with a scale (14 items) previously used for a PFPS systematic review. The full score was 40 with the total possible score given as a percentage. Score ≥70% was considered as “high quality” and score <70% was considered as “low quality”. ***Results:*** The initial search yielded 233 articles and remained 162 articles after duplicated removed. A total of 8 studies were deemed applicable following application of the inclusion and exclusion criteria. There were 5 cross-sectional studies, 2 cohort studies, and 1 randomised controlled trial study. This included 197 individuals with PFPS and 217 healthy controls. Scores ranged from 13 to 25 (32.5 to 62.5%) which meant that all 8 papers were low quality. The findings of this review suggest that there are disagreements on the relationship between the Q-angle and PFPS and the difference of the Q-angle in individuals with and without PFPS. A possible explanation for this conflict may be attributed to the different methodologies and measurement differences of the Q-angle. ***Conclusion:*** Without high quality studies, this updated review is unable to conclude if there is the association between the Q-angle and PFPS or the difference of the Q-angle between individuals with and without PFPS. Four of 8 studies tended to show that the Q-angle was greater in individuals with PFPS, but the quality of the papers was still low.

Keywords: quadriceps angle, Q-angle, patellofemoral pain syndrome

2. INTRODUCTION

According to the previous chapter, knee ROM measurement has been used as one of the criteria to identify if a patient presents with PFPS (Manske & Davies, 2016). The Q-angle is another measurement that has been used to support the diagnosis of PFPS (Emami et al., 2007). The Quadriceps angle or Q-angle is defined as the angle between a line from ASIS to the centre of the patella and a line from the tibial tuberosity to the centre of the patella (the same point of the first line) (Park & Stefanyshyn, 2011; Smith et al., 2008). It is an index of the vector for the combined pull of the extensor mechanism and the patellar tendon (Smith et al., 2008; Silva et al., 2015a). The Q-angle is frequently used as an indicator of patellofemoral dysfunction including PFPS (Emami et al., 2007; Kaya & Doral, 2012; Smith et al., 2008; Piva et al., 2006). An angle that is larger than 15 degrees in males and 20 degrees in females is assumed to influence PFPS by translating the patella laterally and increasing retropatellar pressure (Sheehan et al., 2010; Smith et al., 2008), and, therefore, causing pain (Silva et al., 2015a). Traditionally, the Q-angle is typically a static measurement evaluated with individuals in the supine position, knee extended with the quadriceps muscle relaxed (Sheehan et al., 2010; Smith et al., 2008). It is also assessed in the standing position (Smith et al., 2008). The static measure of the Q-angle is also used to infer the dynamic condition of patellar maltracking (Sheehan et al., 2010).

Previous studies have reported relationships between the Q-angle and PFPS (Naslund et al., 2006; Haim et al., 2006). However, there are still some conflicts about these relationships (Sheehan et al., 2010). Although the Q-angle is assumed to indicate lateral subluxation of the patella, a study found a relationship between the Q-angle and medial patellar displacement in individuals with PFPS (Sheehan et al., 2010). Kaya and Doral (2012) investigated relationships between the Q-angle and lower extremity alignment that is an important etiological factor for PFPS in women with PFPS. The lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA) were used to assess the lower extremity alignment. It was found that there were no relationships between the Q-angle and LDFA and MPTA in both affected and unaffected sides of the patients. (Biedert & Warnke, 2001) evaluated the significance of the Q-angle with respect to the patella positions (lateral patellar displacement (LPD), lateral patellar tilt (LPT), and patella-lateral condyle index (PLCI)) in individuals with PFPS. No significant differences were found between the Q-angle and these patellar positions.

There has been another conflict regarding differences in the Q-angle between individuals with and without PFPS. A previous prospective study compared the Q-angle between healthy individuals and individuals with PFPS both males and females. The results demonstrated that individuals with PFPS presented significant greater Q-angle with females having larger angles than males (Emami et al., 2007). Haim et al. (2006) and Naslund et al. (2016) also found that the Q-angle was greater in patients with PFPS compared to healthy individuals. Similarly, Kaya & Doral (2012) found a significant difference of the Q-angle between affected and unaffected sides of PFPS female participants with the affected sides presenting larger angles than the unaffected sides. In contrast, Stensdotter et al. (2009) found no significant differences of the Q-angle between PFPS individuals and the control group in comparing the Q-angle measurements between standard goniometry, conventional radiography and three-dimensional kinematics in 2 different planes during supine and standing (supine frontal plane, standing frontal plane, supine arbitrary plane, and standing arbitrary plane). Only the goniometer measurement presented that PFPS individuals had significant greater Q-angle compared to the control group.

The latest systematic review investigated outcome predictors for conservative PFPS management. The outcomes in the study consisted of pain, demographics, knee, hip and pelvis, and foot and ankle. Fifteen low quality cohort studies were included in the review. No randomised controlled trials were found. The study intended to identify outcome predictors for specific conservative treatments for PFPS to guide clinicians if the treatments they selected for their patients were effective. The results of the review only presented limited evidence in every outcome with most of the papers focusing on pain. Only 2 studies included the Q-angle as one of the outcomes. Although, it was indicated that increased Q-angle was a significant predictor of a successful outcome, the evidence was still limited as both studies were low quality studies (Lack et al., 2014). A previous review also examined risk factors for PFPS with 7 studies being included. Only 2 studies investigated the Q-angle as a possible risk factor. One study found a significantly greater Q-angle in individuals with PFPS than in healthy people whilst the other study did not find any significant difference between these 2 groups.

This review suggested that the Q-angle may not play a significant role in the cause and development of PFPS (Lankhorst et al., 2012). Since the latest review and the other review did not directly focus on the Q-angle, the association between the Q-angle and PFPS, and the difference of the Q-angle between individuals with and without PFPS remain unclear.

The most recent published systematic review covering Q-angle and PFPS was published in 2013 (Lankhorst et al., 2013). The diversity in evidence and opinion on the role of the Q-angle in PFPS up to 2013 and the publication of key studies since 2013 resulted in the need for an updated systematic review. A systematic review of published articles from 2013 to 2016 was therefore undertaken. The primary purpose of this systematic review was to investigate the association between the Q-angle and PFPS. The secondary purpose was to investigate the difference of the Q-angle between healthy individuals and individuals with PFPS. Several studies have reported that a greater Q-angle is a risk factor for PFPS (Sheehan et al., 2010; Kaya & Doral, 2012; Smith et al., 2008). The first hypothesis was that there would be an association between the Q-angle and PFPS. The second hypothesis was that the Q-angle would be greater in individuals with PFPS compared to individuals without PFPS.

3. METHODOLOGY

Inclusion and exclusion criteria

Case-control or cross-sectional or cohort or randomised controlled studies writing in English and publishing between 2013 and 2016 were eligible for the review. Studies that included patients with patellofemoral pain syndrome as participants. The participants aged from 13 years and above both males and females. Studies that measured the Q-angle as one of the outcomes. Studies were excluded if they were not written in English, did not include individuals with PFPF, included participants under 13 years, and did not measure the Q-angle as one of the outcomes.

Search strategy

The search was conducted in PubMed, Web of Science, Scopus, and CINAHL to recruit studies that have been published between January 2013 and November 2016. The Boolean format for searching was *“((patellofemoral pain syndrome OR PFPS OR* *patellofemoral pain OR PFP OR patello* OR anterior knee pain OR AKP OR knee pain OR femoropatellar pain syndrome OR femoropatellar*) AND (Q-angle OR Q angle OR quadriceps angle OR quadriceps femoris muscle angle))".* The searching criteria was modified form a previous systematic review that evaluated outcome predictors for conservative patellofemoral pain treatments (Lack et al., 2014).

Review process

All titles and abstracts of the studies were downloaded into RefWorks and duplicates removed. The second reviewer rechecked the papers that the first reviewer searched to confirm the same number by using the same search term and filters. The reviewers assessed potential papers following the inclusion and exclusion criteria of the review independently. The full text was obtained for further evaluation if information from the titles and abstracts were not sufficient.

Data extraction

The first reviewer extracted relevant data from the studies. Information on study design (author, and year of publication, location, and type of study), study population (inclusion and exclusion criteria, number of individuals with PFPS and controls, gender, age, weight, and height), Q-angle measurements, duration of intervention, and results were extracted in a standardised form and the second reviewer rechecked the data.

Quality assessment

Quality of the papers was assessed with a scale previously used for a PFPS systematic review (Table 4.1) (Barton et al., 2010c). The scale was modified from (Bizzini et al., 2003) who developed a quality assessment scale for randomised clinical trials (RCTs) for PFPS. The original scale provides a score of 100. The modified version simplified the scale by 60% from 100 to 40 and applied more strict definitions to scoring allocations. The modifications were made to make the scoring clearer and to improve reliability (0.5-0.7 in the original scale). Both reviewers assessed the quality independently. The quality assessment scale consisted of 14 items. It was divided into 4 components which were participants, interventions, outcomes, and data presentations. The full score was 40 with the total possible score given as a percentage. Score ≥70%

was considered as "high quality" and score <70% was considered as "low quality" (Lack et al., 2014).

Table 4.1 Quality assessment scale.

Criteria	Score
1. Population (10 points)	
1.1 Inclusion criteria ***(2 points)*** (i) Diagnosis via clearly defined symptom location (anterior knee, retropatellar, peripatellar, etc.) = 1 (ii) Diagnosis via clearly defined aggravating factors (pain during stairs, squatting, walking, sitting, etc) or accepted clinical tests (eg. Lateral compression) = 1	
1.2 Exclusion criteria ***(2 points)*** (i) Exclusion criteria is clearly defined - Includes previous surgery, other knee pain pathologies, and referred pain = 2 - In Part = 1	
1.3 Adequate number ***(4 points)*** (i) Null hypothesis is rejected or power of the study is discussed for clinical trials and studies evaluating immediate effects of foot orthoses. Studies related to clinical prediction rules should contain at least 10 participants per predictor variable investigated = 2 (ii) Number of participants - Completion of sample size calculation with adequate data to reproduce reported = 2 - Completion of sample size calculation reported but inadequate reporting to reproduce = 1 - Completion of a sample size calculation not reported = 0	
1.4 Homogeneity ***(2 points)*** (i) Similar baseline characteristics (age, sex, pain level, strength, and activity level, etc.) (i.e. There is no significant difference) = 1 (ii) Study must report no significant difference between base line measures of outcome measures or control for any discrepancy = 1	
2. Interventions (10 points)	
2.1 Standardised and described ***(4 points)*** - Interventions used in the study explicitly described, enabling them to be replicated = 4 - Interventions are described to understand the type of intervention but reader would be unable to confidently replicate them from description = 2 - Interventions are not adequately described = 1	
2.2 Control and placebo adequate ***(4 points)*** (i) Study contains a control group (can be an excepted normal treatment) = 2 (ii) An adequate attempt at a placebo intervention has been made (eg. flat insert, sham ultrasound or sham tape) = 2	
2.3 Cointerventions avoided ***(2 points)*** - If parallel interventions are avoided or equal application to all groups = 2 - If allowed but controlled (i.e. participants not allowed to alter parallel interventions) = 1 - If no control or not addressed in methodology = 0	
3. Outcome measures (10 points)	
3.1 Relevant Outcome ***(4 points)*** (i) Outcome measures should be explicitly described so they are able to be replicated = 2 (ii) Outcome measures should be relevant to research question (validity) = 1	

(iii) Outcome measures should be reliable (look for reliability evaluation) = 1	
3.2 Blinded Outcome Assessment ***(4 points)*** (i) Outcome measures must be reassessed by a person masked to group assignment = 2 (ii) Masking strategy is explicitly described = 2	
3.3 Follow-up adequate ***(2 points)*** - 12 months or greater = 2 - 3-11 months = 1 - Less than 3 months = 0	
4. Data presentation and Analysis (10 points)	
4.1 Randomisation described ***(2 points)*** - If true randomisation = 2 - If quasi-randomisation or waiting list control = 1 - If no or inadequate description = 0	
4.2 Dropouts ***(2 points)*** (i) None or reasons for dropouts acknowledged and clearly stated = 1 (ii) Dropout rate of less than 15% = 1	
4.3 Intention to treat ***(2 points)*** - No dropouts or intention to treat analysis used = 2	
4.4 Proper Statistical Procedures Described ***(4 points)*** (i) Statistical analysis methods used are appropriate for data obtained in the study = 2 (ii) Statistical procedures are explicitly described to allow replication = 1 (iii) Statistics are adequately presented including data variability, significance levels and confidence intervals = 1	
TOTAL	

- Randomised controlled (clinical) trials (RCTs) and Controlled clinical trials (CCTs): All criteria should be applied (/40)
- Clinical trials without a control group: Criteria 1.4 and 4.1 are not applicable (/36)
- Clinical prediction rule studies: Criteria 1.4, 2.2, 3.2, 4.1 and 4.3 are not applicable (/30)
- Studies on the immediate effects of foot orthoses: Criteria 1.4, 2.2, 2.3, 3.3, 4.2 and 4.3 are not applicable (/26)

4. RESULTS

Search results

The initial search yielded 233 articles and remained 162 articles after duplicated removed. A total of 8 studies were deemed applicable following application of the inclusion and exclusion criteria (Figure 4.1).

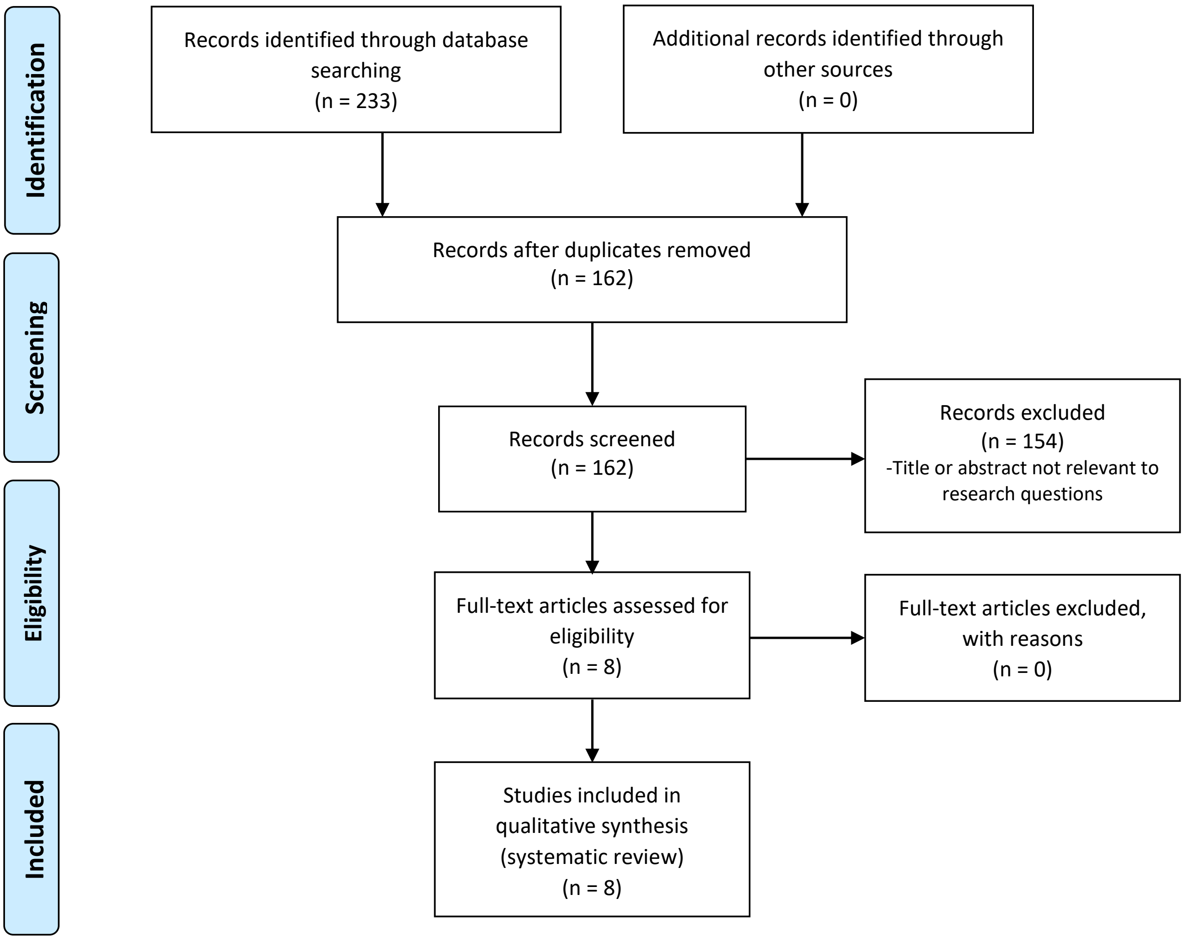


Figure 4.1 PRISMA flow diagram summarising study selection following the inclusion criteria (Lack et al., 2014, p. 1709).

There were 5 cross-sectional studies, 2 cohort studies, and 1 randomised controlled trial study. This included 197 individuals with PFPS and 217 healthy controls. Freedman et al. (2004) did not provide a number of males and females for the PFPS group so an exact number of males and females could not be presented in the present review. Mean ages ranged between 20.50 and 30.80 years from 8 studies reviewed. However, Erkocak et al. (2016) did not provide mean age for the control group. Only mean age for the

PFPS group was presented. Data on individuals' weight were provided by 5 studies which ranged from 54.88 to 65.72 kg. One study did not report weight (Herrington, 2013a) and the other 2 studies reported body mass index (BMI) (Erkocak et al., 2016; Lee et al., 2014). Six studies showed data on height which ranged from 160.70 to 170.10 cm. The other 2 studies did not present information (Erkocak et al., 2016; Herrington, 2013a). These 8 studies were summarised in Table 4.2.

Table 4.2 Summary of the studies that were included in the review.

Study	Design	Population	Q-angle test	Follow-up	Result
Liporaci et al. (2013)	Cross-sectional study	- 19 for PFPS group *(all females)* - 20 for healthy control group *(all females)*	Frequency of increased Q-angle of PFPS group and control group compared with the gold standard of 18°.	0 day	Frequency of increased Q-angle in PFPS group was 84.21% and in control group was 45%. The frequency was significantly higher in PFPS group.
Kwon et al. (2014)	Cross-sectional study	- 14 for PFPS group with unilateral/bilateral knee pain (*5 males, 6 females)* - 42 for healthy control group *(19 males, 23 females)*	Dynamic Q-angle was measured using a camcorder during stairs descending and analysed by motion analysis. Static Q-angle was measured while standing.	0 day	Dynamic Q-angle and static Q-angle were not significantly different between PFPS group and control group.
Herrington (2013)	Cross-sectional study	- 12 for PFPS group with unilateral knee pain *(all females)* - 60 for healthy control group *(all females)*	Q-angle was measured in bilateral and unilateral stance positions from images taken. The angle was obtained by a software.	0 day	The equations generated from control group were used to predict unilateral Q-angle from bilateral Q-angle measurements in PFPS group. They could predict Q-angle in control group and asymptomatic legs in PFPS group but couldn't predict symptomatic legs in PFPS group as they had significantly greater actual Q-angle than the predicted one.
Lee et al. (2014)	Randomised controlled trial study	- 11 for PFPS sling exercise group (SEG) *(8 males, 3 females)*	Static Q-angle was measured in the standing position and dynamic Q-angle was measured while coming down	8 weeks	Decrease of dynamic Q-angle in EBG was significantly greater than that in CG.

		- 13 for PFPS elastic band exercise group (EBG) *(7 males, 6 females)* - 10 for PFPS control group (CG) *(6 males, 4 females)*	the stairs on digital images captured by a digital VDO camera. The angle was calculated by a software.		
Erkocak et al. (2016)	Cross-sectional study	- 35 for PFPS group with unilateral knee pain (group S) - 35 asymptomatic contralateral knees from group S (group A) *(16 males, 19 females)* - 40 for healthy control group (group C) *(18 males, 22 females)*	Q-angle was measured using a goniometer in the supine position.	0 day	Q-angle in group S and group A was significantly greater than one in group C.
Almeida et al. (2016)	Cross-sectional study	- 22 for PFPS group *(all females)*	Q-angle was measured using a universal goniometer in the supine position.	0 day	Q-angle did not present any significant correlation with pain intensity, functional capacity, dynamic knee valgus, or hip abductor torque.
Silva et al. (2015)	Cohort study	- 29 for PFPS group with unilateral knee pain *(all females)* - 25 for healthy control group *(all females)*	Clinical Q-angle measurement was performed with participants positioned in the supine position. Kinematic static Q-angle measurement was performed while participants were standing. Dynamic Q-angle	0 day	Dynamic knee valgus was found to be greater in PFPS group. No significant effects were found for static clinical Q-angle and static Q-angle using 3D system.

			measurement was performed when ascending the stairs. Both were measured by a motion analysis system.		
Freedman et al. (2014)	Cohort study	- 32 for PFPS group (43 knees) *(males: N/A, females: N/A)* - 30 for healthy control group *(8 males, 22 females)*	Three measures of the clinical Q-angle (1) the hip and knee fully extended and the quadriceps fully relaxed (Q-AI); 2) the hip and knee fully extended and with maximum isometric quadriceps contraction (Q AII); and 3) the knee bent to 15° with the quadriceps relaxed (Q-AIII)) were obtained with a goniometer and compared to a fourth MR-based measure of Q-angle (RF-Q).	0 day	Correlations between RF-Q with medial shift and medial tilt and Q-AIII with medial shift and medial tilt were found. This study also found that increased Q-angle correlated to medial patellar displacement not lateral one in PFPS. None of the Q-angle measurements were significantly different between PFPS group and healthy control group. RF-Q-angle presented with significantly lower Q-angle compared to the 3 clinical Q-angle measurements.

Quality of articles

Results from the quality assessment scale are presented in Table 4.3. The table format was modified from (Barton et al., 2010c). The scoring system was taken from Table 4.1. Scores ranged from 13 to 25 (32.5 to 62.5%) which meant that all 8 papers were low quality.

Finding summary

Association between the Q-angle and PFPS*:*

One cross-sectional (Almeida et al., 2016) and one cohort study (Freedman et al., 2014) examined relationships between the Q-angle and PFPS. Almeida et al. (2016) investigated the relationship between the Q-angle and pain, functional capacity, dynamic knee valgus, and hip abductor torque in women with PFPS. It was reported that the Q-angle did not present any significant correlation with pain intensity ($r = -0.29$, $p = 0.19$), functional capacity ($r = -0.08$, $p = 0.72$), dynamic knee valgus ($r = -0.28$, $p = 0.19$), or hip abductor torque ($r = -0.21$, $p = 0.35$). Freedman et al. (2014) demonstrated correlations between the Q-angle and patellofemoral kinematics in individuals with PFPS. The Q-angle was measured in three ways with a goniometer: 1) the hip and knee fully extended and the quadriceps fully relaxed (Q-AI) 2) the hip and knee fully extended and with maximum isometric contraction of the quadriceps (Q-AII) and 3) the knee bent to 15 degrees with the quadriceps relaxed (Q-AIII). Another method of measuring the Q-angle was MR-based rectus femoris Q-angle (RF-Q-angle). The RF-Q-angle was defined similarly to Q-AI except the measurement was made using MR-images and the centre of rectus femoris myotendinous junction was used to represent the true direction of pull of the quadriceps. The results presented that correlations between the Q-angle and PF kinematics were found for the RF-Q-angle and Q-AIII in individuals with PFPS. Increased Q-angle correlated to patellar medial shift (RF-Q: $r = 0.54$, $p < 0.001$; Q-AIII: $r = 0.39$, $p < 0.012$) and patellar medial tilt (RF-Q: $r = 0.48$, $p < 0.001$; Q-AIII: $r = 0.38$, $p < 0.015$).

Differences of the Q-angle between healthy individuals and individuals with PFPS*:*

Seven studies described the Q-angle in individuals with and without PFPS. There were disagreements in differences of the Q-angle between healthy and PFPS individuals in the studies reviewed. Two studies indicated that the Q-angle in individuals with PFPS was greater than that in healthy individuals. Liporaci et al. (2013) determined the frequency of signs and symptoms of PFPS on a functional assessment of the lower extremity including the Q-angle in individuals with and without PFPS. The results showed that frequency of increased Q-angle in the PFPS group (84.21%) was higher than in the control group (45%) compared with the gold standard which was 18 degrees for females. Erkocak et al. (2016) evaluated morphological differences in individuals with PFPS and healthy individuals and found that the individuals with PFPS presented significant greater Q-angle in both symptomatic (p = 0.024) and asymptomatic (p = 0.018) knees compared to the healthy group.

Two studies inferred that individuals with PFPS might have greater Q-angle compared to healthy individuals. Herrington (2013a) generated an equation by measuring the Q-angle in bilateral and unilateral stance positions using images taken with digital photography in healthy individuals then used this equation to predict unilateral Q-angle from bilateral Q-angle measurements in individuals with PFPS. It was presented that the actual unilateral Q-angle of the individuals with PFPS was significantly greater than the predicted Q-angle for each individual (p = 0.01) with the mean difference being 2.3° greater. The RCT study (Lee et al., 2014) did not compare the Q-angle between individuals with and without PFPS but compared different weight-bearing exercises on static and dynamic Q-angle measured in a standing position in individuals with PFPS only. The groups included 1) an elastic band exercise group (EBG) 2) a sling exercise group (SEG) and 3) a control group (CG). After 8 weeks of exercise, EBG showed a significant decrease in dynamic Q-angle and the difference between pre-test and post-test was significantly greater than that of CG. However, there were no significant differences of static Q-angle.

Conversely, three studies did not find significant differences on the Q-angle between individuals with and without PFPS. Kwon et al. (2014) compared static Q-angle and dynamic Q-angle measured in a standing position in individuals with PFPS and healthy individuals. It showed that static Q-angle and dynamic Q-angle were not significantly different between the 2 groups. Silva et al. (2015) also found no significant differences of clinical Q-angle measured with knee bending 15° in a supine position and static Q-angle using 3D system between the PFPS group and the healthy control group. Only dynamic Q-angle was significantly found to be greater in individuals with PFPS.

Similarly, Freedman et al. (2014) showed that there were no significant differences of the Q-angle (Q-AI, Q-AII, Q-AIII, and RF-Q-angle) between the healthy control group and PFPS group.

Table 4.3 Results from quality assessment scale to identify quality of the articles.

Study	1.1 IC (/2)	1.2 EC (/2)	1.3 AN (/4)	1.4 HM (/2)	1 Pop (/10)	2.1 SD (/4)	2.2 CP (/4)	2.3 CA (/2)	2 Int (/10)	3.1 RO (/4)	3.2 BO (/4)	3.3 FA (/2)	3 OM (/10)	4.1 RD (/2)	4.2 DO (/2)	4.3 IT (/2)	4.4 SP (/4)	4 DA (/10)	Total score	% score
Liporaci et al. (2013)	2	1	0	N/A	3	2	N/A	N/A	2	4	0	N/A	4	0	N/A	N/A	4	4	13	32.5
Kwon et al. (2014)	1	1	0	N/A	2	4	N/A	N/A	4	3	0	N/A	3	0	N/A	N/A	4	4	13	32.5
Herrington (2013)	2	2	0	N/A	4	4	N/A	N/A	4	4	0	N/A	4	0	N/A	N/A	3	3	15	37.5
Lee et al. (2014)	1	1	2	1	5	4	2	1	7	3	0	0	3	2	2	2	4	10	25	62.5
Erkocak et al. (2016)	2	1	4	N/A	7	4	N/A	N/A	4	4	4	N/A	8	1	N/A	N/A	4	5	24	60
Almeida et al. (2016)	2	1	0	N/A	3	4	N/A	N/A	4	4	0	N/A	4	0	N/A	N/A	4	4	15	37.5
Silva et al. (2015)	2	1	4	N/A	7	4	N/A	N/A	4	4	4	N/A	8	0	N/A	N/A	4	4	23	57.5
Freedman et al. (2014)	0	1	0	N/A	1	4	N/A	N/A	4	4	4	N/A	8	0	N/A	N/A	4	4	17	42.5

5. DISCUSSION

The intent of this systematic review was to identify the association between the Q-angle and PFPS and the difference of the Q-angle between individuals with and without PFPS. A previous systematic review evaluated factors associated with PFPS and found 9 studies describing differences in the Q-angle between individuals with PFPS and control groups. The review found that results from the pooled data showed significantly greater Q-angle in individuals with PFPS compared to controls (Lankhorst et al., 2013). However, this study did not investigate correlations between the Q-angle and other PFPS parameters such as pain intensity, functional capacity, dynamic knee valgus, or patellar shift. In addition, several studies not included in this systematic review presented a conflicting view on the Q-angle between individuals with PFPS and controls (Emami et al., 2007; Kaya & Doral, 2012; Stensdotter et al., 2009). One study investigated variations in Q-angle in standing and supine positions with different measurement methods in women with and without PFPS. The results showed no difference in Q-angle between the individuals with PFPS and the control group (Stensdotter et al., 2009).

According to the current study, only one cross-sectional (Almeida et al., 2016) and one cohort (Freedman et al., 2014) study investigated correlations between the Q-angle and PFPS and both articles were low quality. Almeida et al. (2016) did not find any correlations between the Q-angle and related factors for PFPS which were pain, functional capacity, dynamic knee valgus, and hip abductor torque. Therefore, the results of the study rejected the hypothesis that the Q-angle would have positive correlations with those variables of the lower extremity in PFPS population. The methodological quality was very limited. This cross-sectional study did not include a control group. Only conventional Q-angle measurement in a supine position (the angle between two lines drawn from ASIS to the midpoint of the patella and from the midpoint of the patella to the tibial tuberosity) with a goniometer was used. There might be a correlation between the Q-angle and the variables in this study if the Q-angle was measured in different methods such as static or dynamic Q-angle during standing or using another tool such as 3D motion analysis or radiography instead of the universal goniometer. The results of the study supported the results of Park & Stefanyshyn (2011) who measured the static Q-angle in a standing position with a goniometer and demonstrated that there was no relationship between the Q-angle and knee abduction moment and impulse. Conversely, there is disagreement from Freedman et al. (2014) who found that increased Q-angle was related to medial patellar displacement and tilt. The Q-angle was measured in 4 different ways by a goniometer and magnetic resonance imaging (MRI). However, the variables and the Q-angle measurements in these 2 studies were different so it prevented the present review from comparing the relationship results between the Q-angle and PFPS between the studies.

Two (Erkocak et al., 2016; Liporaci et al., 2013) of seven studies indicated that the Q-angle in individuals with PFPS and healthy individuals was significantly different. Erkocak et al. (2016) presented that the PFPS group displayed greater conventional Q-angle than that in the healthy group. Similarly, Liporaci et al. (2013) also demonstrated a difference of the Q-angle between individuals with and without PFPS. Frequency of increased Q-angle was higher in individuals with PFPS compared to healthy individuals. However, the methodological quality of this study was very limited as it did not provide how the Q-angle was measured and did not present the Q-angle in degrees. The results of these two studies were in the same line with Kaya & Doral (2012) who found a significant difference ($p < 0.001$) in the Q-angle between the affected (19.61±4.35 degrees) and unaffected (17.63±4.29 degrees) sides in individuals with PFPS. However, the two reviewed studies had different characteristics of presenting the Q-angle as one was in degrees and the other one was in frequency so, they could not be compared. Two studies (Herrington, 2013a; Lee et al., 2014) did not directly compare a difference of the Q-angle between individuals with and without PFPS. Herrington (2013) generated an equation from healthy individuals then used it to predict unilateral and bilateral Q-angle in individuals with PFPS. The actual unilateral Q-angle of the symptomatic knee was significantly greater than that predicted for individuals with PFPS whilst the asymptomatic knee did not show any significant difference between the predicted and actual measured unilateral Q-angle. From the results, it did not provide directly that the Q-angle was different between the 2 groups of population, but it could be inferred that the Q-angle in individuals with PFPS was greater compared to healthy individuals. Lee et al. (2014) conducted an RCT study providing weight-bearing exercise programs in 3 groups of PFPS individuals. The elastic band exercise group demonstrated a significant decrease in dynamic Q-angle. Although this study did not include healthy participants, it could be inferred that individuals with PFPS could have greater Q-angle than healthy individuals because the exercise program had an effect in reducing the dynamic Q-angle in PFPS individuals. However, one of the studies was a cross-sectional study and the other one was an RCT study, so it was not possible to compare as they had different methodologies.

Conflicting evidence was found for differences of the Q-angle between individuals with and without PFPS. Kwon et al. (2014) did not find any significant difference of static and dynamic Q-angle between individual with PFPS and healthy individuals. Similarly, Silva et al. (2015) measured the clinical Q-angle with knee bending 15° in a supine position in individuals with and without PFPS and found no significant differences between the two groups of population supporting growing evidence that static measurement of the Q-angle might not be a risk factor for PFPS development. Freedman et al. (2014) found that none of the Q-angle measurements were significantly different between PFPS and control groups. However, a limitation for these three studies was that Kwon et al. (2014) measured the static and dynamic Q-angle with a camcorder in a standing position whilst Silva et al. (2015) measured the clinical Q-angle in a supine position with knee bending 15° and did not state if it was measured with a goniometer. Freedman et al. (2014) measured the Q-angle in 4 different methods using a universal goniometer and MRI which was different from the other two studies. Therefore, these results were unable to be compared.

The findings of this review suggested that there were disagreements on the relationship between the Q-angle and PFPS and the difference of the Q-angle in individuals with and without PFPS. A possible explanation for this conflict may be attributed to the different methodologies and measurement differences of the Q-angle. Four studies measured the Q-angle using image technologies: a motion analysis system, camcorder, and digital camera (Herrington, 2013a; Kwon et al., 2014; Lee et al., 2014; Silva et al., 2015b) whilst three studies performed the measurement using a universal goniometer (Erkocak et al., 2016; Freedman et al., 2014; Almeida et al., 2016). Liporaci et al. (2013) did not state how the Q-angle was measured. The positions of measurement were also different between the studies as it consisted of both supine and standing positions. Abdel-aziem et al. (2014) examined the effect of body positions on the Q-angle measurement in individuals with PFPS and found that the Q-angle measured in the standing position was significantly larger than the Q-angle measured in the supine position. Several factors that could influence the Q-angle in the standing position include foot pronation, alignment of the adjacent joints, and effects of quadriceps and other muscles surrounding the thigh. However, these factors should not influence the Q-angle measured in the supine position (Erkocak et al., 2016; Abdel-aziem et al., 2014).

6. LIMITATIONS

The studies reviewed in this current systematic review were low quality. The methodological quality of the reviewed studies was limited due to the articles not only focusing on the Q-angle measurement, but also other variables related to PFPS. This might result in having inadequate information describing about the Q-angle measurement and result in less score of criteria 3 (outcome measures) in the quality assessment scale (Table 5.1). This systematic review only obtained data on the Q-angle only and did not focus on other variables in the reviewed articles.

7. IMPLICATIONS

Studies conducted need to be sufficiently powered in order to provide definitive information on the association between the Q-angle and PFPS and the difference of the Q-angle between individuals with and without PFPS. Further high-quality studies with a focus on the association between the Q-angle and PFPS and the difference of the Q-angle between individuals with PFPS and healthy individuals are required with standardised methods and guidelines for measurement of the Q-angle including the body position. Future studies should also focus on providing a clear definition on population, interventions, outcome measurements, and data presentation and analysis in order to obtain high-quality studies.

8. CONCLUSION

This systematic review provides summaries of association between the Q-angle and PFPS and the difference of the Q-angle in individuals with PFPS and healthy individuals. Without high studies, this updated review, including articles from year 2013 to 2016, is unable to conclude if there is association between the Q-angle and PFPS or there is difference of the Q-angle between PFPS individuals and controls.

Although 4 of 8 studies tended to show that the Q-angle was greater in PFPS individuals, the quality of the papers was still low. Further high-quality studies are needed to establish strong evidence and the Q-angle measurement needs to be standardised to have only one standard method.

Chapter 5: Study 4

Effects of different training surfaces on spatiotemporal and pelvic kinematic parameters of gait during walking in healthy individuals

1. ABSTRACT

Introduction: Spatiotemporal and pelvic kinematic parameters of gait have been used in sports, rehabilitation, and health diagnostics. Various training surfaces might have different effects on changes in these parameters of gait. Changing of training surfaces is believed to alter spatiotemporal and pelvic kinematic parameters that could lead to PFPS. However, these parameters on 3 popular basic surfaces (indoor multi-sport game surface, outdoor synthetic surface for track and field, and natural grass surface) have not been investigated to date. Therefore, the aim of the study was to investigate spatiotemporal and pelvic kinematic parameters of gait on the 3 training surfaces during walking in healthy individuals in order to identify training surfaces that may be suitable during rehabilitation. ***Methods:*** 22 healthy active individuals aged 18-35 years were included. They walked on the 3 training surfaces in a random sequence with self-selected walking speed along a 20-m straight distance. Spatiotemporal parameters (cadence, gait speed, stride length, step length) and pelvic kinematic parameters (antero-posterior pelvic tilt and lateral pelvic tilt) were assessed using an accelerometer. ***Results:*** There was a significant difference in cadence between the 3 training surfaces ($p = 0.010$) which the outdoor surface presented with greater cadence compared to the other 2 surfaces. Both natural grass ($p < 0.001$) and outdoor surfaces ($p < 0.001$) significantly presented with higher speed compared to the indoor surface. The natural grass surface presented with the significantly longest stride length compared to the other 2 surfaces ($p < 0.001$). The outdoor surface also presented with significantly longer stride length compared to the indoor surface ($p < 0.001$). The participants significantly produced greater antero-posterior pelvic tilt ($p = 0.004$) and lateral pelvic tilt ($p = 0.028$) when walking on the natural grass surface and the outdoor synthetic surface compared to the indoor surface. ***Conclusion:*** The 3 training surfaces demonstrated different results for spatiotemporal and pelvic kinematic parameters during walking with the natural grass surface presenting with the highest stride length that may lead to overloads to the joints. Future studies should be focused on individuals with PFPS during running as it is a functional activity that is involved in most sports.

Keywords: gait, spatiotemporal, pelvic kinematic, training surface

2. INTRODUCTION

According to the prevalence study of PFPS in chapter 2, one factor that varied between sports was playing surfaces. For example, the football players, volleyball players, and the athletics trained on the football pitch, the indoor surface, and the athletic tracks respectively. However, only relationship between training duration and PFPS was focused in this previous study. It has been proposed that various surfaces have different effects on changes in gait during activities (Fanchiang et al., 2016). Moreover, training surfaces have shown to be an extrinsic risk factor for PFPS (Murphy et al., 2003; Yeung & Yeung, 2001). Nevertheless, effects of playing surfaces on gait were not investigated in the prevalence study. This need to investigate the impact of varying training surfaces on gait is addressed within this chapter.

Gait is a complex process which is different between individuals (Isakov et al., 1996). Gait analysis is the systematic study which involves measurement, description, and assessment of quantities that describes human locomotion (Tao et al., 2012; Ghoussayni et al., 2004). Through this analysis, gait phases, kinematic and kinetic parameters, and musculoskeletal functions can be evaluated. As a result, gait analysis has been used in sports, rehabilitation, and health diagnostics. For example, the method is applied to analyse gait patterns in athletes, so their performances can be evaluated and improved (Tao et al., 2012; Wang et al., 2003). For orthopaedics and rehabilitation, gait analysis is employed to monitor healing process for patients (Tao et al., 2012; Steultjens et al., 2000; Kimmeskamp & Hennig, 2001; Pope et al., 1985). For health diagnostics, gait analysis is used to compare differences between healthy individuals and patients with conditions (Tao et al., 2012).

Spatiotemporal parameters of gait are frequently evaluated to identify possible gait impairments, mainly in orthopaedics (Item-Glatthorn & Maffiuletti, 2014). For clinical practice, the evaluation of complex movements is limited by high-cost equipment. Spatiotemporal parameters of gait can be measured and used as objective clinical indicators of functionality at low cost (Leporace et al., 2016). Previous studies have investigated spatiotemporal parameters of gait as a screening tool for lower extremity injuries including PFPS. Springer et al. (2016) conducted a study to determine whether spatiotemporal parameters of gait could predict lower limb overuse injuries in combat soldiers in the military service in Israel. Stride time variability, stride length variability, step length asymmetry, and duration of the loading response phase of the gait cycle were measured during a walking trial on a treadmill. The results demonstrated that spatiotemporal parameters of gait could be applied as a simple screening tool before military training which may help to identify risks of lower limb overuse injuries. Arazpour et al. (2016) conducted a systematic review to evaluate different walking patterns between individuals with PFPS and healthy individuals. The results presented that PFPS-associated changes in gait parameters produced a reduction in stride length and step length, lower gait velocity, slower swing velocity, decreased cadence, reduced knee extensor moment in the loading response and terminal stance, delayed peak rearfoot eversion during gait, and greater hip adduction.

Pelvic movements are directly related with PFPS. Increased lateral pelvic tilt during walking may be associated with increased hip internal rotation on the opposite side of the pelvis due to gluteus medius tightness (Hertel et al., 2004). The mechanical consequence of greater pelvic tilts could contribute to abnormal mechanics of PFJ (Cibulka & Threlkeld-Watkins, 2005). Excessive femoral internal rotation could result in a medial shift of the patellar that results in increased Q-angle (Powers, 2003).

Various walking or training surfaces may have different effects on changes in spatiotemporal and pelvic kinematic parameters of gait (Fanchiang et al., 2016). However, there is a lack of studies assessing effects of widely used basic surfaces: 1) indoor multi-sport game surface; 2) outdoor synthetic surface for track and field; 3) natural grass surface on these parameters. Moreover, there are only a few studies investigating effects of different walking or training surfaces on spatiotemporal parameters of gait and there is no evidence of investigating effects of different training surfaces on pelvic kinematic parameters of gait. A study (Fanchiang et al., 2016) investigated effects of different walking surfaces on spatiotemporal parameters of gait in children with idiopathic toe walking. The surfaces included vinyl tile, carpet, and pea gravel. The results demonstrated that all children presented with the slowest speed, lowest cadence, and shortest step length walking on the gravel whilst the fastest speed and highest cadence were found walking on the vinyl tile. The children with idiopathic toe walking had significantly less toe-walking on the gravel walkway. It was concluded that walking surfaces played an important role in altering gait patterns in the children (Fanchiang et al., 2016). Menant et al. (2009) examined effects of walking surfaces (control, irregular, and wet) on spatiotemporal parameters of gait in young and older individuals. It was found that when walking on the irregular versus the control surface, the individuals exhibited decreased walking speed, cadence, step length, double-support time, heel horizontal speed at heel strike, as well as greater step width and toe clearance. When walking on the wet surface versus the control surface, the individuals showed reductions in walking speed, step length, and shoe-floor angle at heel strike, as well as an increase in step width. The older individuals exhibited a more conservative walking pattern (slower speed and shorter steps) especially on the irregular and wet surfaces. Schneiders et al. (2010) demonstrated the effect of sports-surface specific footwear and sporting surfaces on dynamic neurological screening (Tandem Gait: TG) for sport-related concussion in 108 amateur athletes. The 3 common surfaces included natural grass (rugby/football boots), hardwood court (court shoes/cross trainers), and artificial turf (turf shoes/cross trainer). It was found that times for TG task depended on sports surfaces and footwear. TG time was the fastest on the grass when walking with footwear and it was the slowest on the artificial turf. However, this study did not focus on effects of different training surfaces on spatiotemporal parameters of gait.

Since the training surfaces has been one of the extrinsic factors for lower limb injuries including PFPS (Murphy et al., 2003; Yeung & Yeung, 2001), effects of different training surfaces on spatiotemporal and pelvic kinematic parameters of gait should be investigated. The results from healthy individuals could lead to a role for selecting a suitable training surface during rehabilitation period and could provide reinjury prevention. Therefore, the aim of the study was to investigate spatiotemporal and pelvic kinematic parameters of gait on widely used basic training surfaces during walking in healthy individuals. From the previous literature, there have been no studies comparing effects of these 3 training surfaces. However, it is stated that natural grass surface presents with higher coefficient of friction compared to the other 2 surfaces (Dura et al., 1999; Jenkins2005). High coefficient of friction assists to avoid slipping and allows individuals to grip a surface better and move faster (Dura et al., 1999). However, individuals who walk or run on a surface that has excessive coefficient of friction are highly at risk of overloads to the joints and injuries may occur (Dura et al., 1999). Therefore, the hypothesis of the present study was that there would be significant differences in spatiotemporal and pelvic kinematic parameters of gait on these 3 different training surfaces during walking with the natural grass surface presenting with higher speed, higher stride length, and greater pelvic movements compared to the other 2 surfaces in healthy individuals.

3. METHODOLOGY

Participants

This cross-sectional study included 22 healthy active individuals aged 18-35 years. This present study recruited participants in this age range as they are highly at risk of PFPS in western countries such as UK, USA, and European countries (Smith et al., 2018; Glaviano et al., 2015). The sample size was calculated using G*Power 3.1.9.2 which is a stand-alone power analysis program for several tests commonly used in the social, behavioral, and biomedical sciences (Faul et al., 2009; Faul et al., 2007). For the calculation on the software, the test family was F-tests with the statistical test of ANOVA: Repeated measures, within factors. In order to calculate power, 4 of 5 variables must be known: 1) number of groups (1) 2) number of observations (3) 3) effect size f (medium: 0.25) --> in this case the previous studies did not provide enough information to calculated the effect size and they were not similar to the present study so medium effect size f defined by Cohen and is acceptable to use was selected (Cohen, 1988) 4) significant level (α) (0.05) and 5) power (1-β) (0.8) is generally accepted. The actual power of the study was 80% (Suresh & Chandrashekara, 2012). Therefore, the estimated sample of the present study was at the power of 0.8, medium effect size (0.25), and a 0.05 alpha level. The total sample size required for the study was 17.

Inclusion criteria

1. Healthy active individuals aged 18-35 years (both males and females).
2. Engaged in physical activities for 2 hours or more per week during the previous 12 months (Arroyo-Morales et al., 2008).
3. Adequately understand verbal explanations or written information given in English.
4. No history of a surgery involving the lower leg, ankle or foot in the last 12 months (Willems et al., 2006).
5. No history of an injury to the lower leg, ankle or foot within 6 months (Willems et al., 2006).
6. No knee pain with any of activities (Aliberti et al., 2010).

7. Normal arch of foot (Aliberti et al., 2010) measured by using the plantar arch index (A/B) (Huang et al., 2004).
8. No discrepancy of 1 cm or greater in lower leg length and major deformities (Aliberti et al., 2010) measured from anterior superior iliac spine (ASIS) to medial malleolus of the same leg.
9. No reported known cardiovascular abnormalities (Willson et al., 2015).

Measurement

Plantar arch index: A line was drawn tangent to the medial forefoot edge and at heel region. The mean point of this line was calculated. From this mean point, a perpendicular line was drawn crossing the footprint. The heel tangency was drawn by the same procedure. Measurements were obtained from the width of the central region of the foot (A) and the heel region (B) in centimetres. The plantar arch index was calculated by dividing A by B (A/B) (Figure 5.1). Normal arch index ranged from 0.3 to 1.0 (Huang et al., 2004). In order to get this measurement, pressure plate (RSscan International, 2m Footscan® 7.0 Gait 2nd Generation) was used to collect plantar arch. The arch index needed to be measured because abnormal arches could affect walking during the stance phase (O'Brien & Tyndyk, 2014).

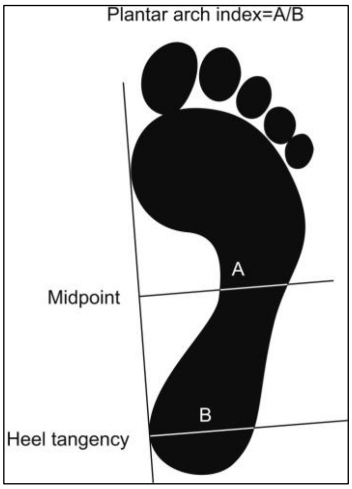


Figure 5.1 Measurement of plantar arch index obtained from the width of the central region of the foot (A) and the heel region (B) (Son et al., 2017, p. 1015).

Clinical measurement of leg length: A subject was supine in a position that closely approximated the anatomical position. One end of the tape measure was placed on

ASIS. The other end of the tape was guided down the anteromedial aspect of the subject's thigh to the medial malleolus of the same leg (Beattie et al., 1990) (Figure 5.2). The measurement was done 3 times and the average is taken. Leg length discrepancy was measured because it results in asymmetrical gait patterns. It could affect duration of the stance phase during walking. (Perttunen et al., 2004).

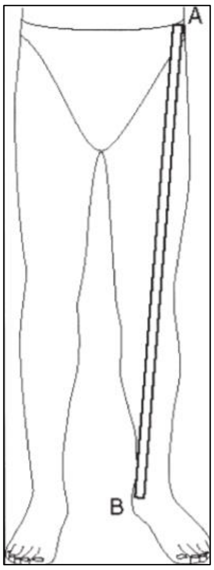


Figure 5.2 Clinical measurement of leg length: ASIS (A) and the medial malleolus (B) (Affatato & Toni, 2000).

Procedure

The study was approved by the School of Sport & Exercise Sciences Research Ethics and Advisory Group (REAG), University of Kent at Medway (Ethics reference: Prop 104_2016_17). All participants gave written informed consent prior to the participation. The participants attended the laboratory two and a half hours for one occasion. Three surfaces (Figure 5.3) in the study included: 1) indoor multi-sport game (wooden) surface; 2) outdoor synthetic surface for track and field; 3) natural grass surface. These 3 surfaces were chosen because of their popularity with users. They were basic sports facilities, widely used, and comply with the rules of various sports (Meinel, 2008; Sport England, 1999).

5.3 A **5.3 B** **5.3 C**

Figure 5.3 Three training surfaces used in the study: 5.3 A) indoor multi-sport game (wooden) surface; 5.3 B) outdoor synthetic surface for track and field; 5.3 C) natural grass surface.

The indoor multi-sport game surface (Figure 5.3 A) consists of the top floor and the sub-floor. The top layer is called “Timber”. It is made of wood in form of strip. The second layer consists of concrete slab, levelling compound over the slab, and sand/cement screed over concrete slab (Sport England,1999). The outdoor synthetic surface (Figure 5.3 B) following the International Association of Athletics Federations (IAAF) requirements consists of several sub-divisions of synthetic surface type. There are 7 layers for the standard synthetic surface which are synthetic surface on the top, open grade asphaltic concrete finishing layer, dense grade asphaltic concrete correction layer, base (crushed stone or gravel), subbase (crushed stone or gravel), and select fill or subgrade as the deepest layer (Watson2008). The natural grass pitch (football/rugby field) (Figure 5.3 C) consists of a living grass, anchored via its root structure to the rootzone or topsoil, and sand-based subsoil. The sand-based subsoil has predominant recently due to its drainage abilities. Good drainage contributes to maintain surface strength and aids to maintain oxygen within the soil for the grass roots (Sport England, 2011; Thomson & Rennie., 2016)

Before the testing started, all participants were made acquainted with the data collection procedures walking on each surface until they felt comfortable (Franklyn-Miller et al., 2014). After the familiarisation, participants were instructed to walk on the 3 surfaces in a random sequence to control potential learning effects with self-selected walking speed (Schneiders et al., 2010) along a 20 m straight distance (Senden et al., 2009). The participants walked with barefoot during the test to eliminate effects of variability of sports shoes. The procedure was repeated 3 times (Senden et al., 2009). A trial began when the participants first stepped into the start line of the walkway and ended when one of the feet stepped out of the finish line. The participants then walked back to the starting point and repeated the trial for another 2 times to complete one surface condition. The participants had 3 minutes to recover during the change of surface conditions (Herrington, 2013b).

Spatiotemporal parameters (cadence, gait speed, stride length, and step length) and pelvic kinematic parameters (antero-posterior pelvic tilt and lateral pelvic tilt) were assessed using an accelerometer (G-Sensor®, BTS Bioengineering S.p.A., Italy) (Figure 5.4). The equipment was attached to the participants' waists using a semi-elastic belt covering the L4-L5 intervertebral space during the testing (Figure 5.5). The collected data was transmitted via Bluetooth to a laptop computer and processed using software (BTS G-Walk®) (Pau et al., 2014). All tests were only performed on sunny days to assure that the ground hardness on the natural grass surface wouldn't change and the grass was not slippery.

5.4 A **5.4 B** **5.4 C**

Figure 5.4 G-Walk system (G-Sensor®, BTS Bioengineering S.p.A., Italy): 5.4 A) Waist belt with a pocket for the wireless inertial sensor; 5.4 B) Wireless inertial sensor; 5.4 C) Bluetooth dongle and Bluetooth extension cable.

Figure 5.5 The G-Walk attached to the participant’s waist using a semi-elastic belt covering the L4-L5 intervertebral space.

Gait parameters

Gait parameters in this study included 1) spatiotemporal parameters: cadence, gait speed, stride length, and step length: 2) pelvic kinematic parameters: antero-posterior pelvic tilt and lateral pelvic tilt. The definitions of the spatiotemporal and pelvic kinematic parameters, obtained from BTS G-Walk user manual (English version 6.1.0) and (Hollman et al., 2011) are explained in Table 5.1.

Table 5.1 Operational definitions of spatiotemporal and pelvic kinematic parameters.

Parameter	Definition
Cadence (steps/min)	- Number of steps per minute.
Gait speed (m/s)	- Average walking speed calculated by dividing the distance walked by the ambulation time.
Stride length (m)	- Anterior-posterior distance between heels of two consecutive footprints of the same foot (left to left, right to right).
Step length (%stride length)	- Anterior-posterior distance from the heel of one footprint to the heel of the opposite footprint.
Antero-posterior pelvic tilt	- Angle of pelvic tilt in the sagittal plane; positive angular values indicate anterior tilt whilst negative angular

	values indicate posterior tilt. In this study, the range between anterior and posterior tilt was analysed.
Lateral pelvic tilt	- Angle of pelvic tilt in the frontal plane: positive angular values indicate up position whilst negative angular values indicate down position. In this study, the range between up and down position was analysed.

Statistical analysis

The parameters (cadence, gait speed, stride length, step length, antero-posterior pelvic tilt, and lateral pelvic tilt) were expressed as mean±standard deviation (SD) using Microsoft Excel. The data were checked for normal distributions using Shapiro-Wilk test. Differences of the variables between the 3 surface conditions were analysed by Repeated Measures ANOVA and Tukey's Post-Hoc test as the data were normally distributed. An Alpha level of $p \leq 0.05$ was used to test statistical significance. The data were analysed using SPSS 24.0 (Norusis/SPSS Inc., Chicago, IL, USA).

4. RESULTS

The total number of participants in the study was 22 (14 males and 8 females). Baseline characteristics of the participants are presented in Table 5.2.

Table 5.2 Baseline characteristics of the participants.

	Male (N = 14)		**Female (N = 8)**		**Total (N = 22)**	
	Mean±SD	Max:Min	Mean±SD	Max:Min	Mean±SD	Max:Min
Age (year)	30±6	35:19	31±6	35:20	30±6	35:19
Weight (kg)	79.3±11.5	102:60	62.1±11.8	80:48	73.1±14.1	102:48
Height (cm)	179.3±7.5	191:168	160.8±5.3	168:150	172.6±11.3	191:150

Significant differences between indoor multi-sport surface, outdoor synthetic surface, and natural grass surface were found in cadence, gait speed, stride length (Table 5.3). The outdoor synthetic surface significantly produced greater cadence compared to the indoor surface and the natural grass surface. The natural grass and outdoor synthetic surface significantly showed higher speed compared to the indoor surface. The natural grass surface significantly presented with the longest stride length compared to the other 2 surfaces. The outdoor synthetic surface also presented with significantly longer stride length compared to the indoor surface.

Table 5.3 Mean differences of cadence, gait speed, and stride length between indoor multi-sport, outdoor synthetic, and natural grass surface.

	Cadence (steps/min)		Speed (m/s)		Stride length (m)	
Indoor multi-sport	112.3±6.9	$p = 0.010$*	1.18±0.16	$p < 0.001$*	1.27±0.14	$p < 0.001$*
Outdoor synthetic	114.7±6.8		1.28±0.17		1.34±0.16	
Natural grass	112.8±8.3		1.29±0.19		1.38±0.18	
Indoor multi-sport	112.3±6.9	$p = 0.007$**	1.18±0.16	$p < 0.001$**	1.27±0.14	$p < 0.001$**
Outdoor synthetic	114.7±6.8		1.28±0.17		1.34±0.16	
Indoor multi-sport	112.3±6.9	$p = 0.581$	1.18±0.16	$p < 0.001$**	1.27±0.14	$p < 0.001$**
Natural grass	112.8±8.3		1.29±0.19		1.38±0.18	
Outdoor synthetic	114.7±6.8	$p = 0.010$**	1.28±0.17	$p = 0.422$	1.34±0.16	$p = 0.013$**
Natural grass	112.8±8.3		1.29±0.19		1.38±0.18	

* Repeated Measures ANOVA $p \leq 0.05$, **Tukey's Post-Hoc test $p \leq 0.05$

For the parameters divided into left and right side (step length, antero-posterior pelvic tilt, and lateral pelvic tilt), there were no significant differences between the left and the right side ($p > 0.05$) so the right side was chosen to present the results of the study as it was the majority of the sample size (1 left and 21 right). Table 5.4 presents mean differences of step length, antero-posterior pelvic tilt, and lateral pelvic tilt between the training surfaces. The outdoor synthetic and natural grass surface significantly demonstrated greater antero-posterior pelvic tilt and lateral pelvic tilt compared to the indoor surface.

Table 5.4 Mean differences of step length, antero-posterior pelvic tilt, and lateral pelvic tilt between indoor multi-sport, outdoor synthetic, and natural grass surface.

	Step length (% stride length)		**Antero-posterior pelvic tilt (degrees)**		**Lateral pelvic tilt (degrees)**	
Indoor multi-sport	49.7±2.9	*p* = 0.897	2.0±0.8	*p* = 0.004*	3.8±1.3	*p* = 0.028*
Outdoor synthetic	49.5±2.5		2.4±0.7		4.1±1.3	
Natural grass	49.5±2.2		2.4±0.7		4.1±1.4	
Indoor multi-sport	49.7±2.9	*p* = 0.686	2.0±0.8	*p* = 0.006**	3.8±1.3	*p* = 0.040**
Outdoor synthetic	49.5±2.5		2.4±0.7		4.1±1.3	
Indoor multi-sport	49.7±2.9	*p* = 0.708	2.0±0.8	*p* = 0.003**	3.8±1.3	*p* = 0.015**
Natural grass	49.5±2.2		2.4±0.7		4.1±1.4	
Outdoor synthetic	49.5±2.5	*p* = 0.979	2.4±0.7	*p* = 0.638	4.1±1.3	*p* = 0.951
Natural grass	49.5±2.2		2.4±0.7		4.1±1.4	

* Repeated Measures ANOVA $p \leq 0.05$, **Tukey's Post-Hoc test $p \leq 0.05$

5. DISCUSSION

The main findings of this study were that significant differences were found in cadence, speed, stride length, antero-posterior pelvic tilt, and lateral pelvic tilt between the indoor multi-sport, outdoor synthetic, and natural grass surface. These findings result in the partial acceptance of the hypothesis that there would be significant differences in spatiotemporal and pelvic kinematic parameters of gait on these 3 different training surfaces with the natural grass surface producing the highest stride length that could result in overloads to the joints in healthy individuals during walking. The natural grass did not present with higher speed and greater pelvic movements compared to the outdoor synthetic surface.

There was a significant difference in cadence between the 3 training surfaces (p = 0.010) which outdoor synthetic surface presented greater cadence compared to the other 2 surfaces. However, a significant difference of cadence was not found between indoor multi-sport and natural grass surface. Previous studies have examined that increasing of cadence at a constant speed could minimise the lower extremity loading (Heiderscheit et al., 2011; Hobara et al., 2012; Hafer et al., 2015) which may be beneficial in reducing lower limb injuries such as stress fracture, iliotibial band syndrome, and patellofemoral pain syndrome (Hafer et al., 2015). One possible explanation for reduced the lower limb loading may be a change in the foot strike pattern. Decreased heel strike distance and ankle dorsiflexion at initial contact can place the knee in a more flexed position (more spring-like landing posture) leading to better distribution of impact through the lower limb (Hobara et al., 2012; Hafer et al., 2015). In contrast, other studies have stated that loading at PFJ is decreased when the cadence is increase because it places the knee in a more extended posture during the stance phase. It is believed that greater knee flexion during stance phase creates a larger moment arm of the quadriceps that increases PFJ stress (Bonacci et al., 2018; Nourbakhsh et al., 2018; Lenhart et al., 2014). In the current study, the outdoor synthetic surface showed significantly higher cadence compared to the other 2 surfaces. A possible explanation for this result may be the property of the surface as it has been designed to meet force reduction by absorbing or reflecting the energy of impact of the foot (Watson2008). This may cause higher cadence during gait. The outdoor synthetic may be suitable for athletes who are in rehabilitation sessions and preparing to return to sports after lower limb injuries including PFPS as this surface resulted in reducing lower limb loading that should not cause reinjury in athletes or patients.

Both natural grass surface ($p < 0.001$) and outdoor synthetic surface ($p < 0.001$) significantly presented with faster speed compared to the indoor multi-sport surface. A significant difference was not found between the outdoor synthetic and the natural grass surface. The possible reason may be due to the surface slipperiness. In sports, high friction avoids slipping and allows individuals to grip a surface better and move faster (Dura et al., 1999). However, excessive friction produces overload in joints and injuries may occur especially in sports with fast turning movements (Dura et al., 1999). It has been reported that gait adaption to avoid a slip on different surfaces includes decrease in walking speed (Menant et al., 2009; Chang et al., 2017). Indoor multi-sport surface which had the timber as the top layer was likely to have lower coefficient of friction compared to the other 2 surfaces, so the surface was more slippery. In the current study, coefficient of friction was not measured for the 3 surfaces. However, Dura et al. (1999) found that friction coefficient of the indoor multi-sport surface (wooden surface) was 0.43 and 0.77 for the outdoor synthetic surface. Friction coefficient of 1.5 was found for the natural grass surface under a dry condition (Jenkins2005). As a result of low coefficient of friction, this may be the reason why the participants reduced walking speed over the indoor multi-sport surface in order to prevent slip and fall injuries

(Chang et al., 2017). Wang et al. (2017) also found that increased walking speed was associated with a greater proximal-distal and anterior-posterior GRF during early impact phase of gait, implying that the joint stability was more demanding at higher walking speed conditions. As walking speed increased, larger dorsiflexion and smaller knee flexion were found at all contact phases. To reduce the impact force, the body would elicit larger knee flexion and ankle plantar flexion at high walking speed. In addition, higher proximal-distal and anterior-posterior knee contact forces were found when participants were walking at higher speed. Therefore, the risk of knee cartilage including PFPS associated with the increased knee contact forces should require further attention. It may be concluded that the indoor surface may be another suitable surface for training during rehabilitation as it would not result in overload at the lower extremity joints including PFJ.

The reason of coefficient of friction also applied to stride length results in the current study as the stride length was also decreased when walking on slippery surfaces (Chang et al., 2017) with the natural grass surface significantly demonstrating longer stride length compared to the indoor multi-sport and the outdoor synthetic surface ($p < 0.001$). There was also a significant difference between the indoor multi-sport and the outdoor synthetic surface with the outdoor synthetic surface showing longer stride length ($p < 0.001$). Short stride length may be considered as a mechanism that influences injury risk and recovery. A systematic review conducting articles of stride frequency and length on running mechanics stated that reduced stride length resulted in decreased GRF, impact shock, energy absorbed at the hip, knee, and ankle (Schubert et al., 2014). The indoor surface may be a suitable surface for training during rehabilitation period whilst the natural grass surface should be avoided as its excessive coefficient of friction produced overload in the lower extremity joints including PFPS.

Step length did not present any significant differences between the surfaces as the sensor measured the variable in % stride length, so the percentage was likely to be 50:50 between left and right foot for every surface. However, Menant et al. (2009) examined the effect of walking surfaces and shoe features on gait parameters associated with balance control and the risk of slips and trips in young and older adults and found that the subjects displayed significant reductions in walking speed and step length when walking on the slippery surface. This supports that speed, stride length, and step length would be reduced on a surface that coefficient of friction is low.

Significant differences of antero-posterior ($p = 0.004$) and lateral pelvic tilt ($p = 0.028$) were found between the 3 surfaces. The participants significantly produced greater antero-posterior pelvic tilt and lateral pelvic tilt when walking on the natural grass surface and the outdoor synthetic surface compared to the indoor surface. A significant difference between the natural grass and the outdoor synthetic surface was not found. There is a literature stating that increased lateral pelvic tilt may be associated with increased hip internal rotation on the opposite side of the pelvis due to gluteus medius tightness (Hertel et al., 2004). This mechanical consequence could influence abnormal mechanics of the PFJ (Cibulka & Threlkeld-Watkins, 2005) and ACL injury (Hertel et al., 2004). Hertel et al. (2009) also suggested that increased anterior pelvic tilt could be a predictor for ACL injury. Watelain et al., (2001) investigated antero-posterior pelvic tilt and lateral pelvic tilt in patients with hip osteoarthritis and healthy subjects during walking with natural speed. It was found that both pelvic tilts were significantly higher in the clinical group during stance phase. Anterior pelvic tilt is resulted from internal rotation of the femur as the head of the femur rotates posteriorly into the posterior acetabulum which forces the pelvis into anterior tilt (Duval et al., 2010). This could be concluded that increased pelvic tilts have negative effects on the lower extremity and PFJ. Pelvic tilts should also be related with the walking speed as the same results occurred. This means that quicker speed allows the pelvis to move more. Therefore, coefficient of friction should have an effect on pelvic tilts as well.

6. LIMITATIONS

The main limitation of this study is that only walking sessions were evaluated whilst most sports involve running. However, due to the increase in the injuries associated with running, walking has become the preferred mode of exercise for millions of people. Because the dynamic loading on the human musculoskeletal system from walking is presumably less than that from running, it is of interest to analyse the effect of walking (Voloshin, 2000). Another limitation is that this was conducted with healthy individuals so further investigations in individuals with PFPS are required. Additionally, variations in the hardness of the natural grass may vary due to precipitation and it is therefore recommended that future studies use a penetrometer to evaluate hardness of the natural grass for every testing conducted. Surface hardness is assumed to have an impact on ground reaction force. (Yamin et al., 2017) investigated effects of 3 different running surface hardness (concrete, artificial grass, and rubber) on GRF response. It was found that GRF was decreased with increasing of surface hardness during barefoot running.

7. IMPLICATIONS

The results of this study provide implications for healthcare providers in suggesting and considering suitable training surfaces for patients or athletes during rehabilitation programmes. On the basis of the findings of this study, it is proposed that rehabilitation should be progressed from the indoor multi-sport surface as it produced the lowest speed, stride length, and pelvic tilts. The outdoor synthetic surface could be the second option as it produced the highest cadence resulting in minimised the lower limb loading which may benefit in reducing lower limb injuries including PFPS. The natural grass surface should be the last alternative to consider as it produced the highest stride length of walking compared to the other 2 surfaces which means quicker movements can be performed for rehabilitation and training. However, if the friction is excessive, it is possible that overload is produced in joints and injuries may reoccur (Dura et al., 1999). It is important for health care professionals to verify that patients or athletes have good progress in recovery from injuries before performing on the natural grass surface.

8. CONCLUSION

Indoor multi-sport, outdoor synthetic, and natural grass surface demonstrated different results for spatiotemporal and pelvic kinematic parameters of gait with the natural grass surface presenting with the longest stride length that may lead to overloads to the joints during walking in healthy individuals. The consultation with rehabilitation professionals needs to be considered for selecting a suitable surface for individuals. Future studies need to include running activities and use a penetrometer to evaluate hardness of the natural grass for every testing conducted.

In addition to the parameters evaluated in this study, foot loading patterns, such as plantar pressures that may be related to the gait during walking need to be further investigated as excessive foot pronation and subsequent rotation of the lower extremity have been hypothesised as being implicated with PFPS.

Chapter 6: Study 5

Effects of McConnell taping and SERF strap on plantar loading patterns in healthy adults during walking and jogging

1. ABSTRACT

Introduction: PFPS is believed to be associated with a reduction in the contact area of the PFJ. This reduction occurs due to alterations in the dynamic alignment of the tibiofemoral joint. It is stated that excessive and/or prolonged foot pronation can lead to excessive medial rotation of the tibia. This medial rotation of the tibia would influence a compensatory medial rotation of the femur. When the femur medially rotates, the compression between the lateral surface of the patella and the lateral femoral condyle increases. As a result, PFJ stress increases. Plantar pressure distribution is an indirect method of estimating pronation of the foot when there is a lack of equipment for measuring it directly. McConnell taping is associated with alterations in patellofemoral joint reaction forces that is also related with excessive foot pronation. The stability through external rotation of the femur (SERF) strap has been developed to pull the femur externally to stabilise the patellofemoral joint, in order to reduce patellofemoral pain and improve lower limb kinematics. A lack of literature has examined effects of these two methods on plantar pressures. Therefore, the aim of this study was to investigate the effects of McConnell taping and the SERF strap on plantar loading patterns during walking and jogging in healthy adults. ***Methods:*** Twenty-three participants (12 males and 11 females, age: 27±6 years) were randomly tested under 3 conditions: 1) no tape; 2) McConnell taping; 3) SERF strap for both walking and jogging trials. Each participant was instructed to walk/jog on a 2 m pressure plate at their own natural pace. Three valid stance phases of the right foot were recorded for each condition. Foot balance, contact area of HM and HL, foot axis angle, and COPs were collected. ***Results:*** There was a significant difference of the medio-lateral ratio of the foot balance with the SERF strap presenting more laterally directed pressure distribution at FFPOP compared to the no-tape condition during walking. However, significant differences of other variables were not found. ***Conclusion:*** The result suggests that there could be a clinical role for SERF strap use in reducing foot pronation in people with lower extremity problems especially patellofemoral pain syndrome.

Keywords: McConnell taping, SERF strap, plantar pressures, patellofemoral pain syndrome

2. INTRODUCTION

Changes in patellofemoral joint biomechanics have the potential to influence function of the lower extremity as the joint improves the ability of knee flexion and extension. It is also assumed to have developed through human’s ability of having adopted a bipedal gait. Forces in the patellofemoral joint are a result of quadriceps contraction force and the angle of knee flexion. These forces depend on the distance between the patellofemoral joint and the centre of gravity. It can be explained that the different activities may exert variations in patellofemoral joint reaction forces and contact pressures (Schindler & Scott, 2011).

PFPS is believed to be associated with a reduction in the contact area of the PFJ. This reduction occurs due to alterations in the dynamic alignment of the tibiofemoral joint (Salsich & Perman, 2007). It is stated that excessive and/or prolonged foot pronation especially at the rearfoot/heel region (rearfoot eversion) (Aliberti et al., 2011; Thijs et al., 2007) can lead to excessive medial rotation of the tibia during a closed kinetic chain (Tiberio, 1987). This medial rotation of the tibia would influence a compensatory medial rotation of the femur to maintain the relative lateral rotation of the tibial plateau in relation to the femoral condyles, which are related to knee extension during the midstance phase of gait (Aliberti et al., 2011). When the femur medially rotates, the compression between the lateral surface of the patella and the lateral femoral condyle increases. As a result, PFJ stress increases (Willson et al., 2015; Bek et al., 2011; Rathleff et al., 2014; Aliberti et al., 2011; Powers, 2010; Boling et al., 2009).

The forces on the knee during weight-bearing activities are transmitted from the foot to the knee. Hence, loading of the knee and patellofemoral joint can be influenced by force and loading patterns at the foot (Rathleff et al., 2014). By correcting excessive foot pronation, external tibial rotation is increased, eliciting a relative medial patellar glide (Nyland et al., 2002). Higher loading on the medial areas of the plantar surface as well as excessive pronation of the foot during running and other weight-bearing activities have been suggested to be important factors for the development of lower limb injuries including PFPS. (Rathleff et al., 2014; Aliberti et al., 2011). Plantar pressure distribution is an indirect method of evaluating pronation of the foot when there is a lack of equipment for measuring it directly such as a 3D motion analysis system (Willems et al., 2006). Willems et al. (2006) and Willems et al. (2007) found increased pronation, accompanied with more pressure on the medial side of the foot in healthy people who developed exercise-related lower leg pain during barefoot running. These findings are interesting because a greater medial foot-loading pattern may increase lateral force on the patellofemoral joint. Thijs et al., (2007) also conducted plantar pressure in military during barefoot gait and observed a relationship between PFPS and lateralised support of the feet. It was found that individuals who developed PFPS exhibited a heel strike in a less pronated position and a foot rollover that was more directed toward the lateral side of the foot. However, the authors stated that the plantar pressure distribution findings and their relationship to PFPS are not a consensus with the literature and further investigation is needed.

Medial patellar taping is an inexpensive treatment option that has been proposed to immediately reduce pain following application in individuals with PFPS (Mostamand et al., 2012; Callaghan et al., 2008; Hinman et al., 2003). Patellar taping has become widely used since the introduction of the original approach by Jenny McConnell in 1984 (Campolo et al., 2013) . It is believed that the reduction of pain following the medial tape application is associated with alterations in patellofemoral joint reaction forces that is also related with excessive foot pronation (Mostamand et al., 2012). In addition to pain reduction, medial patellar taping has also been proposed to improve the activity of VMO and facilitating strengthening exercises of quadriceps femoris muscle (Herrington & Payton, 1997; Verma & Krishnan, 2012; Christou, 2004; Kowall et al., 1996). Patellofemoral alignment (Larsen et al., 1995; Somes et al., 1997; Worrell et al., 1998) and stride length (Powers et al., 1997) during ramp ascent were have also been shown to be improved after medial taping application. However, there is a lack of literature examining the effects of medial patellar taping on plantar pressures during walking. Only one study examined effects of infrapatellar strap on plantar pressure during barefoot walking and jogging in patients with PFPS and it was presented that there were no significant differences in plantar pressures comparing infrapatellar strap to no strap (Bek et al., 2011).

The Stability through External Rotation of the Femur® (SERF) strap (Don Joy Orthopedics Inc, Vista, CA) has been developed to pull the femur into external rotation to stabilise the patellofemoral joint, in order to reduce patellofemoral pain and improve lower limb kinematics during dynamic activities (Herrington, 2013b; Wallace & Barr, 2012; Austin et al., 2008a). Since it has been suggested that abnormal patellar tracking may be the result of excessive internal rotation of the femur and tibia from excessive foot pronation, it is proposed that the application of the SERF strap should alter plantar loading patterns by pulling the femur laterally resulting in a reduction in medial tibial rotation and foot pronation. Although McConnell taping has become very popular for patellofemoral pain management, relatively little is known regarding its effect on foot pressures (Nyland et al., 2002). Therefore, the aims of this study were to investigate the effects of both McConnell taping and the SERF strap on plantar loading patterns during walking and jogging in healthy adults. On the basis of the review and the evidence that is presented, the McConnell taping has been associated with changing of patellofemoral joint reaction force and the SERF strap has been developed to pull the femur laterally, which is associated with pronation of the foot, so the hypotheses of this study were that both McConnell taping and the SERF strap would decrease medial plantar loading patterns of the foot during walking and jogging.

3. METHODOLOGY

Participants

This cross-sectional study included 23 healthy active individuals. The sample size was calculated using G*Power 3.1.9.2 which is a stand-alone power analysis program for several tests commonly used in the social, behavioral, and biomedical sciences (Faul et al., 2009; Faul et al., 2007). For the calculation on the software, the test family was F-tests with the statistical test of ANOVA: Repeated measures, within factors. In this study, the researcher calculated the effect size using the results from a previous study (Aliberti et al., 2010). The effect size was 0.23 but the previous study compared healthy individuals and individuals with PFPS during stair descent. In the present study, only healthy individuals were recruited, and it was during walking and jogging so the medium effect size was chosen as it is acceptable (Suresh & Chandrashekara, 2012). Therefore, the estimated sample was at the power of 0.8, medium effect size (0.06), and a 0.05 alpha level. The total sample size required for the study was 17.

Inclusion criteria

1. Healthy active individuals aged 18-35 years (both males and females).

2. Engaged in physical activities for 2 hours or more per week during the previous 12 months (Arroyo-Morales et al., 2008).
3. Adequately understand verbal explanations or written information given in English.
4. Weight between 66-88 kg for height 147 cm
   64-86 kg for 150 cm or
   61-86 kg for 152 cm or
   59-84 kg for 155 cm or
   57-84 kg for 157 cm or
   54-82 kg for 160 cm or
   52-82 kg for 163 cm or
   50-79 kg for 165-168 cm or
   41-77 kg for 170-173 cm or
   41-75 kg for 175-178 cm as these ranges fit the SERF size M
5. No history of a surgery involving the lower leg, ankle or foot in the last 12 months (Willems et al., 2006).
6. No history of an injury to the lower leg, ankle or foot within 6 months (Willems et al., 2006).
7. No knee pain with any of activities (Aliberti et al., 2010).
8. Normal arch of foot (Aliberti et al., 2010) measured by using the plantar arch index (A/B) (Huang et al., 2004) as described in the chapter 5.
9. No discrepancy of 1 cm or greater in lower leg length and major deformities (Aliberti et al., 2010) measured from ASIS to medial malleolus of the same leg as described in the chapter 5.
10. No reported known cardiovascular abnormalities
    (Willson et al., 2015).
11. Not allergic to zinc oxide or the inside of SERF strap.

Outcome measurement

There were four outcomes measured in this study and the definitions of the outcomes acquired from Footscan® pressure plate entry level system user guide: Version 7, Gait software and Footwear Adviser software (RSscan International, Belguim) are described in Table 6.1.

Table 6.1 Operational definitions of plantar loading outcomes.

Parameter	Definition
Foot balance	- Defined as total foot balance during stance phase. It is calculated by comparing the medial part of the foot (M1+M2+HM) with the lateral part of the foot (M3+M4+M5+HL), and the pressure under these zones. The foot is pronating when the pressure is higher under the medial part, the foot is supinating when the pressure is higher under the lateral part. A positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution.
Contact area of medial heel (HM) and lateral heel (HL) (cm^2)	- Defined as an area on the medial and lateral side of the heel region that touches the ground/pressure plate during gait. A previous study found that individuals with PFPS presented with a larger contact area at the medial rearfoot during initial contact of gait (Aliberti et al., 2011).
Foot axis angle (degree)	- Defined as the position of internal or external rotation of the foot related to the gait direction. A positive angle indicates abduction of the foot, a negative angle indicates adduction of the foot. Abduction is one of the 3 movements (dorsiflexion, eversion, and abduction) that creates 3D motion called “pronation”. Adduction is one of the 3 movements (plantarflexion, inversion, and adduction) that creates 3D motion called “supination” (Brockett & Chapman, 2016). Excessive pronation of the foot is associated with PFPS.
Centre of pressure (COPx) (mm)	- Defined as the displacement of the centre of pressure in medial-lateral direction with respect to the x-axis perpendicular on the longitudinal foot axes during the initial contact phase of gait. Medial displacements (pronation) of the COPx are expressed as positive values, lateral displacements (supination) as negative values. Initial contact phase of gait is considered important as it has been associated with greater knee joint loading

	including PFJ (Goss et al., 2015). Medial displacement could result in PFPS as the foot presents greater pronation (Aliberti et al., 2011).

Taping and SERF strap applications

Starting with the participant lying on their back, a rolled-up towel was placed under the right knee. Before the tape application, the participant's knee was shaved using a razor. During the McConnell tape application, an approximately 15 cm length of hypoallergenic tape (5-cm wide) was first applied on the knee with no tension to avoid allergic reactions (Figure 6.1 A) (Whittingham et al., 2004). A 10-cm-length of zinc oxide tape (3.8-cm wide) as commonly used for McConnell taping was placed over the hypoallergenic tape on the lateral patellar border and the other end of the tape was medially pulled over the patella and secured near the medial femoral condyle (Figure 6.1 B) (Nyland et al., 2002). Wrinkles of the skin at the inner aspect of the knee (Figure 6.1 C) were used as an indication that the patella had been moved medially.

In the SERF strap condition, the SERF strap was applied on the right leg while the participants sat on a chair. The strap was wrapped around the lower limb from the knee to the waist (Figure 6.2). The tensioning of the strap and the direction of pull was to facilitate lateral rotation of the femur.

6.1 A **6.1 B** **6.1 C**

Figure 6.1 McConnell taping application method: 6.1 A) hypoallergenic tape application; 6.1 B) zinc oxide tape application; 6.1 C) wrinkles created after the zinc oxide application.

Figure 6.2 SERF strap (Don Joy Orthopedics Inc, Vista, CA) application on the right leg.

Procedure

The study was approved by the School of Sport & Exercise Sciences Research Ethics and Advisory Group (REAG), University of Kent at Medway (Ethics reference: Prop 143_2014_2015). All participants gave written informed consent prior to the participation. The participants attended the laboratory two hours for one occasion. The participants were randomly tested in walking and jogging activities under 3 conditions: 1) no tape; 2) McConnell taping; 3) SERF strap. Plantar loadings (foot balance, contact area of HM and HL, foot axis angle, and COPx) were collected using a 2 m pressure plate (Figure 6.3). Before the testing started, all participants were acquainted with the data collection procedures including walking and jogging on the pressure plate (5-6 trials with no tape) until they felt comfortable (Franklyn-Miller et al., 2014). The jogging speed is considered to be slower than regular running at the speed of 1.5-2.5 m/s (5.4-9.0 km/h) (Ho et al., 2010). During the study, each participant was instructed to walk and jog on the pressure plate at their own natural pace while looking straight ahead and not towards the floor (Bek et al., 2011). The participants were asked to start walking with their left foot first so that a completed right foot step was recorded. The participants performed all tests barefoot. The condition order (no tape, McConnell taping, and SERF strap) and movement order (walking and jogging) were assigned randomly between participants to control potential order effects. Three valid stance phases of the right foot were recorded for each condition. A trial was considered valid when the entire right foot was captured (Figure 6.4). Participants were given 3 minutes to recover between each of the conditions (Herrington, 2013b) .

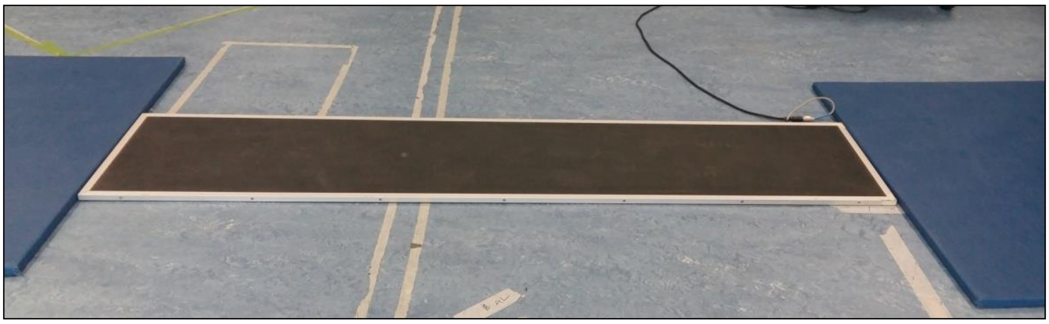


Figure 6.3 Footscan® pressure plate (RSscan International, Belgium).

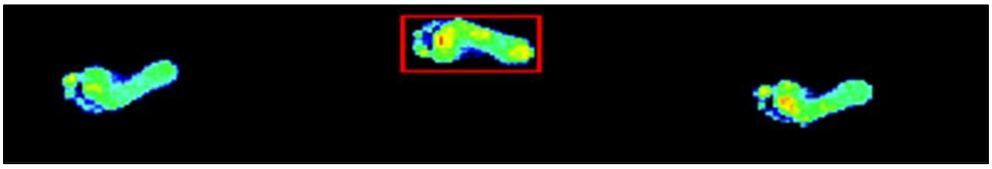
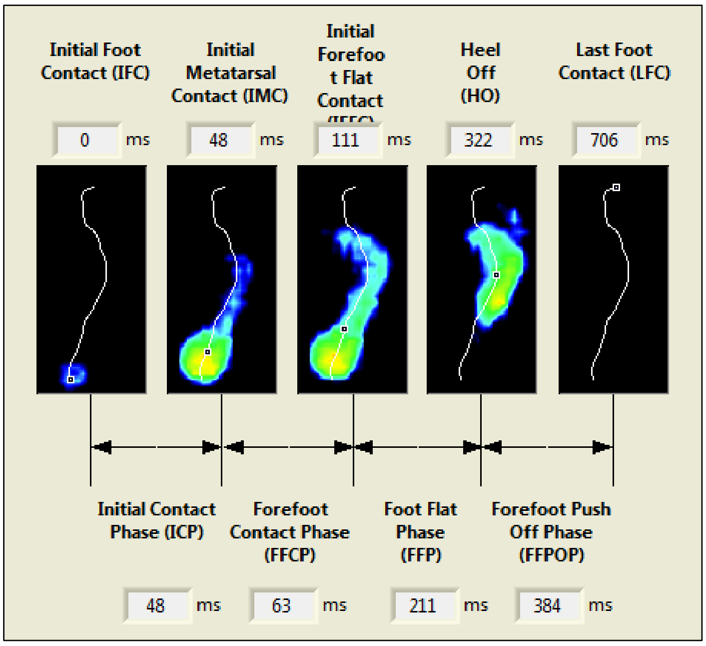


Figure 6.4 A successful trial captured from the pressure plate software (Footscan® 7.0 Gait 2nd Generation software).

Foot balance analysis

Foot balance was analysed following the previous study of relationship between gait biomechanics and inversion sprains (Willems et al. 2005). Seven anatomical pressure areas were identified. These areas were defined as medial heel (HM), lateral heel (HL), and metatarsal heads 1-5 (M1, M2, M3, M4, M5). Five distinct instants of foot rollover were determined for each trial: 1) initial foot contact (IFC) 2) initial metatarsal contact (IMC) 3) initial forefoot flat contact (IFFC) 4) heel off (HO) 5) last foot contact (LFC). IFC was defined as the instant the foot made first contact with the pressure plate. IMC was defined as the instant when one of the metatarsal heads contacted the pressure plate. IFFC was defined as the first instant all metatarsal heads made contact with the pressure plate. HO was defined as the instant the heel region lost contact with the pressure plate. LFC was defined as the last contact of the foot on the plate. Based on these 5 instants, total foot contact could be divided into four phases: 1) initial contact phase (ICP; IFC→ IMC), forefoot contact phase (FFCP; IMC → IFFC), foot flat phase (FFP; IFFC→ HO) and forefoot push off phase (FFPOP; HO→ LFC) (Figure 6.5). A medio-lateral pressure ratio was calculated at these five instants of foot contact (ratio = [(M1+M2+HM) − (M3+M4+M5+HL)]/sum of pressure underneath these areas). This ratio describes the pressure distribution in the whole foot. Excursion ranges of these ratios were calculated over the four phases (ICP, FFCP, FFP, FFPOP).



Initial Foot Contact (IFC) 0 ms
Initial Metatarsal Contact (IMC) 48 ms
Initial Forefoot Flat Contact (IFFC) 111 ms
Heel Off (HO) 322 ms
Last Foot Contact (LFC) 706 ms

Initial Contact Phase (ICP) 48 ms
Forefoot Contact Phase (FFCP) 63 ms
Foot Flat Phase (FFP) 211 ms
Forefoot Push Off Phase (FFPOP) 384 ms

Figure 6.5 Five distinct instants and phases relative to total foot contact (Footscan® 7.0 Gait 2nd Generation software).

Statistical analysis

All foot plantar loadings were expressed as mean±standard deviation (SD) using Microsoft Excel. The data were checked for normal distributions using Shapiro-Wilk test. Foot balance (ICP and FFPOP of walking and FFPOP of jogging), contact area of HM and HL for jogging trials were not normally distributed, so they were analysed by Friedman test: the non-parametric alternative to the one-way ANOVA with repeated measures for testing differences between no tape, McConnell taping, and SERF strap and Wilcoxon Signed Rank test: the non-parametric test used to compare differences between 2 interventions (no tape and McConnell taping, no tape and SERF strap, McConnell taping and SERF strap). The rest of the loading patterns were analysed by repeated measures ANOVA and Tukey’s Post-Hoc test as the data were normally distributed. The data were analysed using SPSS 16.0 (Norusis/SPSS Inc., Chicago, IL, USA). An Alpha level of $p \leq 0.05$ was used to test statistical significance.

4. RESULTS

Twenty-three participants (12 males and 11 females) were recruited in the study. The average age of the participants was 27±6 years, weight of 69.7±14.8 kg, and height of 171.7±8.9 cm (Table 6.2). Twenty-three participants' data were calculated for the walking sessions but only 9 participants were counted for the jogging sessions as the rest did not perform the jogging with heel contact.

Table 6.2 Baseline characteristics of the participants.

	Male (N = 12)		**Female (N =11)**		**Total (N = 23)**	
	Mean±SD	Max:Min	Mean±SD	Max:Min	Mean±SD	Max:Min
Age (year)	29±6	35:18	24±6	33:18	27±6	35:18
Weight (kg)	78.2±14.2	106:54	60.4±8.3	72:43	69.7±14.8	106:43
Height (cm)	177.0±6.3	191:170	165.9±7.7	175:150	171.7±8.9	191:150

The medio-lateral ratios (Table 6.3) show that pressure distribution was significantly more medially directed at FFPOP in no-tape condition compared to SERF strap ($p = 0.011$) condition during the walking sessions. No significant differences were found in the jogging sessions.

Table 6.3 Mean differences of the medio-lateral ratio of foot balance at the four phases of the stance phase of gait (ICP, FFCP, FFP, FFPOP).

Walking (n = 23)	**No tape**	**McConnell**	**SERF**	***p*-value**
Ratio ICP	0.312±0.673	0.210±0.695	0.318±0.765	0.751
Ratio FFCP	-0.160±0.153	-0.172±0.143	-0.162±0.131	0.752
Ratio FFP	-0.006±0.175	-0.002±0.190	-0.017±0.209	0.716
Ratio FFPOP	0.745±0.425	0.685±0.403	0.636±0.397*	0.031**
Jogging (n = 9)	**No tape**	**McConnell**	**SERF**	***p*-value**
Ratio ICP	0.147±0.478	0.222±0.400	0.174±0.424	0.761
Ratio FFCP	-0.041±0.196	-0.125±0.147	-0.116±0.160	0.056
Ratio FFP	0.157±0.189	0.130±0.131	0.102±0.121	0.227
Ratio FFPOP	0.576±0.484	0.656±0.412	0.531±0.549	0.618

** Friedman test $p \leq 0.05$, * Wilcoxon signed rank test $p \leq 0.05$ (compared to No tape)

A positive ratio indicates a medially directed pressure distribution, a negative ratio a laterally directed pressure distribution.

Table 6.4 and 6.5 show that no significant differences of contact area of HM and HL, foot axis angle, and COPx were found between no tape, McConnell taping, and SERF strap for the jogging trails.

Table 6.4 Mean differences of contact area of HM and HL, foot axis angle, and COPx during walking.

Walking (n = 23)	No tape	McConnell	SERF	*p*-value
Contact area of HM (cm^2)	16.7±2.7	16.6±2.8	16.7±2.8	0.422
Contact area of HL (cm^2)	14.9±2.3	14.6±2.5	14.8±2.5	0.273
Foot axis angle (degree)	12.69±8.57	11.77±8.55	12.06±8.50	0.216
COPx (mm)	-1.00±2.21	-0.95±2.60	-1.36±1.97	0.146

Table 6.5 Mean differences of contact area of MH and LH, foot axis angle, and COPx during jogging.

Jogging (n = 9)	No tape	McConnell	SERF	*p*-value
Contact area of HM (cm^2)	19.1±2.2	19.0±2.6	19.0±2.6	0.794
Contact area of HL (cm^2)	16.7±1.9	16.6±2.1	16.6±2.2	0.937
Foot axis angle (degree)	13.90±5.49	14.14±6.49	14.95±5.67	0.620
COPx (mm)	1.30±3.30	1.18±2.78	1.84±3.67	0.478

5. DISCUSSION

Abnormal patellar tracking may result from excessive internal rotation of the femur and tibia from excessive foot pronation (Barton et al., 2010b; Barton et al., 2009; Petersen et al., 2014; Powers, 2003). It is proposed that the application of the SERF strap and McConnell taping should reduce medial plantar loading patterns with the SERF strap pulling the femur laterally resulting in a reduction in medial tibial rotation and foot pronation and McConnell taping altering patellofemoral joint reaction force (Mostamand et al., 2012). This study was the first to evaluate the effects of McConnell taping and SERF strap on foot plantar loading patterns during walking and jogging. The main finding of this study was that there was a significant difference of the medio-lateral ratio of the foot balance with the SERF strap presenting more laterally directed pressure distribution at FFPOP compared to the no-tape condition during walking. This finding partially resulted in the acceptance of the hypothesis that both McConnell taping and the SERF strap would decrease medial plantar loading patterns of the foot during walking and jogging.

The SERF strap has been used to assist lower limb kinematics and support femoral abduction and external rotation (Herrington, 2013b; Wallace & Barr, 2012; Austin et al., 2008a). In the present study, the SERF strap resulted in more laterally directed pressure distribution at FFPOP, meaning that the medial pressure distribution at FFPOP was reduced during walking. A possible reason is that the SERF strap could be pulling the femur and the tibia laterally and (Herrington, 2013b; Wallace & Barr, 2012; Austin et al., 2008a), in so doing, reducing pronation of the foot and increasing the lateral loading of the foot. Reduced foot pronation causes the head of talus to dorsiflex and slide laterally and dorsiflexion of the talus will force the tibia to rotate externally resulting in decreasing PFJ stress on the lateral side of the patella (Cheung et al., 2006).

However, the other variables in the present study during walking and jogging did not present any significant differences between the taping conditions. This may due to: 1) the participants recruited in the study were healthy so plantar loading, foot posture, and gait patterns were different from individuals with PFPS (Aliberti et al., 2011; Thijs et al., 2007). Barton et al. (2010a) evaluated the foot posture in 15 young healthy volunteers and 15 volunteers with PFPS and found that significantly greater pronated foot posture between subtalar joint neutral and relaxed stance were indicated in PFPS group compared to healthy group. Levinger & Gilleard, (2007) measured rearfoot, tibia motion, and ground reaction force during the stance phase of walking in patients with PFPS and healthy individuals. The results indicated prolonged rearfoot eversion during the stance phase of walking in PFPS participants 2) a Type II error may have occurred due to the small sample size in this study especially during the jogging sessions. Only nine from 23 participants were selected for statistical analysis for jogging as the rest did not perform jogging with the initial contact so their data were removed from the analysis. A larger sample size may have resulted in a significant difference. The demonstration that the SERF strap changes plantar loading patterns in healthy participants supports the need for future studies to evaluate the effect of the SERF strap on plantar pressure in people with PFPS.

McConnell taping is believed to unload abnormally stressed soft tissue around the patellofemoral joint, to improve patellar alignment, and to improve lower limb mechanics including the foot (Whittingham et al., 2004). In the present study, the application of McConnell taping did not present any significant differences compared to the no tape and SERF strap. The result is not in line with Nyland et al. (2002) who found significant differences on anterior-posterior peak plantar force location of the forefoot and peak plantar force onset with the participants displaying a more forefoot directed peak plantar force location and delaying peak plantar force onset following initial ground contact when applying McConnell taping on basketball players while running and dribbling a basketball before the lay-up. The possible reason may due to the heathy participants in the present study and the type II error following the small sample size especially during jogging sessions.

6. LIMITATIONS

The study only included healthy participants. The researcher spent 3 months looking to recruit individuals with PFPS in a sports injury clinic at University of Kent and a physiotherapy clinic but there was a lack of PFPS patients. Therefore, healthy participants were recruited in the study. However, the main finding from the present study should benefit further research by conducting individuals with PFPS with the same methodology. Another limitation was that the participants were instructed to take their first step on the pressure plate with their left foot so some of them might not feel comfortable and did not perform 100% of natural walk and jog. The solution may be using a longer pressure plate, or the participants perform walking and jogging until the completed right foot is captured without being instructed to take the first step on the pressure plate with the left foot.

7. IMPLICATIONS

The result advances the field of research that the SERF strap not only reduced pain in PFPS but also reduced medial pressure distribution at FFPOP in healthy people during walking. The result also improves the knowledge of effects of SERF strap application as there was only one published study of the SERF strap use.

8. CONCLUSION

The application of the SERF strap resulted in more laterally directed pressure distribution at FFPOP compared to no tape during walking. This result suggests that there could be a clinical role for the SERF strap use in reducing foot pronation in people with lower limb injuries especially PFPS.

Chapter 7

Discussion and conclusion

1. DISCUSSION

Several assessments of lower extremity variables and extrinsic factors that are believed to be associated with PFPS still remain unclear or have not been addressed in previous research. Understanding the demographics of PFPS before considering other variables is important as it helps to determine the best practices in the diagnosis and treatment of the pathology and to provide early interventions (Glaviano et al., 2015). Moreover, interventions resulted from the improved understanding of the lower extremity variables and extrinsic factors related to PFPS may be able to reduce prevalence of PFPS. The studies in this thesis have contributed to an improved understanding of the lower extremity variables and extrinsic factors related to PFPS that were not investigated in the past.

Prevalence of PFPS in young Thai athletes

Prevalence of PFPS assessed by AKPS was not investigated in any groups of Thai athletes before. The possible reason is that Thailand is a developing country that aims to improve sport performance at the international level rather than focusing on injury prevention and management (The Ministry of Tourism and Sports Thailand, 2017; Chaisena, 2013). Moreover, there may be a lack of sport health professionals in the country especially physiotherapists (The Ministry of Tourism and Sports Thailand, 2017) as there are approximately 8,000 practising physiotherapists in Thailand, but the majority does not engage in sports injury prevention and treatment (World Confederation for Physical Therapy., 2015). The results of the study have brought out new knowledge about unexpectedly low prevalence of PFPS in the young Thai athletes as Thailand is a developing country where training strategies and sports science and technology are not as good as ones in developed countries (The Ministry of Tourism and Sports Thailand, 2017). This normally results in training error which could cause overuse injuries (Drew & Purdam, 2016) including PFPS. The new knowledge from this prevalence study presents wider understanding of PFPS that the syndrome can occur in any groups of active population. This group of Thai population in the prevalence study may not have the training level as high as collegiate or professional athletes as they were only novices, but PFPS was still seen. This implies that there is a need for further investigations of prevalence of PFPS in other groups of Thai population as the prevalence might be higher than 6% in some groups.

The present study also shows that longer training duration may be a factor for PFPS. The result supports a previous systematic review reporting that longer training duration is related to overuse injuries including PFPS (Jones et al., 1994). In addition to training duration, there should be other factors that are important in aetiology of PFPS. For instance, badly worn or poorly designed shoes may produce excessive foot pronation and cause flatfoot which may result in PFPS (Nejati et al., 2010). Running distance and playing surfaces may also be related to PFPS. Running distance is probably one of major factors in PFPS aetiology (Nejati et al., 2010). However, the relationship between PFPS and all these factors still remain unclear. These factors have brought about a new question that could develop into further research investigations. Nevertheless, without the investigation in the present study, prevalence of PFPS in young Thai athletes would remain unknown. Proper knowledge of prevalence of PFPS is important not only for researchers planning for further investigations but also for sports coaches when designing training programmes and schedule for athletes. Healthcare professionals including physiotherapists should be responsible for management and clinical application of the syndrome.

Measuring knee ROM using stretch sensors

The previous prevalence study of PFPS in young Thai athletes presented with low prevalence. However, the result is only limited in this group of population as the prevalence of PFPS in other countries across the world is still high (Callaghan & Selfe, 2007). Interventions resulted from studies of the lower extremity variables and extrinsic factors related to PFPS along with conventional treatment interventions may help in reducing prevalence of PFPS in other countries where the prevalence is high. Therefore, it is essential to improve an understanding of the lower extremity variables. Knee ROM is considered one of the lower extremity variables related to the lower extremity injuries including PFPS (Harmer et al., 2009; Mook et al., 2009; Ritter et al., 2003).

In clinic, surgeons will often estimate ROM visually. It is only a quick and relatively easy method, but not typically accurate. Goniometers in both short and long-arm form are conveniently used in the orthopaedic surgeons and physiotherapists for measuring joint angles (Hancock et al., 2018) but measurement offsets caused by the human eye's subjective judgement are inevitable (Chiang et al., 2017). Furthermore, knee ROM measurement using a universal goniometer was problematic during the physical examination in the present prevalence study in this thesis as substantial measurement error may occur. The use of radiographs is considered "the gold standard" for measuring knee ROM (Edwards et al., 2004) but they are high-cost, immobile and cause radiation exposure (Chiang et al., 2017). Moreover, these measurement methods cannot assess knee ROM during functional movements. Three-dimensional (3D) motion capture systems are considered "the gold standard" in the evaluation of ROM including the knee joint during functional activities. Nevertheless, they are laboratory-based equipment and have limited application in the clinical setting due to high price and time-consuming setup (Schurr et al., 2017). A useful method for knee ROM measurement should have good reliability, low potential error in measurement, cost savings, and be able to measure knee ROM during functional activities. It should also be key to be user-friendly and quick for use (Hancock et al., 2018). Validating knee ROM measurement using a small portable tool such as a stretch sensor may benefit healthcare providers in order to monitor recovery of injuries, not only limited to PFPS but also other lower extremity injuries (Harmer et al., 2009; Mook et al., 2009; Ritter et al., 2003).

The present study investigated knee ROM using a stretch sensor during passive non-weight-bearing. However, the application of the stretch sensor is not only limited to passive non-weight-bearing as Papi et al. (2018) investigated the use of the stretch sensor on measurement of knee flexion during gait compared to the gold standard (10 camera motion capture system). It was found that the sensor demonstrated high test-retest reliability. From the findings of the present study and the support from the previous study (Papi et al., 2018), it can be concluded that the stretch sensor has potential to be used in the future directions for clinical settings as a discreet, unobtrusive wearable device for a wider area such as gait analysis that may be affected by PFPS. Compared to the visual tracking systems, the gold standard for measuring knee ROM during dynamic activities, the stretch sensors are cost effective and more convenient to use. Knee rehabilitation programs enable athletes to restore their functional capability to normal. To achieve this target, continuous monitoring of knee ROM during rehabilitation programs are required. The propose on continuous monitoring is to monitor recovery progress of knee ROM on individuals with PFPS and the stretch sensors may play an important role on this rehabilitation monitoring.

Association between the Q-angle and PFPS

Knee ROM can be influenced by movements of the patellar, tibia, and femur (Lee et al., 2003). These movements can result in changing of the Q-angle, another lower extremity variable believed to influence PFPS (Freedman et al., 2014; Loudon, 2016). With a conflict that whether greater Q-angle is related to PFPF or not, the systematic review of association between the Q-angle and PFPS was conducted. This current systematic review has filled the gap for a lack of new systematic review of an association between the Q-angle and PFPS during year 2013-2016. However, the clinical relevance of using the Q-angle measurement as a clinical assessment to identify PFPS for clinicians and physiotherapists is still debatable. Further studies are required for the future directions to confirm the relationship between the Q-angle and PFPS, and the difference of the Q-angle between PFPS and healthy individuals. Future investigations should directly focus on findings of the relationship between individuals with PFPS and greater Q-angle in young active adults as the key elements. The difference of the Q-angle between individuals with PFPS and healthy individuals also needs to be investigated. Following this, clinicians and physiotherapists will then be able to determine whether the Q-angle is suitable to be used as a clinical indicator for PFPS and patellar instability. This will then allow a more appropriate debate over the usefulness of this measurement for evaluation of these complex musculoskeletal disorders (Smith et al., 2008). Furthermore, the Q-angle measurement especially the goniometric method can be simply performed without expensive equipment (Chevidikunnan et al., 2015).

Training surfaces on spatiotemporal and pelvic kinematic parameters of gait

Following the prevalence study in chapter 2, it was found that training surfaces were a factor that varied between sports. However, this factor was not focused on the prevalence study. Training surfaces have been shown to be an extrinsic factor for PFPS (Murphy et al., 2003; Yeung & Yeung, 2001). The need to investigate the impact of varying training surfaces on gait was addressed in this present study. A new insight from this study is that the natural grass surface was found to be the surface that could result in a greater load to the lower extremity joints when compared to the indoor multi-sport and outdoor synthetic surface. Training on the natural grass allows individuals to grip the surface better and move faster due to its high coefficient of friction (Dura et al., 1999) but the greater load could lead to overuse injuries including PFPS. The natural grass surface has been used for various types of sport for a long period. It is a traditional surface especially for football matches and training (Ekstrand et al., 2006). Compared to the artificial turf surface, playing or training on the natural grass surface has been proposed to affect lower injury rate (Dragoo et al., 2013). Dragoo et al. (2013) demonstrated an increased incidence of non-contact ACL injury on the artificial turf surface versus the natural grass surface. The artificial turf surface presented with higher frictional forces, peak torques, and rotational stiffness compared with the natural grass surface. These results may imply that training on the natural grass surface may not result in highest load to the lower extremity. However, this previous study only investigated the incidence of ACL injury and the present study in this thesis did not include the artificial turf surface. These limitations highlight the need for further investigation of the artificial turf surface on spatiotemporal and pelvic kinematic parameters of gait as the artificial turf surface provides cost-effective, all-weather alternatives to natural grass surfaces and have been widely used for sports and activities (Wright & Webner, 2010). Further investigations of different training surfaces on gait in individuals with PFPS are also required.

In addition to the training surfaces, other extrinsic factors implicated as possible causes of PFPS include changes in training frequency or intensity and inappropriate footwear (Hryvniak et al., 2014). A feature of footwear technology aims to reduce excessive movements of the rearfoot during sports activities. It is possible that a motion control system of the footwear may control foot over-pronation. However, no studies have reported a direct association between footwear and PFPS (Cheung et al., 2006). Training frequency or intensity has been proposed to influence overuse injuries, but no previous studies have examined its relationship with PFPS directly (Halabchi et al., 2017). The need to investigate an association between this training regimen and PFPS is required in detail for future directions. There is no evidence that one extrinsic factor is more valuable than another. From the researcher’s point of view, all of the extrinsic factors related to PFPS are equally important. The training surfaces were selected in the present study as the beginning of an investigation of extrinsic factors affecting rehabilitation. Other related extrinsic factors need to be investigated for more detail. Nevertheless, the results from the present study give directions to healthcare professionals in recommendation for a suitable training surface for each individual. The present study also highlights the need for further investigations of different training surfaces on gait during jogging and running as only walking sessions were investigated in the present study due to limitations of the equipment used.

McConnell taping and SERF strap on plantar loading patterns

In addition to the parameters examined in the previous study of different training surfaces on gait, foot loading patterns that may be related to the gait need a further investigation. Excessive foot pronation and subsequent rotation of the lower extremity has been proposed to be implicated with PFPS (Noehren et al., 2012; Powers et al., 2002; Rathleff et al., 2014). The new knowledge gained from this study is that the SERF strap has the ability to direct pressure distribution laterally at FFPOP during walking. The SERF strap was developed with the aim of assisting lower extremity kinematics, decreasing knee valgus through supporting femoral abduction and external rotation (Herrington, 2013b). With all these abilities, it was proposed that the SERF strap would affect plantar loading patterns as foot pronation is associated with internal rotation of the tibia and femur (Loudon, 2016). The result of this present study would benefit individuals who aim to reduce foot pronation immediately as the SERF strap is convenient and easy to wear and does not require experienced healthcare professionals. Long-term effects of the SERF strap on plantar loading patterns should also be investigated in the future. McConnell taping did not alter plantar loading patterns as it was hypothesised to. Moreover, when compared to the SERF strap application, the McConnell taping application requires skills and experience for the tension applied on the knee (Nyland et al., 2002).

In addition to the SERF strap in the present study, several previous studies investigated effects of braces and insoles/foot orthoses on plantar pressure during gait. Bonanno et al. (2019) examined effects of foot orthosis and a flat insole on plantar pressure during walking. It was found that the foot orthosis and the flat insole significantly increased peak plantar pressure, maximum force, and contact area at the medial midfoot. At the medial forefoot, the foot orthosis and flat insole increased maximum force. At the lateral forefoot, the foot orthosis and flat insole increased contact area with the flat insole also increasing maximum force. Similarly, McCormick et al. (2013) investigated the effectiveness of 4 types of foot orthoses on plantar pressure at the heel, midfoot, and forefoot for both medial and lateral sides. The foot orthoses consist of 1) customised foot orthosis, 2) contoured polyethylene sham foot orthosis, 3) contoured EVA sham foot orthosis, and 4) flat EVA sham foot orthosis. The results presented that the contoured EVA sham orthosis, the flat EVA sham orthosis, and the customised orthosis significantly reduced peak pressure at the heel region compared to the shoe alone which was the control group. For the midfoot and forefoot region, all of the sham orthoses evaluated did not significantly alter plantar pressures. Almeida et al. (2009) compared effects of custom and prefabricated insoles on plantar pressure at the rearfoot. There was no statistically significant difference of plantar pressure in the comparison between groups. These previous studies have presented with some limitations regarding the plantar pressure on the foot regions and comfort of the insole application. Even though the insoles altered plantar pressure distribution in these previous studies, their applications did not prove to reduce plantar pressure on the medial side of the foot whilst the present study aimed to reduce foot pronation. Moreover, it must be noted that the insoles may cause discomfort over an extended period of time, such as during prolonged standing or walking (Bonanno et al., 2019). In the researcher's point of view, the SERF strap is more suitable for individuals to use by themselves as it does not require any skills for the application and should not result in discomfort during usage.

2. CONCLUSION

In conclusion, the original work of this thesis extends the body of knowledge of the lower extremity variables and extrinsic factors in the context of PFPS. The first prevalence study of PFPS in the young Thai athletes was examined. An investigation of the silicone stretch sensor directly attached on the skin for knee ROM measuring through capacitance was conducted. The needs for an updated systematic review of the Q-angle and PFPS during year 2013-2016, an investigation of effects of different training surfaces on spatiotemporal and pelvic kinematic parameters of gait during walking, and an investigation of effects of McConnell taping and SERF strap on plantar pressure during walking and jogging were investigated. These results were found to have potential implications within PFPS research and should benefit clinicians, physiotherapists, sport rehabilitation professionals and related-area researchers in applying for clinical practice including treatment and rehabilitation plans and assessments in terms of objectively measuring recovery after various knee injuries including PFPS.

From the present results of this thesis, it is suggested that long training duration should be taken into consideration when designing training programs for athletes as it may influence PFPS. The stretch sensor directly attached on the skin is recommended for passive knee ROM measurement on an individual basis in a laboratory situation following its convenience of use. It is suggested that before considering the Q-angle as a predictor for PFPS, the association of the Q-angle and PFPS and the difference of the Q-angle between PFPS individuals and healthy individuals still need to be investigated. Different training surfaces significantly affected gait and it is advised that rehabilitation should begin with the indoor multi-sport surface, outdoor synthetic surface, and natural grass surface respectively. Finally, with the ability to produce more laterally directed pressure distribution at FFPOP, the SERF strap is recommended to use in individuals who aim to reduce foot pronation.

REFERENCES

Abdel-aziem, A.A., Abdelraouf, O.R. & El-Gohary, T.M. (2014). Effect of body position on measurement of Q angle in trained individuals with and without patellofemoral pain. *International Journal of Therapies and Rehabilitation Research, 3*, 1-5.

Abulhasan, J.F. & Grey, M.J. (2017). Anatomy and physiology of knee stability. *Journal of Functional Morphology and Kinesiology, 2*, 1-11.

Affatato, S. & Toni, A. (2000). Leg length measurement: A new method to assure the correct leg length in total hip arthroplasty. *Medical Engineering & Physics, 22*, 435-439.

Al-Hakim, W., Jaiswal, P.K., Khan, W. & Johnstone, D. (2012). The non-operative treatment of anterior knee pain. *The Open Orthopaedics Journal, 6,* 320-326.

Aliberti, S., Costa Mde, S., Passaro Ade, C., Arnone, A.C., Hirata, R. & Sacco, I.C. (2011). Influence of patellofemoral pain syndrome on plantar pressure in the foot rollover process during gait. *Clinics, 66*, 367-372.

Aliberti, S., Costa, M.S., Passaro, A.C., Arnone, A.C. & Sacco, I.C. (2010). Medial contact and smaller plantar loads characterize individuals with patellofemoral pain syndrome during stair descent. *Physical Therapy in Sport, 11*, 30-34.

Allseits, E., Kim, K.J., Bennett, C., Gailey, R., Gaunaurd, I. & Agrawal, V. (2018). A novel method for estimating knee angle using two leg-mounted gyroscopes for continuous monitoring with mobile health devices. *Sensors*, *18*, 1-17.

Almeida, G.P., Silva, A.P., Franca, F.J., Magalhaes, M.O., Burke, T.N. & Marques, A.P. (2016). Q-angle in patellofemoral pain: Relationship with dynamic knee valgus, hip abductor torque, pain and function. *Revista Brasileira De Ortopedia, 51*, 181-186.

Almeida, J.S., Filho, G.C., Pastre, C.M., Padovani, C.R. & Martins, R.A.D.M. (2009). Comparison of plantar pressure and musculoskeletal symptoms with the use of custom and prefabricated insoles in the work environment. *Brazilian Journal of Physical Therapy, 13*, 542-548.

Amis, A.A. (2007). Current concepts on anatomy and biomechanics of patellar stability. *Sports Medicine and Arthroscopy Review, 15*, 48-56.

Amis, A.A., Senavongse, W. & Bull, A.M. (2006). Patellofemoral kinematics during knee flexion-extension: An in vitro study. *Journal of Orthopaedic Research, 24*, 2201-2211.

Anderson, G. & Herrington, L. (2003). A comparison of eccentric isokinetic torque production and velocity of knee flexion angle during step down in patellofemoral pain syndrome patients and unaffected subjects. *Clinical Biomechanics, 18,* 500-504.

Andrish, J.T. (2015). Biomechanics of the patellofemoral joint. *Operative Techniques in Sports Medicine, 23,* 62-67.

Anloague, P.A. (2011). The effect of taping on patellar position as determined by video fluoroscopy in patients with PFPS: A pilot study. *Journal of Applied Research, 11*, 97-104.

Arazpour, M., Bahramian, F., Abutorabi, A., Nourbakhsh, S.T., Alidousti, A. & Aslani, H. (2016). The Effect of Patellofemoral Pain Syndrome on Gait Parameters: A Literature Review. *The Archives of Bone and Joint Surgery, 4,* 298-306.

Arroyo-Morales, M., Olea, N., Martinez, M., Moreno-Lorenzo, C., Diaz-Rodriguez, L. & Hidalgo-Lozano, A. (2008). Effects of myofascial release after high-intensity exercise: A randomized clinical trial. *Journal of Manipulative and Physiological Therapeutics, 31*, 217-223.

Austin, A.B., Souza, R.B., Meyer, J.L. & Powers, C.M. (2008a). Identification of abnormal hip motion associated with acetabular labral pathology. *The Journal of Orthopaedic and Sports Physical Therapy, 38,* 558-565.

Austin, M.S., Ghanem, E., Joshi, A., Trappler, R., Parvizi, J. & Hozack, W.J. (2008b). The assessment of intraoperative prosthetic knee range of motion using two methods. *The Journal of Arthroplasty, 23*, 515-521.

Bagwell, J.J., Fukuda, T.Y. & Powers, C.M. (2016). Sagittal plane pelvis motion influences transverse plane motion of the femur: Kinematic coupling at the hip joint. *Gait & Posture, 43*, 120-124.

Bandyopadhyay, A. & Mahapatra, D. (2012). Taping in sports: a brief update. *Journal of Human Sport & Exercise, 7*, 544-552.

Banerjee, A., Chitnis, U.B., Jadhav, S.L., Bhawalkar, J.S. & Chaudhury, S. (2009). Hypothesis testing, type I and type II errors. *Industrial Psychiatry Journal, 18,* 127-131.

Barber Foss, K.D., Myer, G.D., Chen, S.S. & Hewett, T.E. (2012). Expected prevalence from the differential diagnosis of anterior knee pain in adolescent female athletes during preparticipation screening. *Journal of Athletic Training, 47*, 519-524.

Barber-Westin, S.D., Noyes, F.R. & Galloway, M. (2006). Jump-land characteristics and muscle strength development in young athletes: A gender comparison of 1140 athletes 9 to 17 years of age. *The American Journal of Sports Medicine, 34*, 375-384.

Barton, C., Bonanno, D., Levinger, P. & Menz, H. (2010a). Determining the reliability and sensitivity of foot posture measures in individuals with patellofemoral pain syndrome. *The Journal of Orthopaedic and Sports Physical Therapy, 40,* A30.

Barton, C.J., Bonanno, D., Levinger, P. & Menz, H.B. (2010b). Foot and ankle characteristics in patellofemoral pain syndrome: A case control and reliability study. *The Journal of Orthopaedic and Sports Physical Therapy, 40,* 286-296.

Barton, C.J., Munteanu, S.E., Menz, H.B. & Crossley, K.M. (2010c). The efficacy of foot orthoses in the treatment of individuals with patellofemoral pain syndrome: A systematic review. *Sports Medicine, 40,* 377-395.

Barton, C.J., Levinger, P., Menz, H.B. & Webster, K.E. (2009). Kinematic gait characteristics associated with patellofemoral pain syndrome: A systematic review. *Gait & Posture, 30*, 405-416.

Beattie, P., Isaacson, K., Riddle, D.L. & Rothstein, J.M. (1990). Validity of derived measurements of leg-length differences obtained by use of a tape measure. *Physical Therapy, 70,* 150-157.

Bek, N., Kinikli, G.I., Callaghan, M.J. & Atay, O.A. (2011). Foot biomechanics and initial effects of infrapatellar strap on gait parameters in patients with unilateral patellofemoral pain syndrome. *Foot, 21*, 114-118.

Bellemans, J. (2003). Biomechanics of anterior knee pain. *The Knee, 10*, 123-126.

Bennett, D., Hanratty, B., Thompson, N. & Beverland, D. (2009). Measurement of knee joint motion using digital imaging. *International Orthopaedics, 33*, 1627-1631.

Berceanu, C., Marghitu, D.B., Gudavalli, M.R., Raju, P.K. & Vikas, Y. (2016). Gait analysis parameters of healthy human subjects with asymmetric loads. *Computer Methods in Biomechanics and Biomedical Engineering, 19,* 855-863.

Bergmann, J.H., Smith, I.C. & Mayagoitia, R.E. (2012). Using a body sensor network to measure the effect of fatigue on stair climbing performance. *Physiological Measurement, 33,* 287-296.

Bergmann, J.H.M., Anastasova-Ivanova, S., Spulber, I., Gulati, V., Georgiou, P. & McGregor, A. (2013). An attachable clothing sensor system for measuring knee joint angles. *IEEE Sensors Journal, 13*, 4090-4097.

Biedert, R.M. & Warnke, K. (2001). Correlation between the Q angle and the patella position: a clinical and axial computed tomography evaluation. *Archives of Orthopaedic and Trauma Surgery, 121*, 346-349.

Biggs, A. & Shelbourne, K.D. (2006). Use of knee extension device during rehabilitation of a patient with type 3 arthrofibrosis after ACL reconstruction. *North American Journal of Sports Physical Therapy, 1*, 124-131.

Birrer, R.B. & Poole, B. (2004). Taping of sports injuries: review of a basic skill: general principles, specifics for the ankle. *The Journal of Musculoskeletal Medicine, 21,* 197-211.

Bizzini, M., Childs, J.D., Piva, S.R. & Delitto, A. (2003). Systematic review of the quality of randomized controlled trials for patellofemoral pain syndrome. *The Journal of Orthopaedic and Sports Physical Therapy, 33*, 4-20.

Blalock, D., Miller, A., Tilley, M. & Wang, J. (2015). Joint instability and osteoarthritis. *Clinical Medicine Insights: Arthritis and Musculoskeletal Disorders, 8*, 15-23.

Bloom, N. & Cornbleet, S.L. (2014). Hip rotator strength in healthy young adults measured in hip flexion and extension by using a hand-held dynamometer. *The Journal of Injury, Function and Rehabilitation, 6,* 1137-1142.

Bolgla, L.A., Malone, T.R., Umberger, B.R. & Uhl, T.L. (2008). Hip strength and hip and knee kinematics during stair descent in females with and without patellofemoral pain syndrome. *The Journal of Orthopaedic and Sports Physical Therapy, 38*, 12-18.

Boling, M., Padua, D., Marshall, S., Guskiewicz, K., Pyne, S. & Beutler, A. (2010). Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scandinavian Journal of Medicine & Science in Sports, 20,* 725-730.

Boling, M.C., Padua, D.A., Marshall, S.W., Guskiewicz, K., Pyne, S. & Beutler, A. (2009). A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. *The American Journal of Sports Medicine, 37*, 2108-2116.

Bonacci, J., Hall, M., Fox, A., Saunders, N., Shipsides, T. & Vicenzino, B. (2018). The influence of cadence and shoes on patellofemoral joint kinetics in runners with patellofemoral pain. *Journal of Science and Medicine in Sport, 21*, 574-578.

Bonanno, D.R., Ledchumanasarma, K., Landorf, K.B., Munteanu, S.E., Murley, G.S. & Menz, H.B. (2019). Effects of a contoured foot orthosis and flat insole on plantar pressure and tibial acceleration while walking in defence boots. *Scientific Reports, 9*, 1-10.

Boonthathip, M., Chen, L., Trudell, D. & Resnick, D. (2011). Lateral ankle ligaments: MR arthrography with anatomic correlation in cadavers. *Clinical Imaging, 35,* 42-48.

Brantingham, J.W., Globe, G.A., Jensen, M.L., Cassa, T.K., Globe, D.R., Price, J.L., et al. (2009). A feasibility study comparing two chiropractic protocols in the treatment of patellofemoral pain syndrome. *Journal of Manipulative and Physiological Therapeutics, 32,* 536-548.

Brechter, J.H. & Powers, C.M. (2002). Patellofemoral stress during walking in persons with and without patellofemoral pain. *Medicine and Science in Sports and Exercise, 34,* 1582-1593.

Bremner, C.B., Girouard, T.J., Samuel, M.N., Turner, C.L., Santo, A.S. & Mercer, J.A. (2015). The acute effect of hip external rotator stretches on hip internal rotation range of motion. *International Journal of Exercise Science, 8,* 75-84.

Brockett, C.L. & Chapman, G.J. (2016). Biomechanics of the ankle. *Orthopaedics and Trauma, 30,* 232-238.

Brosseau, L., Tousignant, M., Budd, J., Chartier, N., Duciaume, L., Plamondon, S., et al. (1997). Intratester and intertester reliability and criterion validity of the parallelogram and universalgoniometers for active knee flexion in healthy subjects. *Physiotherapy Research International, 2,* 150-166.

Buist, I., Bredeweg, S.W., Lemmink, K.A., Pepping, G.J., Zwerver, J., van Mechelen, W., et al. (2007). The GRONORUN study: is a graded training program for novice runners effective in preventing running related injuries? Design of a randomized controlled trial. *BMC Musculoskeletal Disorders, 8,* 24.

Buldt, A.K., Allan, J.J., Landorf, K.B. & Menz, H.B. (2018). The relationship between foot posture and plantar pressure during walking in adults: A systematic review. *Gait & Posture, 62,* 56-67.

Butterworth, P.A., Urquhart, D.M., Landorf, K.B., Wluka, A.E., Cicuttini, F.M. & Menz, H.B. (2015). Foot posture, range of motion and plantar pressure characteristics in obese and non-obese individuals. *Gait & Posture, 41,* 465-469.

Cael, C. (2010). *Functional Anatomy Musculoskeletal Anatomy Kinesiology and Palpation for Manual Therapists.* China: Lippincott Williams & Wilkins.

Callaghan, M.J. & Selfe, J. (2007). Has the incidence or prevalence of patellofemoral pain in the general population in the United Kingdom been properly evaluated? *Physical Therapy in Sport, 8,* 37-43.

Callaghan, M.J., Selfe, J., McHenry, A. & Oldham, J.A. (2008). Effects of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. *Manual Therapy, 13,* 192-199.

Calpur, O.U., Ozcan, M., Gurbuz, H. & Turan, F.N. (2005). Full arthroscopic lateral retinacular release with hook knife and quadriceps pressure-pull test: long-term follow-up. *Knee Surgery, Sports Traumatology, Arthroscopy, 13,* 222-230.

Campolo, M., Babu, J., Dmochowska, K., Scariah, S. & Varughese, J. (2013). A comparison of two taping techniques (kinesio and mcconnell) and their effect on anterior knee pain during functional activities. *International Journal of Sports Physical Therapy, 8,* 105-110.

Cavanagh, P.R. & Rodgers, M.M. (1987). The arch index: a useful measure from footprints. *Journal of Biomechanics, 20*, 547-551.

Chaisena, P. (2013). Scenario of exercise, fundamental sports and mass sports in Thailand. *Silpakorn University Journal of Social Sciences, Humanities, and Arts, 13*, 63-73.

Chang, W., Chang, C., Lesch, M.F. & Matz, S. (2017). Gait adaptation on surfaces with different degrees of slipperiness. *Applied Ergonomics, 59*, 333-341.

Chas, J., Mariot, P., Tassart, M. & Pialoux, G. (2014). New aetiology of patellofemoral pain syndrome. *BMJ Case Reports, 2014*, 1-2.

Cheung, R.T.H., Ng, G.Y.F. & Chen, B.F.C. 2006). Association of footwear with patellofemoral pain syndrome in runners. *Sports Medicine, 36*, 199-205.

Chevidikunnan, M.F., Al Saif, A., Pai, H.K. & Mathias, L. (2015). Comparing goniometric and radiographic measurement of Q angle of the knee. *Asian Biomedicine, 9*, 631-636.

Chiang, C.Y., Chen, K.H., Liu, K.C., Hsu, S.J. & Chan, C.T. (2017). Data collection and analysis using wearable sensors for monitoring knee range of motion after total knee arthroplasty. *Sensors (Basel, Switzerland), 17*, 1-14.

Christou, E.A. (2004). Patellar taping increases vastus medialis oblique activity in the presence of patellofemoral pain. *Journal of Electromyography and Kinesiology, 14*, 495-504.

Cibulka, M.T. & Threlkeld-Watkins, J. (2005). Patellofemoral pain and asymmetrical hip rotation. *Physical Therapy, 85*, 1201-1207.

Clarkson, H.M. (2005). Knee. In P. Lappies (Ed.), *Joint motion and function assessment: A research-based practical guide* (pp. 187-189). London: Lippincott Williams & Wilkins.

Cleffken, B., van Breukelen, G., Brink, P., van Mameren, H. & Olde Damink, S. (2007). Digital goniometric measurement of knee joint motion. Evaluation of usefulness for research settings and clinical practice. *Knee, 14*, 385-389.

Clement, D.B., Taunton, J.E., Smart, G.W. & McNicol, K.L. (1981). A survey of overuse running injuries. *The Physician and Sportsmedicine, 9*, 47-58.

Clifford, A.M. & Harrington, E. (2013). The effect of patellar taping on squat depth and the perception of pain in people with anterior knee pain. *Journal of Human Kinetics, 37*, 109-117.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Erlbaum.

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, 62,* 17-24.

Costa, L.A.V., Mestriner, M.B., Amaral, T.A., Barbosa, B.S., Kaleka, C.C. & Cury, R.P.L. (2018). Histological study of the posterior cruciate ligament femoral insertion. *Revista Brasileira De Ortopedia, 53,* 415-420.

Cowan, S.M., Bennell, K.L., Crossley, K.M., Hodges, P.W. & McConnell, J. (2002a). Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. *Medicine and Science in Sports and Exercise, 34*, 1879-1885.

Cowan, S.M., Bennell, K.L. & Hodges, P.W. (2002b). Therapeutic patellar taping changes the timing of vasti muscle activation in people with patellofemoral pain syndrome. *Clinical Journal of Sport Medicine, 12,* 339-347.

Cowan, S.M., Bennell, K.L., Hodges, P.W., Crossley, K.M. & McConnell, J. (2001). Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Archives of Physical Medicine and Rehabilitation, 82*, 183-189.

Cowan, S.M., Hodges, P.W., Bennell, K.L. & Crossley, K.M. (2002). Altered vastii recruitment when people with patellofemoral pain syndrome complete a postural task. *Archives of Physical Medicine and Rehabilitation, 83,* 989-995.

Cowan, S.M., Hodges, P.W., Crossley, K.M. & Bennell, K.L. (2006). Patellar taping does not change the amplitude of electromyographic activity of the vasti in a stair stepping task. *British Journal of Sports Medicine, 40*, 30-34.

Cronin, J., Nash, M. & Whatman, C. (2006). Assessing dynamic knee joint range of motion using siliconcoach. *Physical Therapy in Sport, 7*, 191-194.

Crossley, K., Cowan, S.M., Bennell, K.L. & McConnell, J. (2000). Patellar taping: is clinical success supported by scientific evidence? *Manual Therapy, 5,* 142-150.

Crossley, K.M., Bennell, K.L., Cowan, S.M. & Green, S. (2004). Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Archives of Physical Medicine and Rehabilitation, 85,* 815-822.

Crossley, K.M., Callaghan, M.J. & van Linschoten, R. (2016). Patellofemoral pain. *British Journal of Sports Medicine, 50,* 247-250.

Crossley, K.M., Cowan, S.M., Bennell, K.L. & McConnell, J. (2004). Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. *Journal of Orthopaedic Research, 22,* 267-274.

Cunningham, C., Scheuer, L. & Black, S. (2016). The Lower Limb. In C. Cunningham, L. Scheuer & S. Black (Eds.), *Developmental Juvenile Osteology* (pp. 385-472). Elsevier Ltd.

Dahle, L.K., Mueller, M.J., Delitto, A. & Diamond, J.E. (1991). Visual assessment of foot type and relationship of foot type to lower extremity injury. *The Journal of Orthopaedic and Sports Physical Therapy, 14*, 70-74.

Davies, H., Unwin, A. & Aichroth, P. (2004). The posterolateral corner of the knee. Anatomy, biomechanics and management of injuries. *Injury, 35*, 68-75.

Dawe, E.J.C. & Davis, J. (2011). (vi) Anatomy and biomechanics of the foot and ankle. *Orthopaedics and Trauma, 25*, 279-286.

Dixit, S., DiFiori, J.P., Burton, M. & Mines, B. (2007). Management of patellofemoral pain syndrome. *American Family Physician, 75*, 194-202.

Dos Santos, R.A., Derhon, V., Brandalize, M., Brandalize, D. & Rossi, L.P. (2017). Evaluation of knee range of motion: Correlation between measurements using a universal goniometer and a smartphone goniometric application. *Journal of Bodywork and Movement Therapies, 21*, 699-703.

Dragoo, J.L. & Braun, H.J. (2010). The Effect of Playing Surface on Injury Rate. *Sports Medicine, 40*, 981-990.

Dragoo, J.L., Braun, H.J. & Harris, A.H. (2013). The effect of playing surface on the incidence of ACL injuries in National Collegiate Athletic Association American Football. *The Knee, 20*, 191-195.

Drew, M.K. & Purdam, C. (2016). Time to bin the term 'overuse' injury: is 'training load error' a more accurate term? *British Journal of Sports Medicine, 50*, 1423-1424.

Drouin, J.L., McAlpine, C.T., Primak, K.A. & Kissel, J. (2013). The effects of kinesiotape on athletic-based performance outcomes in healthy, active individuals: a literature synthesis. *The Journal of the Canadian Chiropractic Association, 57*, 356-365.

Dura, J.V., Hoyos, J.V., Martinez, A. & Lozano, L. (1999). The influence of friction on sports surfaces in turning movements. *Sports Engineering, 2*, 97-102.

Duval, K., Lam, T. & Sanderson, D. (2010). The mechanical relationship between the rearfoot, pelvis and low-back. *Gait & Posture, 32*, 637-640.

Ebeye, O.A., Abade, P.O. & Okwoka, B.O. (2014). Influence of gender on quadriceps (Q) angle among adult Urhobos in Nigeria population. *Journal of Experimental and Clinical Anatomy, 13*, 50-53.

Edwards, J.Z., Greene, K.A., Davis, R.S., Kovacik, M.W., Noe, D.A. & Askew, M.J. (2004). Measuring flexion in knee arthroplasty patients. *The Journal of Arthroplasty, 19*, 369-372.

Ekstrand, J., Timpka, T. & Hagglund, M. (2006). Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *British Journal of Sports Medicine, 40*, 975-980.

Eichelberger, P., Blasimann, A., Lutz, N., Krause, F. & Baur, H. (2018). A minimal markerset for three-dimensional foot function assessment: measuring navicular drop and drift under dynamic conditions. *Journal of Foot and Ankle Research, 1*.

Ellapen, T.J., Satyendra, S., Morris, J. & van Heerden, H.J. (2013). Common running musculoskeletal injuries among recreational half-marathon runners in KwaZulu-Natal. *South African Journal of Sports Medicine, 25*, 39-43.

Ellenbogen, R.G., Sekhar, L.N. & Kitchen, N. (2018). Principle of neurological surgery (4th ed.). London: Elsevier.

Emami, M.J., Ghahramani, M.H., Abdinejad, F. & Namazi, H. (2007). Q-angle: An invaluable parameter for evaluation of anterior knee pain. *Archives of Iranian Medicine, 10*, 24-36.

Erkocak, O.F., Altan, E., Altintas, M., Turkmen, F., Aydin, B.K. & Bayar, A. (2016). Lower extremity rotational deformities and patellofemoral alignment parameters in patients with anterior knee pain. *Knee Surgery, Sports Traumatology, Arthroscopy, 24*, 3011-3020.

Esculier, J.F., Roy, J.S. & Bouyer, L.J. (2013). Psychometric evidence of self-reported questionnaires for patellofemoral pain syndrome: a systematic review. *Disability and Rehabilitation, 35*, 2181-2190.

Fanchiang, H.D., Geil, M.D., Wu, J., Ajisafe, T. & Chen, Y.P. (2016). The effects of walking surface on the gait pattern of children with idiopathic toe walking. *Journal of Child Neurology, 31*, 858-863.

Faul, F., Erdfelder, E., Buchner, A. & Lang, A.G. (2009). Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behavior Research Methods, 41*, 1149-1160.

Faul, F., Erdfelder, E., Lang, A.G. & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175-191.

Feldhege, F., Mau-Moeller, A., Lindner, T., Hein, A., Markschies, A., Zettl, U.K., et al. (2015). Accuracy of a custom physical activity and knee angle measurement sensor system for patients with neuromuscular disorders and gait abnormalities. *Sensors, 15*, 10734-10752.

Flandry, F. & Hommel, G. (2011). Normal anatomy and biomechanics of the knee. *Sports Medicine and Arthroscopy Review, 19*, 82-92.

Franklyn-Miller, A., Bilzon, J., Wilson, C. & McCrory, P. (2014). Can RSScan footscan((R)) D3D software predict injury in a military population following plantar pressure assessment? A prospective cohort study. *Foot, 24*, 6-10.

Fredericson, M. & Powers, C.M. (2002). Practical management of patellofemoral pain. *Clinical Journal of Sport Medicine, 12*, 36-38.

Fredericson, M. & Yoon, K. (2006). Physical examination and patellofemoral pain syndrome. *American Journal of Physical Medicine & Rehabilitation, 85*, 234-243.

Freedman, B.R., Brindle, T.J. & Sheehan, F.T. (2014). Re-evaluating the functional implications of the Q-angle and its relationship to in-vivo patellofemoral kinematics. *Clinical Biomechanics, 29,* 1139-1145.

Fulkerson, J.P. (2002). Diagnosis and treatment of patients with patellofemoral pain. *The American Journal of Sports Medicine, 30,* 447-456.

Ghoussayni, S., Stevens, C., Durham, S. & Ewins, D. (2004). Assessment and validation of a simple automated method for the detection of gait events and intervals. *Gait & Posture, 20*, 266-272.

Glaviano, N.R., Kew, M., Hart, J.M. & Saliba, S. (2015). Demographic and epidemiological trends in patellofemoral pain. *International Journal of Sports Physical Therapy, 10,* 281-290.

Golano, P., Vega, J., de Leeuw, P.A.J., Malagelada, F., Manzanares, M.C., Gotzens, V., et al. (2016). Anatomy of the ankle ligaments: a pictorial essay. *Knee Surgery, Sports Traumatology, Arthroscopy, 24*, 944-956.

Goldblatt, J.P. & Richmond, J.C. (2003). Anatomy and biomechanics of the knee. *Operative Techniques in Sports Medicine, 11*, 172-186.

Goss, D.L., Lewek, M., Yu, B., Ware, W.B., Teyhen, D.S. & Gross, M.T. (2015). Lower extremity biomechanics and self-reported foot-strike patterns among runners in traditional and minimalist shoes. *Journal of Athletic Training*

Grabiner, M.D., Koh, T.J. & Draganich, L.F. (1994). Neuromechanics of the patellofemoral joint. *Medicine and Science in Sports and Exercise, 26*, 10-21.

Groth, A.T., Guyton, G.P. & Schon, L.C. (2010). Lateral ankle ligament injuries in athletes: diagnosis and treatment. *Operative Techniques in Sports Medicine, 18,* 18-26.

Hadizadeh, M., Amri, S., Mohafez, H., Roohi, S.A. & Mokhtar, A.H. (2016). Gait analysis of national athletes after anterior cruciate ligament reconstruction following three stages of rehabilitation program: Symmetrical perspective. *Gait & Posture, 48*, 152-158.

Hafer, J.F., Brown, A.M., deMille, P., Hillstrom, H.J. & Garber, C.E. (2015). The effect of a cadence retraining protocol on running biomechanics and efficiency: a pilot study. *Journal of Sports Sciences, 33*, 724-731.

Haim, A., Yaniv, M., Dekel, S. & Amir, H. (2006). Patellofemoral pain syndrome: validity of clinical and radiological features. *Clinical Orthopaedics and Related Research, 451*, 223-228.

Halabchi, F., Abolhasani, M., Mirshahi, M. & Alizadeh, Z. (2017). Patellofemoral pain in athletes: clinical perspectives. *Open Access Journal of Sports Medicine, 8*, 189-203.

Halabchi, F., Mazaheri, R. & Seif-Barghi, T. (2013). Patellofemoral pain syndrome and modifiable intrinsic risk factors; how to assess and address? *Asian Journal of Sports Medicine, 4*, 85-100.

Hallaceli, H., Uruc, V., Uysal, H.H., Ozden, R., Hallaceli, C., Soyuer, F., et al. (2014). Normal hip, knee and ankle range of motion in the Turkish population. *Acta Orthopaedica Et Traumatologica Turcica, 48*, 37-42.

Hancock, G.E., Hepworth, T. & Wembridge, K. (2018). Accuracy and reliability of knee goniometry methods. *Journal of Experimental Orthopaedics, 5*.

Hang, B. (2013). Acute sports-related lower extremity injuries. *Clinical Pediatric Emergency Medicine, 14*, 304-317.

Harmer, A.R., Naylor, J.M., Crosbie, J. & Russell, T. (2009). Land-based versus water-based rehabilitation following total knee replacement: a randomized, single-blind trial. *Arthritis and Rheumatism, 61*, 184-191.

Harshitha, M., Senthil Kumar, K. & Madhavi, K. (2014). Effects of kinesiotaping along with quadriceps strengthening exercises on pain, joint range of motion and functional activities of knee in subjects with patellofemoral osteoarthritis. *International Journal of Physiotherapy, 1*, 135-143.

Hattam, P. & Smeatham, A. (2010). CHAPTER 6 - KNEE. In P. Hattam & A. Smeatham (Eds.), *Special Tests in Musculoskeletal Examination* (pp. 181-234). Edinburgh: Churchill Livingstone.

Heiderscheit, B.C., Chumanov, E.S., Michalski, M.P., Wille, C.M. & Ryan, M.B. (2011). Effects of step rate manipulation on joint mechanics during running. *Medicine and Science in Sports and Exercise, 43*, 296-302.

Herrington, L. (2013a). Does the change in Q angle magnitude in unilateral stance differ when comparing asymptomatic individuals to those with patellofemoral pain? *Physical Therapy in Sport, 14*, 94-97.

Herrington, L. (2013b). Effect of a SERF strap on pain and knee-valgus angle during unilateral squat and step landing in patellofemoral patients. *Journal of Sport Rehabilitation, 22*, 27-32.

Herrington, L. & Payton, C. (1997). Effects of corrective taping of the patella on patients with patellofemoral pain. *Physiotherapy, 83,* 566-572.

Herrmann, D.B. (1990). Validity study of head and neck flexion-extension motion comparing measurements of a pendulum goniometer and roentgenograms. *The Journal of Orthopaedic and Sports Physical Therapy, 11,* 414-418.

Hertel, J., Dorfman, J.H. & Braham, R.A. (2004). Lower extremity malalignments and anterior cruciate ligament injury history. *Journal of Sports Science & Medicine, 3,* 220-225.

Hespanhol Junior, L.C., Pena Costa, L.O. & Lopes, A.D. (2013). Previous injuries and some training characteristics predict running-related injuries in recreational runners: a prospective cohort study. *Journal of Physiotherapy, 59,* 263-269.

Hills, A.P., Andersen, L.B. & Byrne, N.M. (2011). Physical activity and obesity in children. *British Journal of Sports Medicine, 45,* 866-870.

Hinman, R.S., Bennell, K.L., Crossley, K.M. & McConnell, J. (2003). Immediate effects of adhesive tape on pain and disability in individuals with knee osteoarthritis. *Rheumatology, 42*, 865-869.

Hirata, I., Nakamoto, H., O otaka, H., Tada, M. (2015). The flexible interface using a stretch sensor. *Procedia Manufacturing, 3,* 845-849.

Ho, I.J., Hou, Y.Y., Yang, C.H., Wu, W.L., Chen, S.K. & Guo, L.Y. (2010). Comparison of plantar pressure distribution between different speed and incline during treadmill jogging. *Journal of Sports Science & Medicine, 9*, 154-160.

Hobara, H., Sato, T., Sakaguchi, M., Sato, T. & Nakazawa, K. (2012). Step frequency and lower extremity loading during running. *International Journal of Sports Medicine, 33,* 310-313.

Hollman, J.H., McDade, E.M. & Petersen, R.C. (2011). Normative spatiotemporal gait parameters in older adults. *Gait & Posture, 34,* 111-118.

Horton, M.G. & Hall, T.L. (1989). Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures. *Physical Therapy, 69*, 897-901.

Hryvniak, D., Magrum, E. & Wilder, R. (2014). Patellofemoral pain syndrome: An update. *Current Physical Medicine and Rehabilitation Reports, 2,* 16-24.

Huang, B., Li, M., Mei, T., McCoul, D., Qin, S., Zhao, Z., et al. (2017). Wearable stretch sensors for motion measurement of the wrist joint based on dielectric elastomers. *Sensors, 17*, 1-12.

Huang, Y.C., Wang, L.Y., Wang, H.C., Chang, K.L. & Leong, C.P. (2004). The relationship between the flexible flatfoot and plantar fasciitis: ultrasonographic evaluation. *Chang Gung Medical Journal, 27*, 443-448.

Ireland, M.L., Willson, J.D., Ballantyne, B.T. & Davis, I.M. (2003). Hip strength in females with and without patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 33*, 671-676.

Isakov, E., Burger, H., Krajnik, J., Gregoric, M. & Marincek, C. (1996). Influence of speed on gait parameters and on symmetry in trans-tibial amputees. *Prosthetics and Orthotics International, 20*, 153-158.

Item-Glatthorn, J.F. & Maffiuletti, N.A. (2014). Clinical assessment of spatiotemporal gait parameters in patients and older adults. *Journal of Visualized Experiments, 93, 1-6.*

Jaiyesimi, A.O. & Jegede, O.O. (2009). Influence of gender and leg dominance on Q-angle among young adult Nigerians. *African Journal of Physiotherapy and Rehabilitation Sciences, 1*, 18-23.

Jakobsen, M.D., Sundstrup, E., Andersen, C.H., Aagaard, P. & Andersen, L.L. (2013). Muscle activity during leg strengthening exercise using free weights and elastic resistance: Effects of ballistic vs controlled contractions. *Human Movement Science, 32*, 65-78.

Jenkins, S. (2005). *Sports Science Handbook: Volume 1: The Essential Guide to Kinesiology, Sport & Exercise Science,* 1 edn. Essex: Multi-Science Publishing Co. Ltd.

Jones, B.H., Cowan, D.N. & Knapik, J.J. (1994). Exercise, training and injuries. *Sports Medicine, 18,* 202-214.

Kaya, D. & Doral, M.N. (2012). Is there any relationship between Q-angle and lower extremity malalignment? *Acta Orthopaedica Et Traumatologica Turcica, 46*, 416-419.

Keet, J.H.L., Gray, J., Harley, Y. & Lambert, M.I. (2007). The effect of medial patellar taping on pain, strength and neuromuscular recruitment in subjects with and without patellofemoral pain. *Physiotherapy, 93,* 45-52.

Khamis, S. & Yizhar, Z. (2007). Effect of feet hyperpronation on pelvic alignment in a standing position. *Gait & Posture, 25,* 127-134.

Khuman, R., Devi, S., Vaiyapuri, A., Kamlesh, T., Satani, K. & Nambi, G. (2012). Patello femoral pain syndrome: A comparative study of mobilization versus taping. *International Journal of Pharmaceutical Science and Health Care, 6,* 89-96.

Kievit, A.J., Breugem, S.J., Sierevelt, I.N., Heesterbeek, P.J., van de Groes, S.A., Kremers, K.C., et al. (2013). Dutch translation of the Kujala Anterior Knee Pain Scale and validation in patients after knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy, 21*, 2647-2653.

Kimmeskamp, S. & Hennig, E.M. (2001). Heel to toe motion characteristics in Parkinson patients during free walking. *Clinical Biomechanics, 16,* 806-812.

Koh, D.H., Lee, J.D. & Kim, K. (2015). Plantar pressures in individuals with normal and pronated feet according to static squat depths. *Journal of Physical Therapy Science, 27,* 2833-2835.

Komdeur, P., Pollo, F.E. & Jackson, R.W. (2002). Dynamic knee motion in anterior cruciate impairment: a report and case study. *Proceedings (Baylor University.Medical Center), 15,* 257-259.

Kowall, M.G., Kolk, G., Nuber, G.W., Cassisi, J.E. & Stern, S.H. (1996). Patellar taping in the treatment of patellofemoral pain. A prospective randomized study. *The American Journal of Sports Medicine, 24,* 61-66.

Kujala, U.M., Jaakkola, L.H., Koskinen, S.K., Taimela, S., Hurme, M. & Nelimarkka, O. (1993). Scoring of patellofemoral disorders. *Arthroscopy, 9,* 159-163.

Kumar, Y., Yen, S.C., Tay, A., Lee, W., Gao, F., Zhao, Z., et al. (2015). Wireless wearable range-of-motion sensor system for upper and lower extremity joints: a validation study. *Healthcare Technology Letters, 2,* 12-17.

Kwon, O., Yun, M. & Lee, W. (2014). Correlation between Intrinsic Patellofemoral Pain Syndrome in Young Adults and Lower Extremity Biomechanics. *Journal of Physical Therapy Science, 26,* 961-964.

Labotz, M. (2004). Patellofemoral syndrome: diagnostic pointers and individualized treatment. *The Physician and Sportsmedicine, 32,* 22-29.

Lack, S., Barton, C., Vicenzino, B. & Morrissey, D. (2014). Outcome predictors for conservative patellofemoral pain management: a systematic review and meta-analysis. *Sports Medicine, 44,* 1703-1716.

Landorf, K.B. & Keenan, A.M. (2000). Efficacy of foot orthoses. What does the literature tell us? *Journal of the American Podiatric Medical Association, 90,* 149-158.

Lankhorst, N.E., Bierma-Zeinstra, S.M. & van Middelkoop, M. (2013). Factors associated with patellofemoral pain syndrome: a systematic review. *British Journal of Sports Medicine, 47,* 193-206.

Lankhorst, N.E., Bierma-Zeinstra, S.M. & van Middelkoop, M. (2012). Risk factors for patellofemoral pain syndrome: a systematic review. *The Journal of Orthopaedic and Sports Physical Therapy, 42,* 81-94.

LaPrade, R.F., Engebretsen, A.H., Ly, T.V., Johansen, S., Wentorf, F.A. & Engebretsen, L. (2007). The anatomy of the medial part of the knee. *The Journal of Bone and Joint Surgery.American Volume, 89,* 2000-2010.

Larsen, B., Andreasen, E., Urfer, A., Mickelson, M.R. & Newhouse, K.E. (1995). Patellar taping: a radiographic examination of the medial glide technique. *The American Journal of Sports Medicine, 23*, 465-471.

Lee, J., Lee, H. & Lee, W. (2014). Effect of weight-bearing therapeutic exercise on the Q-angle and muscle activity onset times of elite athletes with patellofemoral pain syndrome: A randomized controlled trial. *Journal of Physical Therapy Science, 26*, 989-992.

Lee, J., Yoon, J. & Cynn, H. (2017). Foot exercise and taping in patients with patellofemoral pain and pronated foot. *Journal of Bodywork and Movement Therapies, 21*, 216-222.

Lee, S. I., et al. (2016). A novel flexible wearable sensor for estimating joint-angles. *2016 IEEE 13th International Conference on Wearable and Implantable Body Sensor Networks*, 377-382.

Lee, T.Q., Morris, G. & Csintalan, R.P. (2003). The influence of tibial and femoral rotation on patellofemoral contact area and pressure. *The Journal of Orthopaedic and Sports Physical Therapy, 33*, 686-693.

Leetun, D.T., Ireland, M.L., Willson, J.D., Ballantyne, B.T. & Davis, I.M. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine and Science in Sports and Exercise, 36*, 926-934.

Lenssen, A.F., van Dam, E.M., Crijns, Y.H., Verhey, M., Geesink, R.J., van den Brandt, P.A., et al. (2007). Reproducibility of goniometric measurement of the knee in the in-hospital phase following total knee arthroplasty. *BMC Musculoskeletal Disorders, 8*, 83-2474-8-83.

Leporace, G., Metsavaht, L., Zeitoune, G., Marinho, T., Oliveira, T., Pereira, G.R., et al. (2016). Use of spatiotemporal gait parameters to determine return to sports after acl reconstruction. *Acta Ortopedica Brasileira, 24*, 73-76.

Levinger, P. & Gilleard, W. (2007). Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. *Gait & Posture, 25*, 2-8.

Liporaci, R.F., Saad, M.C., Felicio, L.R., Baffa Ado, P. & Grossi, D.B. (2013). Contribution of the evaluation of the clinical signals in patients with patellofemoral pain syndrome. *Acta Ortopedica Brasileira, 21*, 198-201.

Lotscher, P. & Hintermann, B. (2014). Medial ankle ligament injuries in athletes. *Operative Techniques in Sports Medicine, 22*, 290-295.

Loudon, J.K. (2016). Biomechanics and pathomechanics of the patellofemoral joint. *International Journal of Sports Physical Therapy, 11*, 820-830.

Lowry, C.D., Cleland, J.A. & Dyke, K. (2008). Management of patients with patellofemoral pain syndrome using a multimodal approach: a case series. *The Journal of Orthopaedic and Sports Physical Therapy, 38,* 691-702.

Makris, E.A., Hadidi, P. & Athanasiou, K.A. (2011). The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. *Biomaterials, 32*, 7411-7431.

Mall, N.A., Lee, A.S., Cole, B.J. & Verma, N.N. (2013). The functional and surgical anatomy of the anterior cruciate ligament. *Operative Techniques in Sports Medicine, 21*, 2-9.

Manske, R.C. & Davies, G.J. (2016). Examination of the patellofemoral joint. *The International Journal of Sports Physical Therapy, 11*, 831-853.

McCormick, C.J., Bonanna, D.R. & Landorf, K.B. (2013). The effect of customised and sham foot orthoses on plantar pressures. *Journal of Foot and Ankle Research, 6*.

McGinnis, R. S., et al. (2016). Skin mounted accelerometer system for measuring knee range of motion. *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 5298-5302.

McKenzie, K., Galea, V., Wessel, J. & Pierrynowski, M. (2010). Lower extremity kinematics of females with patellofemoral pain syndrome while stair stepping. *The Journal of Orthopaedic and Sports Physical Therapy, 40*, 625-632.

Meinel, K. (2008). General aspects of planning. In AAF track and field facilities manual editorial board (Ed.), *IAAF Track and Field Facilities Manual* (pp. 11-25). Monaco: Editions EGC.

Meira, E.P. & Brumitt, J. (2011). Influence of the hip on patients with patellofemoral pain syndrome: a systematic review. *Sports Health, 3*, 455-465.

Menant, J.C., Steele, J.R., Menz, H.B., Munro, B.J. & Lord, S.R. (2009). Effects of walking surfaces and footwear on temporo-spatial gait parameters in young and older people. *Gait & Posture, 29*, 392-397.

Menz, H.B., Fotoohabadi, M.R., Wee, E. & Spink, M.J. (2012). Visual categorisation of the arch index: a simplified measure of foot posture in older people. *Journal of Foot and Ankle Research, 5*, 1-7.

Menz, H.B., Tiedemann, A., Kwan, M.M., Latt, M.D., Sherrington, C. & Lord, S.R. (2003). Reliability of clinical tests of foot and ankle characteristics in older people. *Journal of the American Podiatric Medical Association, 93*, 380-387.

Mook, W.R., Miller, M.D., Diduch, D.R., Hertel, J., Boachie-Adjei, Y. & Hart, J.M. (2009). Multiple-ligament knee injuries: a systematic review of the timing of operative intervention and postoperative rehabilitation. *The Journal of Bone and Joint Surgery, 91*, 2946-2957.

Mostamand, J., Bader, D.L. & Hudson, Z. (2012). Reliability testing of the patellofemoral joint reaction force (PFJRF) measurement during double-legged squatting in healthy subjects: a pilot study. *Journal of Bodywork and Movement Therapies, 16,* 217-223.

Mullaney, M.J. & Fukunaga, T. (2016). Current Concepts and Treatment of Patellofemoral Compressive Issues. *International Journal of Sports Physical Therapy, 11*, 891-902.

Murphy, D.F., Connolly, D.A. & Beynnon, B.D. (2003). Risk factors for lower extremity injury: a review of the literature. *British Journal of Sports Medicine, 37*, 13-29.

Myer, G.D., Barber Foss, K.D., Gupta, R., Hewett, T.E. & Ittenbach, R.F. (2016). Analysis of patient-reported anterior knee pain scale: implications for scale development in children and adolescents. *Knee Surgery, Sports Traumatology, Arthroscopy, 24,* 653-660.

Myer, G.D., Ford, K.R., Barber Foss, K.D., Goodman, A., Ceasar, A., Rauh, M.J., et al. (2010). The incidence and potential pathomechanics of patellofemoral pain in female athletes. *Clinical Biomechanics, 25*, 700-707.

Nadeau, S., Gravel, D., Hébert, L.J., Arsenault, A.B. & Lepage, Y. (1997). Gait study of patients with patellofemoral pain syndrome. *Gait & Posture, 5*, 21-27.

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, 22,* 105-118.

National Statistical Office Ministry of Information and Communication Technology (2012). Survey on Population Behavior in Playing Sport Or Physical Exercise and Mental Health, 2011. Retrieved from http://service.nso.go.th/nso/nsopublish/themes/files/exerFull54.pdf. Last accessed: 22 Oct 2018.

Naylor, J.M., Ko, V., Adie, S., Gaskin, C., Walker, R., Harris, I.A., et al. (2011). Validity and reliability of using photography for measuring knee range of motion: a methodological study. *BMC Musculoskeletal Disorders, 12,* 1-10.

Nejati, P., Forogh, B., Moeineddin, R., Baradaran, H.R. & Nejati, M. (2011). Patellofemoral pain syndrome in Iranian female athletes. *Acta Medica Iranica, 49*, 169-172.

Nielsen, R.O., Nohr, E.A., Rasmussen, S. & Sorensen, H. (2013). Classifying running-related injuries based upon etiology, with emphasis on volume and pace. *International Journal of Sports Physical Therapy, 8*, 172-179.

Noehren, B., Pohl, M.B., Sanchez, Z., Cunningham, T. & Lattermann, C. (2012). Proximal and distal kinematics in female runners with patellofemoral pain. *Clinical Biomechanics, 27,* 366-371.

Nordin, M. and Frankel, V. H. (2001). *Basic Biomechanics of the Musculoskeletal System*. 3rd edn. London: Lippincott Williams & Wilkins.

Nyland, J.A., Ullery, L.R. & Caborn, D.N. (2002). Medial patellar taping changes the peak plantar force location and timing of female basketball players. *Gait & Posture, 15*, 146-152.

Oakes, E.H. (2005). *The Encyclopedia of Sports Medicine.* New York: Facts On File.

O'Brien, D.L. & Tyndyk, M. (2014). Effect of arch type and body mass index on plantar pressure distribution during stance phase of gait. *Acta of Bioengineering and Biomechanics, 16*, 131-135.

Ogundimu, E.O., Altman, D.G. & Collins, G.S. (2016). Adequate sample size for developing prediction models is not simply related to events per variable. *Journal of Clinical Epidemiology, 76*, 175-182.

Pal, S., Draper, C.E., Fredericson, M., Gold, G.E., Delp, S.L., Beaupre, G.S., et al. (2011). Patellar maltracking correlates with vastus medialis activation delay in patellofemoral pain patients. *The American Journal of Sports Medicine, 39*, 590-598.

Papi, E., Bo, Y.N. & McGregor, A.H. (2018). A flexible wearable sensor for knee flexion assessment during gait. *Gait & Posture, 62*, 480-483.

Pappas, E. & Wong-Tom, W.M. (2012). Prospective predictors of patellofemoral pain syndrome: A systematic review with meta-analysis. *Sports Health, 4*, 115-120.

Park, S.-. & Stefanyshyn, D.J. (2011). Greater Q angle may not be a risk factor of patellofemoral pain syndrome. *Clinical Biomechanics, 26*, 392-396.

Parreira Pdo, C., Costa Lda, C., Takahashi, R., Hespanhol Junior, L.C., Luz Junior, M.A., Silva, T.M., et al. (2014). Kinesio taping to generate skin convolutions is not better than sham taping for people with chronic non-specific low back pain: a randomised trial. *Journal of Physiotherapy, 60*, 90-96.

Pasanen, K., Parkkari, J., Rossi, L. & Kannus, P. (2008). Artificial playing surface increases the injury risk in pivoting indoor sports: a prospective one-season follow-up study in Finnish female floorball. *British Journal of Sports Medicine, 42*, 194-197.

Pau, M., Leban, B., Collu, G. & Migliaccio, G.M. (2014). Effect of light and vigorous physical activity on balance and gait of older adults. *Archives of Gerontology and Geriatrics, 59*, 568-573.

Pearse, M.F., Harry, L. & Nanchahal, J. (2002). Acute compartment syndrome of the leg: Fasciotomies must be performed early, but good surgical technique is important. *British Medical Journal, 325*, 557-558.

Pechar, J. & Lyons, M.M. (2016). Acute compartment syndrome of the lower leg: A review. *The Journal for Nurse Practitioners, 12,* 265-270.

Perttunen, J.R., Anttila, E., Sodergard, J., Merikanto, J. & Komi, P.V. (2004). Gait asymmetry in patients with limb length discrepancy. *Scandinavian Journal of Medicine & Science in Sports, 14,* 49-56.

Peters, P.G., Herbenick, M.A., Anloague, P.A., Markert, R.J. & Rubino, L.J.3. (2011). Knee range of motion: reliability and agreement of 3 measurement methods. *American Journal of Orthopedics, 40,* 249-252.

Petersen, W., Ellermann, A., Gosele-Koppenburg, A., Best, R., Rembitzki, I.V., Bruggemann, G.P., et al. (2014). Patellofemoral pain syndrome. *Knee Surgery, Sports Traumatology, Arthroscopy, 22,* 2264-2274.

Peterson, L. & Renstrom, P. (2005). *Sports injuries: Their prevention and treatment*, 3rd edn. United Kingdom: Martin Dunitz.

Pfeil, J. & Siebert, W.E. (2010). Anatomy of the hip joint. In J. Pfeil (Ed.), *Minimally invasive surgery in total hip arthroplasty* (pp. 9-10). Berlin: Springer.

Phillips, A., Goubran, A., Naim, S., Searle, D., Mandalia, V. & Toms, A. (2012). Reliability of radiographic measurements of knee motion following knee arthroplasty for use in a virtual knee clinic. *Annals of the Royal College of Surgeons of England, 94,* 506-512.

Phillips, J. & Coetsee, M.F. (2007). Incidence of non-traumatic anterior knee pain among 11 - 17-years-olds. *South African Journal of Sports Medicine, 19,* 60-64.

Pinshaw, R., Atlas, V. & Noakes, T.D. (1984). The nature and response to therapy of 196 consecutive injuries seen at a runners' clinic. *South African Medical Journal, 65,* 291-298.

Pinto, R.Z., Souza, T.R., Trede, R.G., Kirkwood, R.N., Figueiredo, E.M. & Fonseca, S.T. (2008). Bilateral and unilateral increases in calcaneal eversion affect pelvic alignment in standing position. *Manual Therapy, 13,* 513-519.

Piva, S.R., Fitzgerald, K., Irrgang, J.J., Jones, S., Hando, B.R., Browder, D.A., et al. (2006). Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskeletal Disorders, 7.*

Pope, M.H., Bevins, T., Wilder, D.G. & Frymoyer, J.W. (1985). The relationship between anthropometric, postural, muscular, and mobility characteristics of males ages 18-55. *Spine, 10,* 644-648.

Powers, C.M. (2010). The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *The Journal of Orthopaedic and Sports Physical Therapy, 40,* 42-51.

Powers, C.M. (2003). The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *The Journal of Orthopaedic and Sports Physical Therapy, 33*, 639-646.

Powers, C.M., Chen, P.Y., Reischl, S.F. & Perry, J. (2002). Comparison of foot pronation and lower extremity rotation in persons with and without patellofemoral pain. *Foot & Ankle International, 23*, 634-640.

Powers, C.M., Landel, R., Sosnick, T., Kirby, J., Mengel, K., Cheney, A., et al. (1997). The effects of patellar taping on stride characteristics and joint motion in subjects with patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 26*, 286-291.

Rabin, A., Kozol, Z., Moran, U., Efergan, A., Geffen, Y. & Finestone, A.S. (2014). Factors associated with visually assessed quality of movement during a lateral step-down test among individuals with patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 44*, 937-946.

Ranawat, A.S. & Kelly, B.T. (2005). Anatomy of the hip: Open and arthroscopic structure and function. *Operative Techniques in Orthopaedics, 15*, 160-174.

Rathleff, M.S., Richter, C., Brushoj, C., Bencke, J., Bandholm, T., Holmich, P., et al. (2014). Increased medial foot loading during drop jump in subjects with patellofemoral pain. *Knee Surgery, Sports Traumatology, Arthroscopy, 22*, 2301-2307.

Redmond, A.C., Crane, Y.Z. & Menz, H.B. (2008). Normative values for the foot posture index. *Journal of Foot and Ankle Research, 1*, 6-1146-1-6.

Reischl, S.F., Powers, C.M., Rao, S. & Perry, J. (1999). Relationship between foot pronation and rotation of the tibia and femur during walking. *Foot & Ankle International, 20*, 513-520.

Remigio, W., Tsai, N., Layos, L. & Chavez, M. (2017). Inter-rater and intra-rater reliability of the fluid goniometer for measuring active knee flexion in painful knees; correlations do not mean agreement. *Journal of Physical Therapy Science, 29*, 984-988.

Ritter, M.A., Harty, L.D., Davis, K.E., Meding, J.B. & Berend, M.E. (2003). Predicting range of motion after total knee arthroplasty. Clustering, log-linear regression, and regression tree analysis. *The Journal of Bone and Joint Surgery, 85-A*, 1278-1285.

Rivera, J.E. (1994). Open versus closed kinetic chain rehabilitation of the lower extremity: A functional and biomechanical analysis. *Journal of Sport Rehabilitation, 3*, 154-167.

Roberts, J.M. & Wilson, K. (1999). Effect of stretching duration on active and passive range of motion in the lower extremity. *British Journal of Sports Medicine, 33*, 259-263.

Robinson, R.L. & Nee, R.J. (2007). Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. *The Journal of Orthopaedic and Sports Physical Therapy, 37,* 232-238.

Roper, J.L., Harding, E.M., Doerfler, D., Dexter, J.G., Kravitz, L., Dufek, J.S., et al. (2016). The effects of gait retraining in runners with patellofemoral pain: A randomized trial. *Clinical Biomechanics, 35*, 14-22.

Roush, J.R. & Bay, R.C. (2012). Prevalence of anterior knee pain in 18-35 year-old females. *International Journal of Sports Physical Therapy, 7*, 396-401.

Saggio, G., Quitadamo, L.R. & Albero, L. (2014). Development and evaluation of a novel low-cost sensor-based knee flexion angle measurement system. *The Knee, 21,* 896-901.

Sakunkaruna, S., Sakunkaruna, Y. & Sakulsriprasert, P. (2015). Thai version of the Kujala Patellofemoral Questionnaire in knee pain patients: Cross-cultural validation and test-retest reliability. *Journal of the Medical Association of Thailand, 98,* 81-85.

Salsich, G.B., Brechter, J.H., Farwell, D. & Powers, C.M. (2002). The effects of patellar taping on knee kinetics, kinematics, and vastus lateralis muscle activity during stair ambulation in individuals with patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 32,* 3-10.

Salsich, G.B. & Perman, W.H. (2007). Patellofemoral joint contact area is influenced by tibiofemoral rotation alignment in individuals who have patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 37*, 521-528.

Sanchis-Alfonso, V., Ordoño, F., Subías-López, A. & Monserrat, C. (2006). Pathogenesis of anterior knee pain and patellar instability in the active young. In V. Sanchis-Alfonso (Ed.), *Anterior Knee Pain and Patellar Instability* (pp. 21-31). London: Springer

Santos, J.O.L, Manfio, E.F., Carpes, F.P, Bezerra, E.S, Palhano, R. & Avila, A.O.V. (2017). Change of pronation angle of the subtalar joint has influence on plantar pressure distribution. *Brazilian Journal of Kinanthropometry and Human Performance, 19,* 316-322.

Saraswat, P., MacWilliams, B.A., Davis, R.B. & D'Astous, J.L. (2014). Kinematics and kinetics of normal and planovalgus feet during walking. *Gait & Posture, 39,* 339-345.

Sarma, A., Borgohain, B. & Saikia, B. (2015). Proximal tibiofibular joint: Rendezvous with a forgotten articulation. *Indian Journal of Orthopaedics, 49,* 489-495.

Sbernini, L., Pallotti, A. & Saggio, G. (2016). Evaluation of a stretch sensor for its inedited application in tracking hand finger movements. *2016 IEEE International Symposium on Medical Measurements and Applications,* 1-6.

Schindler, O.S. & Scott, W.N. (2011). Basic kinematics and biomechanics of the patello-femoral joint. Part 1: The native patella. *Acta Orthopaedica Belgica, 77,* 421-431.

Schneiders, A.G., Sullivan, S.J., Kvarnstrom, J., Olsson, M., Yden, T. & Marshall, S. (2010). The effect of footwear and sports-surface on dynamic neurological screening for sport-related concussion. *Journal of Science and Medicine in Sport, 13*, 382-386.

Schubert, A.G., Kempf, J. & Heiderscheit, B.C. (2014). Influence of stride frequency and length on running mechanics: a systematic review. *Sports Health, 6*, 210-217.

Schurr, S.A., Marshall, A.N., Resch, J.E., Saliba, S.A. (2017). Two-dimensional video analysis is comparable to 3D motion capture in lower extremity movement assessment. *International Journal of Sports Physical Therapy, 12*, 163-172.

Scott, G., Menz, H.B. & Newcombe, L. (2007). Age-related differences in foot structure and function. *Gait & Posture, 26*, 68-75.

Senden, R., Grimm, B., Heyligers, I.C., Savelberg, H.H. & Meijer, K. (2009). Acceleration-based gait test for healthy subjects: reliability and reference data. *Gait & Posture*, *30*, 192-196.

Sheehan, F.T., Derasari, A., Fine, K.M., Brindle, T.J. & Alter, K.E. (2010). Q-angle and J-sign: Indicative of maltracking subgroups in patellofemoral pain. *Clinical Orthopaedics and Related Research, 468*, 266-275.

Silva, D.O., Briani, R.V., Pazzinatto, M.F., Gonçalves, A.V., Ferrari, D., Aragão, F.A., et al. (2015a). Q-angle static or dynamic measurements, which is the best choice for patellofemoral pain? *Clinical Biomechanics, 30*, 1083-1087.

Silva, D.O., Briani, R.V., Pazzinatto, M.F., Goncalves, A.V., Ferrari, D., Aragao, F.A., et al. (2015b). Q-angle static or dynamic measurements, which is the best choice for patellofemoral pain? *Clinical Biomechanics, 30*, 1083-1087.

Singer, B. & Singer, K. (2009). Anterior knee pain scale. *Australian Journal of Physiotherapy, 55*, 140.

Smith, B.E., Selfe, J., Thacker, D., Hendrick, P., Bateman, M., Moffatt, F., et al. (2018). Incidence and prevalence of patellofemoral pain: A systematic review and meta-analysis. *PloS One, 13*, 1-18.

Smith, T.O., Hunt, N.J. & Donell, S.T. (2008). The reliability and validity of the Q-angle: A systematic review. *Knee Surgery, Sports Traumatology, Arthroscopy, 16*, 1068-1079.

Somes, S., Worrell, T.W., Corey, B. & Lngersol, C.D. (1997). Effects of patellar taping on patellar position in the open and closed kinetic chain: a preliminary study. *Journal of Sport Rehabilitation, 6*, 299-308.

Son, Y., Kang, H.J., Song, Y.M. & Hwang, J.H. (2017). Relationships between selfawareness and clinical diagnostic findings of abnormal foot arch height in Koreans. *Annals of Rehabilitation Medicine, 41*, 1013-1018.

Soucie, J.M., Wang, C., Forsyth, A., Funk, S., Denny, M., Roach, K.E., et al. (2011). Range of motion measurements: reference values and a database for comparison studies. *Haemophilia, 17*, 500-507.

Souza, R.B. (2016). An evidence-based videotaped running biomechanics analysis. *Physical Medicine and Rehabilitation Clinics of North America, 27*, 217-236.

Sport England (2011). Natural Turf for Sport. Retrieved from https://www.sportengland.org/media/4564/natural-turf-for-sport.pdf. Last accessed: 25 Jan 2017.

Sport England (1999). *Floors for Indoor Sports.* England: Sport England Publications.

Springer, S., Gottlieb, U. & Lozin, M. (2016). Spatiotemporal gait parameters as predictors of lower-limb overuse injuries in military training. *The Scientific World Journal, 2016*, 1-5.

Staheli, L.T., Chew, D.E. & Corbett, M. (1987). The longitudinal arch. A survey of eight hundred and eighty-two feet in normal children and adults. *The Journal of Bone and Joint Surgery, 69*, 426-428.

Stensdotter, A.K., Andersson, P.I., Rydh, A. & Häger-Ross, C. (2009). Q-angle variations in standing and supine positions and for different measurement methods in women with and without patellofemoral pain. *Advances in Physiotherapy, 11*, 88-96.

Steultjens, M.P.M., Dekker, J., van Baar, M.E., Oostendorp, R.A.B. & Bijlsma, J.W.J. (2000). Range of joint motion and disability in patients with osteoarthritis of the knee or hip. *Rheumatology, 39*, 955-961.

Stevens, C.G., Jarbo, K., Economopoulos, K. & Chhabra, A. (2015). Anatomy and biomechanics of the posterior cruciate ligament and their surgical implications. *Posterior Cruciate Ligament Injuries*, 19-31.

Stretchsense. (n.d.a). 10-Channel SPI Sensing Board. Retrieved from https://www.stretchsense.com/wp-content/uploads/2018/04/10-channel-SPI-Sensing-Board-0CTX-Data-Sheet.pdf. Last accessed: 17 May 2018.

Stretchsense. (n.d.b). How Fast can You Measure Strain?. Retrieved from https://www.stretchsense.com/article-resources/case-study/how-fast-can-you-measure-strain/. Last accessed: 17 May 2018.

Stretchsense. (n.d.c). How to Measure Joint Angle with Stretch Sensors. Retrieved from https://www.stretchsense.com/articles-resources/case-studies/how-to-measure-joint-angle-with-stretch-sensors/. Last accessed: 16 Feb 2019.

Stretchsense. (n.d.d). Silicone Stretch Sensor. Retrieved from https://www.stretchsense.com/wp-content/uploads/2017/11/silicone-stretch-sensor-brochure-web.pdf. Last accessed: 3 May 2018.

Stretchsense. (n.d.e). Technology Overview. Retrieved from https://www.stretchsense.com/wp-content/uploads/2018/03/technology-overview.pdf. Last accessed: 15 May 2018.

Suresh, K.P. & Chandrshekara, S. (2012). Sample size estimation and power analysis for clinical research studies. *Journal of Human Reproductive Sciences, 5,* 7-13.

Tajali, S.B., MacDermid, J.C., Grewal, R. & Young, C. (2016). Reliability and validity of electro-goniometric range of motion measurements in patients with hand and wrist limitations. *The Open Orthopaedics Journal, 10,* 190-205.

Tandeter, H.B., Shvartzman, P. & Stevens, M.A. (1999). Acute knee injuries: use of decision rules for selective radiograph ordering. *American Family Physician, 60,* 2599-2608.

Tao, W., Liu, T., Zheng, R. & Feng, H. (2012). Gait analysis using wearable sensors. *Sensors, 12,* 2255-2283.

Tateuchi, H., Wada, O. & Ichihashi, N. (2011). Effects of calcaneal eversion on three-dimensional kinematics of the hip, pelvis and thorax in unilateral weight bearing. *Human Movement Science, 30,* 566-573.

Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R. & Zumbo, B.D. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine, 36,* 95-101.

The Ministry of Tourism and Sports Thailand (2017). *The Sixth National Sports Development Plan (2017-2021).* Bangkok: Roland Berger.

Thijs, Y., De Clercq, D., Roosen, P. & Witvrouw, E. (2008). Gait-related intrinsic risk factors for patellofemoral pain in novice recreational runners. *British Journal of Sports Medicine, 42,* 466-471.

Thijs, Y., Van Tiggelen, D., Roosen, P., De Clercq, D. & Witvrouw, E. (2007). A prospective study on gait-related intrinsic risk factors for patellofemoral pain. *Clinical Journal of Sport Medicine, 17,* 437-445.

Thomas, J.L., Kunkel, M.W., Lopez, R. & Sparks, D. (2006). Radiographic values of the adult foot in a standardized population. *The Journal of Foot and Ankle Surgery, 45,* 3-12.

Thomson, A. & Rennie, D. (2016). Evolution of Natural Grass Playing Surfaces for Elite Football. Retrieved from http://www.aspetar.com/journal/articles.aspx?issueid=41&issuename=Issue%202. Last accessed: 25 Jan 2017.

Tiberio, D. (1987). The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. *The Journal of Orthopaedic and Sports Physical Therapy, 9,* 160-165.

Tognetti, A., Lorussi, F., Carbonaro, N. & de Rossi, D. (2015). Wearable goniometer and accelerometer sensory fusion for knee joint angle measurement in daily life. *Sensors, 15,* 28435-28455.

Tucker, N., Reid, D. & McNair, P. (2007). Reliability and measurement error of active knee extension range of motion in a modified slump test position: a pilot study. *The Journal of Manual & Manipulative Therapy, 15,* E85-91.

Tweed, J.L., Campbell, J.A., Thompson, R.J. & Curran, M.J. (2008). The function of the midtarsal joint: A review of the literature. *The Foot, 18,* 106-112.

Unver, B., Karatosun, V. & Bakirhan, S. (2009). Reliability of goniometric measurements of flexion in total knee arthroplasty patients: with special reference to the body position. *Journal of Physical Therapy Science, 21,* 257-262.

Van Middelkoop, M., Kolkman, J., Van Ochten, J., Bierma-Zeinstra, S.M. & Koes, B.W. (2008). Risk factors for lower extremity injuries among male marathon runners. *Scandinavian Journal of Medicine & Science in Sports, 18,* 691-697.

Verma, C. & Krishnan, V. (2012). Comparison between Mc connell patellar taping and conventional physiotherapy treatment in the management of patellofemoral pain syndrome - A randomised controlled trial. *Journal of Krishna Institute of Medical Sciences University, 1,* 95-104.

Voloshin, A. (2000). The influence of walking speed on dynamic loading on the human musculoskeletal system. *Medicine and Science in Sports and Exercise, 32,* 1156-1159.

Vora, M., Curry, E., Chipman, A., Matzkin, E. & Li, X. (2018). Patellofemoral pain syndrome in female athletes: A review of diagnoses, etiology and treatment options. *Orthopedic Reviews, 9*, 98-104.

Wallace, D. & Barr, C. (2012). The effect of hip bracing on gait in patients with medial knee osteoarthritis. *Arthritis, 2012,* 1-7.

Wang, L., Hu, W. & Tan, T. (2003). Recent developments in human motion analysis. *Pattern Recognition, 36*, 585-601.

Wang, X., Ma, Y., Hou, B.Y. & Lam, W.K. (2017). Influence of gait speeds on contact forces of lower limbs. *Journal of Healthcare Engineering, 2017,* 1-7.

Waryasz, G.R. & McDermott, A.Y. (2008). Patellofemoral pain syndrome (PFPS): a systematic review of anatomy and potential risk factors. *Dynamic Medicine, 7,* 9-5918-7-9.

Watelain, E., Dujardin, F., Babier, F., Dubois, D. & Allard, P. (2001). Pelvic and lower limb compensatory actions of subjects in an early stage of hip osteoarthritis. *Archives of Physical Medicine and Rehabilitation, 82*, 1705-1711.

Watson, C.J., Propps, M., Ratner, J., Zeigler, D.L., Horton, P. & Smith, S.S. (2005). Reliability and responsiveness of the lower extremity functional scale and the anterior knee pain scale in patients with anterior knee pain. *The Journal of Orthopaedic and Sports Physical Therapy, 35*, 136-146.

Watson, V. (2008). Construction of the track. In International Association of Athletics Federations (Ed.), *IAAF Track and Field Facilities Manual* (pp. 91-144). Monaco: Editions EGC.

Wearing, S.C., Hills, A.P., Byrne, N.M., Hennig, E.M. & McDonald, M. (2004). The arch index: a measure of flat or fat feet? *Foot & Ankle International, 25*, 575-581.

Whittingham, M., Palmer, S. & Macmillan, F. (2004). Effects of taping on pain and function in patellofemoral pain syndrome: a randomized controlled trial. *The Journal of Orthopaedic and Sports Physical Therapy, 34*, 504-510.

Wilken, J.M., Rodriguez, K.M., Brawner, M. & Darter, B.J. (2012). Reliability and minimal detectible change values for gait kinematics and kinetics in healthy adults. *Gait & Posture, 35,* 301-307.

Willems, T., Witvrouw, E., Delbaere, K., De Cock, A. & De Clercq, D. (2005). Relationship between gait biomechanics and inversion sprains: a prospective study of risk factors. *Gait & Posture, 21,* 379-387.

Willems, T.M., De Clercq, D., Delbaere, K., Vanderstraeten, G., De Cock, A. & Witvrouw, E. (2006). A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait & Posture, 23*, 91-98.

Willems, T.M., Witvrouw, E., De Cock, A. & De Clercq, D. (2007). Gait-related risk factors for exercise-related lower-leg pain during shod running. *Medicine and Science in Sports and Exercise, 39*, 330-339.

Willson, J.D. & Davis, I.S. (2009). Lower extremity strength and mechanics during jumping in women with patellofemoral pain. *Journal of Sport Rehabilitation, 18,* 76-90.

Willson, J.D. & Davis, I.S. (2008). Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands. *Clinical Biomechanics, 23,* 203-211.

Willson, J.D., Ellis, E.D. & Kernozek, T.W. (2015). Plantar loading characteristics during walking in females with and without patellofemoral pain. *Journal of the American Podiatric Medical Association, 105*, 1-7.

Willson, J.D., Sharpee, R., Meardon, S.A. & Kernozek, T.W. (2014). Effects of step length on patellofemoral joint stress in female runners with and without patellofemoral pain. *Clinical Biomechanics, 29*, 243-247.

Witvrouw, E., Cambier, D., Danneels, L., Bellemans, J., Werner, S., Almqvist, F., et al. (2003). The effect of exercise regimens on reflex response time of the vasti muscles in patients with anterior knee pain: a prospective randomized intervention study. *Scandinavian Journal of Medicine & Science in Sports, 13*, 251-258.

Wood, L., Peat, G., Wilkie, R., Hay, E., Thomas, E. & Sim, J. (2006). A study of the noninstrumented physical examination of the knee found high observer variability. *Journal of Clinical Epidemiology, 59*, 512-520.

World Confederation for Physical Therapy. (2015). Thailand: A Profile of the Profession. Retrieved from https://www.wcpt.org/node/25472/cds. Last accessed: 20 Oct 2018.

Worrell, T., Ingersoll, C.D., Bockrath-Pugliese, K. & Minis, P. (1998). Effect of patellar taping and bracing on patellar position as determined by MRI in patients with patellofemoral pain. *Journal of Athletic Training, 33*, 16-20.

Wright, J.M., Webner, D. (2010). Playing field issues in sports medicine. *Current Sports Medicine Reports, 9*, 129-133.

Xu, D., Michel, S., McKay, T., O’Brien, B., Gisby, T. & Anderson, I. (2015). Sensing frequency design for capacitance feedback of dielectric elastomers. *Sensors and Actuators A: Physical, 232*, 195-201.

Xu, X., Yao, C., Wu, R., Yan, W., Yao, Y., Song, K., et al. (2018). Prevalence of patellofemoral pain and knee pain in the general population of Chinese young adults: a community-based questionnaire survey. *BMC Musculoskeletal Disorders, 19*, 1-6.

Yamin, N., Amran, M., Basaruddin, K., Salleh, A. & Rusli, W. (2017). Ground reaction force response during running on different surface hardness. *Journal of Engineering and Applied Sciences, 12*, 2313-2318.

Yang, J., Tibbetts, A.S., Covassin, T., Cheng, G., Nayar, S. & Heiden, E. (2012). Epidemiology of overuse and acute injuries among competitive collegiate athletes. *Journal of Athletic Training, 47*, 198-204.

Yazdifar, M., Yazdifar, M.R., Mahmud, J., Esat, I. & Chizari, M. (2013). Evaluating the hip range of motion using the goniometer and video tracking methods. *Procedia Engineering, 68*, 77-82.

Yeung, E.W. & Yeung, S.S. (2001). A systematic review of interventions to prevent lower limb soft tissue running injuries. *British Journal of Sports Medicine, 35*, 383-389.

APPENDICES

1. CHAPTER 2

Assent form for participants under 16

Title of project: Prevalence of patellofemoral pain syndrome in young Thai athletes
Name of investigator: Somruthai Poomsalood
Tel: 44 (0)1634 888903 email: sp620@kent.ac.uk
Participant Identification Number for this project:

Please circle "Yes or No" on the following questions

1. Have you read information about this project?	Yes or No
2. Do you understand what this project is about?	Yes or No
3. Do you understand it's OK to stop taking part at any time?	Yes or No
4. Are you happy to take part?	Yes or No

If any answers are "No" or you don't want to take part, don't sign your name.

If you do want to take part, you can write your name below

Your name	Date	Signature
Name of parent	Date	Signature
Lead researcher	Date	Signature

Consent form for guardians of participants under 16

Title of project: Prevalence of patellofemoral pain syndrome in young Thai athletes

Name of investigator: Somruthai Poomsalood

Tel: 44 (0)1634 888903 **email:** sp620@kent.ac.uk

Participant Identification Number for this project:

Please initial box

1. I confirm I have read and understand the information sheet (version 1) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that participation of my child is voluntary and that he/she is free to withdraw at any time without giving any reason. ☐
3. I understand that responses will be anonymised before analysis. I give permission for members of the research team to have access to my child's anonymised responses. ☐
4. I agree that my child can take part in the above research project. ☐

____________________	____________________	____________________
Name of guardian	Date	Signature
____________________	____________________	____________________
Lead researcher	Date	Signature

Consent form for participants at 16 to 18

Title of project: Prevalence of patellofemoral pain syndrome in young Thai athletes
Name of investigator: Somruthai Poomsalood
Tel: 44 (0)1634 888903 **email:** sp620@kent.ac.uk
Participant Identification Number for this project:

Please initial box

1. I confirm I have read and understand the information sheet (version 1) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐

3. I understand that my responses will be anonymised before analysis. I give permission for members of the research team to have access to my anonymised responses. ☐

4. I agree to take part in the above research project. ☐

______________________	______________________	______________________
Name of participant	Date	Signature
______________________	______________________	______________________
Lead researcher	Date	Signature

Participant information sheet

School of Sport and Exercise Sciences, University of Kent, Medway Building,
Chatham Maritime, Kent, ME4 4AG
Somruthai Poomsalood
Tel: 44 (0)1634 888903 email: sp620@kent.ac.uk

If you have any queries, please contact: **Somruthai Poomsalood (see above)**

Title: Prevalence of patellofemoral pain syndrome in young Thai athletes

Invitation

You are being invited to take part in a research project. Before you decide if you wish to participate, it is important that you understand why this study is being conducted and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for your time and consideration.

Why is this study being done?

Patellofemoral pain syndrome (PFPS) or pain around the kneecap is one of the most common knee pain found in sports medicine clinics. The disorder is usually related with sports and activities of daily living and can be frequently seen in active young people. Thailand is one of the developing countries that sports are starting to get popular day by day. Unfortunately, there have been no studies looking at prevalence of PFPS in any population in this country. It is also believed that lower limb injuries especially the knee joint are the result from long training. If the training time and the prevalence of PFPS are really related, this information would be very useful for training recommendations in young athletes.

What are the purposes of the study?

1. To determine the prevalence of patellofemoral pain syndrome in young athletes.
2. To determine the relationship between patellofemoral pain syndrome and training time per week.

Who are participants?

Students who have enrolled in Phitsanulok Provincial Administrative Organization Sports School, Thailand

How long it will take?

It will take around 30 minutes for the questionnaire and 45 minutes for the physical examination.

What will happen to me in the study?

If you decide to take part in the study, you will be asked to complete anterior knee pain scale (AKPS) questionnaire. The questionnaire was designed to ascertain patellofemoral pain. It is a self-report questionnaire consisting of 13 questions to assess the symptoms and the level of disability of patients with PFPS. If your score is less than 100, you will undergo physical examination on another day. The physical examination consists of a subjective examination and an objective examination. You will be asked about past history and activities relating to your knee pain and you will be examined by inspection, palpation, and measurementat your legs. The physical examination will be chaperoned by a member of school staff during all contact with children

What will I wear for the physical examination?

You will be required to wear shorts during the examination.

Do I have to take part?

No, it is up to you and whether or not you decide to participate will not influence opinion of you in any way. If you are 16 years old or younger, you will need permission from your parents to participate in the study.

Who has reviewed the study?

The School of Sport and Exercise Sciences Research Ethics Committee, University of Kent

What are the risks related with the experiment?

This is just a survey study but you will receive the physical examination. Some special tests might aggravate your pain at the knee but it is only temporary during the tests or it won’t happen at all. Resting and ice will be the best ways to take away the pain. There will be a place to rest and ice provided during the study.

What are the benefits of the study?

Once the study has been completed, you will (if you wish) be provided with a summary of the results and information about how to manage when you experience PFPS.

Will my confidentiality be protected?

The researcher might use information gained from this study in scientific journal articles or in presentations. You will be identified by number only and none of the information will identify you personally. The data will be stored for in the researcher's laptop computer and will not be released without written permission.

If I decide to start the study can I change my mind?

Your decision to participate in this research is entirely voluntary and you can withdraw at any time without having to tell us why. If some of your data are already collected, we will delete them.

How can I get information about the study?

You will be able to get information about your results and the study findings by contacting SomruthaiPoomsalood (sp620@kent.ac.uk).

What if I have questions?

If you have any questions about this research project, please contact the research investigator, SomruthaiPoomsalood (sp620@kent.ac.uk) or Dr. Mark Burnley (M.Burnley@kent.ac.uk).

APPENDIX

ANTERIOR KNEE PAIN (Participant identification number:________________)

ชื่อ:____________________________________ วันที่:________________

อายุ:__________

ข้อเข่าข้างที่มีอาการ: 1. ไม่มีอาการ 2. ซ้าย 3. ขวา

4. ทั้งสองข้าง (ระบุข้างที่มีอาการมากกว่า: ....)

ระยะเวลาที่มีอาการ:______ปี ______เดือน

จงวงกลมคำตอบ (เฉพาะตัวอักษรข้างหน้า) ที่มีความสอดคล้องกับอาการล่าสุดของข้อเข่าของท่าน

1. อาการอ่อนแรง

(a) ไม่อ่อนแรง (5)

(b) อ่อนแรงเล็กน้อยหรือเป็นระยะ (3)

(c) อ่อนแรงตลอดเวลา (0)

2. ยืน

(a) ยืนได้โดยไม่มีอาการเจ็บ (5)

(b) ยืนได้แต่มีอาการเจ็บ (3)

(c) ไม่สามารถยืนได้ (0)

3. เดิน

(a) เดินได้ไม่จำกัด (5)

(b) เดินได้มากกว่า 2 กิโลเมตร (3)

(c) เดินได้ 1-2 กิโลเมตร (2)

(d) ไม่สามารถเดินได้ (0)

4. ขึ้น-ลงบันได

(a) ไม่มีความยากลำบาก (10)

(b) มีอาการเจ็บเล็กน้อยตอนลง (8)

(c) มีอาการเจ็บทั้งตอนลงและตอนขึ้น (5)

(d) ไม่สามารถขึ้น-ลงบันไดได้ (0)

5. นั่งยอง

(a) ไม่มีความยากลำบาก (5)

(b) มีอาการเจ็บเมื่อนั่งยองซ้ำๆ (4)

(c) มีอาการเจ็บทุกครั้งที่นั่งยอง (3)

(d) ลงน้ำหนักได้ไม่เต็มที่เวลานั่งยอง (2)

(e) ไม่สามารถนั่งยองได้ (0)

6. วิ่ง

(a) ไม่มีความยากลำบาก (10)

(b) มีอาการเจ็บหลังวิ่งไปแล้วมากกว่า 2 กิโลเมตร (8)

(c) มีอาการเจ็บเล็กน้อยตอนเริ่มวิ่ง (6)

(d) มีอาการเจ็บมาก (3)

(e) ไม่สามารถวิ่งได้ (0)

7. กระโดด

(a) ไม่มีความยากลำบาก (10)

(b) มีความยากลำบากเล็กน้อย (7)

(c) มีอาการเจ็บตลอดเวลา (2)

(d) ไม่สามารถกระโดดได้ (0)

8. นั่งงอเข่าเป็นเวลานาน

(a) ไม่มีความยากลำบาก (10)

(b) มีอาการเจ็บหลังออกกำลังกาย (8)

(c) มีอาการเจ็บตลอดเวลา (6)

(d) อาการเจ็บทำให้ต้องเหยียดเข่าชั่วคราว (4)

(e) ไม่สามารถนั่งงอเข่าได้ (0)

9. อาการเจ็บ

(a) ไม่มีอาการ (10)

(b) มีอาการเล็กน้อยและเป็นครั้งคราว (8)

(c) อาการเจ็บรบกวนการนอนหลับ (6)

(d) อาการเจ็บรุนแรงเป็นครั้งคราว (3)

(e) อาการเจ็บรุนแรงและเป็นตลอดเวลา (0)

10. อาการบวม

(a) ไม่มีอาการ (10)

(b) บวมหลังจากการออกแรงอย่างหนัก (8)

(c) บวมหลังจากทำกิจวัตรประจำวัน (6)

(d) บวมทุกเย็น (4)

(e) บวมตลอดเวลา (0)

11. การเคลื่อนไหวที่ผิดปกติของกระดูกสะบ้าข้างที่มีอาการ

(a) ไม่มีความผิดปกติ (10)

(b) เคลื่อนออกจากแนวกลางของข้อเข่าเล็กน้อยเป็นครั้งคราวเมื่อทำกิจกรรมที่เกี่ยวกับกีฬา (6)

(c) เคลื่อนออกจากแนวกลางของข้อเข่าเล็กน้อยเป็นครั้งคราวเมื่อทำกิจวัตรประจำวัน (4)

(d) มีการเคลื่อนหลุดออกไปจากแนวกลางของข้อเข่าอย่างน้อย 1 ครั้ง (2)

(e) มีการเคลื่อนหลุดออกไปจากแนวกลางของข้อเข่ามากกว่า 2 ครั้ง (0)

12. การฝ่อลีบของกล้ามเนื้อต้นขา

(a) ไม่มีการฝ่อลีบ (5)

(b) ฝ่อลีบเล็กน้อย (3)

(c) ฝ่อลีบมาก (0)

13. การจำกัดการงอเข่า

(a) ไม่จำกัด (5)

(b) จำกัดเล็กน้อย (3)

(c) จำกัดมาก (0)

Physical examination form

Physical examination form for patellofemoral pain syndrome

Participant identification number……………..

Subjective examination

Present history...

……………………………………………………………………………………

………...…………………………………………………………………………

…………………...………………………………………………………………

Past history………………………………………………………………….

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Objective examination

Components and finding	**Result**	
	Right knee	**Left knee**
Inspection		
Lateral patellar tracking ("J" sign)	……………………	…………………
Poor VMO tone	……………………	…………………
Palpation		
Effusion	……………………	…………………
Tenderness of:		
Patellar retinaculum (medial and lateral)	……………………	…………………
Facets (medial and lateral)	……………………	…………………
Patella	……………………	…………………
Quadriceps and patellar tendon	……………………	…………………
Joint line	……………………	…………………

Measurement Q-angle	……………………	…………………
Range of motion Knee flexion/extension Crepitus Popping/clicking	AROM…………… PROM…………… ………………… ……………………	AROM………… PROM………… ………………… …………………
Special test Patellar apprehension test Patellofemoral grind test	…………………… ……………………	………………… …………………
Muscle flexibility Quadriceps	……………………	…………………
Muscle strength Knee flexor Knee extensor	…………………… ……………………	………………… …………………

Diagnosis..

Appendix 2

University of Kent

OVERSEAS TRAVEL RISK ASSESSMENT FORM

(BASED ON HSE "FIVE STEPS TO RISK ASSESSMENT")

Sheet No: 1

Department/Section Sport and Exercise Sciences

Work Area Sports rehabilitation

Date of Assessment March 14, 2016

Assessor Somruthai Poomsalood

Signature

Date of Review March 22, 2016

HAZARD (List)	**PERSONS AT RISK AND HOW** (Consider all persons, including those who may not be involved with the job)	**EXISTING CONTROL MEASURES AND ADEQUACY** (List the control measures appropriate to each hazard and consider the level of residual risk; is it high, medium or low?) If using a risk matrix then show risk factor (R) = (hazard x risk)	**ADDITIONAL REQUIREMENTS** (If the residual risk is high, you must take additional practicable measures to reduce it, or abort the proposed task)
Medical emergency	Somruthai Poomsalood	Fitness to travel certificate and insurance certificate obtained from University of Kent. However, the researcher is a local resident and will be able to receive immediate first aid and aftercare	
Weather condition (rainy season)	Somruthai Poomsalood	Traveling by a private car	
Problem encountered when traveling using local transport	Somruthai Poomsalood	Traveling by a private car	

<u>NOTE</u>: All assessors should read the Performance Standard for undertaking risk assessments and have been trained in risk assessment. On completion, appropriate employees should be briefed by the assessor who should ensure that they fully understand the risk assessment.

2. CHAPTER 3

Consent form

Title of project: Will there be significant differences in gait parameters on different training surfaces during walking in healthy individuals?

Name of investigator: Somruthai Poomsalood

Participant Identification Number for this project:

Please initial box

1.	I confirm I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
2.	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.	☐
3.	I understand that my responses will be anonymised before analysis. I give permission for members of the research team to have access to my anonymised responses.	☐
4.	I agree to take part in the above research project.	☐

Name of participant	Date	Signature
Lead researcher	Date	Signature

Inclusion criteria questionnaire

Participant number………………………………………………………….

Date of birth……………………............ Age…..........years Gender…………….

Weight…………………..kg Height……….....………..cm

To be measured by researcher

Right leg length………………cm Left leg length……………….cm

Right arch of foot………………... Left arch of foot………………...

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you have all the inclusion criteria for the study

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1. Are you a healthy active person aged 18-35 years?		
2. Are you engaged in physical activities for 2 hours or more per week during the past 12 months?		
3. Do you adequately understand verbal explanation or written information given in English?		
4. Have you had any surgery on your lower leg, ankle or foot in the last 12 months? (If YES, please specify:…………………………………………………….)		
5. Have you had any injury to the lower leg, ankle or foot within the last 6 months? (If YES, please specify:…………………………………………………….)		
6. Do you have any pain in your knees with activities? (If YES, please specify: ……..……………………………………………….)		
7. Do you have any heart problem?		

Participant information sheet

School of Sport and Exercise Sciences, University of Kent, Medway Building,
Chatham Maritime, Kent. ME4 4AG.
Somruthai Poomsalood
Tel: 44 (0)1634 888903 email: sp620@kent.ac.uk

If you have any queries, please contact: **Somruthai Poomsalood (see above)**

Title: Will there be significant differences in gait parameters on different training surfaces during walking in healthy individuals?

Invitation

We are inviting you to be part of a research project. Before you decide if you wish to join, it is important that you know why we want to do this study and what it will involve. Please take time to read the following information carefully and talk with others if you wish. Ask us if there is anything that is not clear or if you need more information. Take time to decide whether you want to join or not. Thank you so much for your time.

Why are we doing this study?

We are doing this study because we think that gait analysis is very useful to evaluate our walking pattern. The analysis is widely used among patients and healthy people. Our walking pattern might change when walking on different surfaces. However, there is no evidence of walking patterns on synthetic surface, indoor court, or grass.

What is the aim of the study?

We want to find out how different training surfaces affect your walking pattern.

Who are participants?

Healthy active people both men and women (age 18-35 years) who do physical activities for 5 to 10 hours a week during the past 12 months. Have no history of lower leg, ankle, or foot surgery in the last 12 months. Have no history of an injury to the lower leg, ankle, or foot within 6 months. Have no knee pain with any activities. No reported known cardiovascular diseases. Understand English in both listening and reading adequately.

How long it will take?

You will come to the laboratory only 1 time and less than 3 hours.

What will happen if you join the study?

If you decide to join our study, you will sign the informed consent form and complete the inclusion criteria questionnaire. Your leg length will be measured whilst you are laying down by the researcher using a measuring tape. Your arch of foot will be measured using a force plate. For the testing session, you will be walking for 20 m with barefoot (thin socks are allowed) on each of the surfaces shown in Figure 1, which are 1) synthetic surface 2) indoor court and 3) grass. You will have a small device on your waist (Figure 2) to record your walking during the test. See pictures below:

Figure 1 Training surfaces 1) outdoor synthetic 2) indoor court 3) grass

Figure 2 Device for recording walking

Do you have to take part?

No, it is up to you and whether you decide to join or not and your decision will not affect our opinion of you in any way.

Who has reviewed the study?

The School of Sport and Exercise Sciences Research Ethics Committee, University of Kent

What are the risks related with the testing?

There are no risks because you are only required to walk at your natural speed.

What are the benefits of the study?

Once we complete the study, we will (if you wish) provide you with a summary of the results and information about your walking.

Will your private information be protected?

We might use your information from this study in journal articles or in presentations. We will identify you by number only and none of the information will identify you personally.

If you decide to join the study can you change my mind?

Your decision to join this research is voluntary and you can leave the study at any time without having to tell us why. If you leave the study and some of your data are already collected, we will delete them.

How can you get information about the study?

You can get information about your results and the study findings by contacting Somruthai Poomsalood (sp620@kent.ac.uk).

What if you have questions?

If you have any questions about this research project, please contact us, Somruthai Poomsalood (sp620@kent.ac.uk) or Dr. Karen Hambly (K.Hambly@kent.ac.uk).

3. CHAPTER 4

Consent form

Title of project: Effects of McConnell taping and SERF Strap on Plantar Loading Pattern during Walking and Jogging

Name of investigator: Somruthai Poomsalood

Participant Identification Number for this project:

Please initial box

1. I confirm I have read and understand the information sheet dated… (version…) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. *(Insert contact number here of lead researcher/member of research team, as appropriate).* ☐
3. I understand that my responses will be anonymised before analysis. I give permission for members of the research team to have access to my anonymised responses. *(Also add here a statement about publication of anonymised direct quotes, if this will be done).* ☐
4. I agree to take part in the above research project. ☐

Name of participant	Date	Signature
Name of person taking consent *(if different from lead researcher)* *To be signed and dated in presence of the participant*	Date	Signature
Lead researcher	Date	Signature

Inclusion criteria questionnaire

Name…………………………………………………………

Date of birth…………………….......... Age…..........years Gender……………

Weight…………………..kg Height………......………..cm

Right leg length………………cm Left leg length……………….cm

Right arch of foot………………... Left arch of foot………………...

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you have all the inclusion criteria for the study

Please read the 12 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1. Are you a healthy active individual aged 18-35 years?		
2. Are you engaged in physical activities for 2 hours or more per week during the past 12 months?		
3. Do you adequately understand verbal explanation or written information given in English?		
4. Have you had any surgery on your lower leg, ankle or foot in the last 12 months? (If YES, please specify: ……………………………………………………………….)		
5. Have you had any injury to the lower leg, ankle or foot within the last 6 months? (If YES, please specify: ……………………………………………………………….)		
6. Do you have any pain in your knees with activity? (If YES, please specify: ……………………………………………………………….)		
7. Do you have normal arch of foot?		
8. Do you have any known allergies to adhesive tape or latex?		

Please read and sign the declaration below:

I, the undersigned, have read, understood and completed this questionnaire to the best of my knowledge.

Signature: …………………………………………………………

Date: …………………….…..............

Health questionnaire

Name……………………………………………………………………

Date of Birth………………………………. Age………………

Please answer these questions truthfully and completely. The sole purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete the exercise test.

ANY INFORMATION CONTAINED HEREIN WILL BE TREATED AS CONFIDENTIAL.

SECTION 1: GENERAL HEALTH QUESTIONS

Please read the 8 questions below carefully and answer each one honestly: check YES or NO.

	YES	NO
1. Has your doctor ever said that you have a heart condition or high blood pressure?	☐	☐
2. Do you feel pain in your chest at rest, during your daily activities of living, or when you do physical activity?	☐	☐
3. Do you lose balance because of dizziness or have you lost consciousness in the last 12 months? (Please answer NO if your dizziness was associated with over-breathing including vigorous exercise).	☐	☐
4. Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	☐	☐
If yes, please list condition(s) here:		
5. Are you currently taking prescribed medications for a chronic medical condition?	☐	☐
If yes, please list condition(s) and medications here:		
6. Do you currently have (or have you had within the past 12 months) a bone, joint or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer NO if you had a problem in the past but it *does not limit your ability* to be physically active.	☐	☐
If yes, please list condition(s) here:		
7. Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐
8. Are you, or is there any chance you could be, pregnant?	☐	☐

If you answered NO to all of the questions above, you are cleared to take part in the exercise test

✓ **Go to SECTION 3 to sign the form. You do not need to complete section 2.**

✗ **If you answered YES to one or more of the questions in Section 1 - PLEASE GO TO SECTION 2.**

SECTION 2: CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.

		YES	NO
1.	**Do you have arthritis, osteoporosis, or back problems?** If YES answer questions 1a-1c. If NO go to Question 2.	☐	☐
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebrae (e.g. spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	☐	☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	☐	☐
2.	**Do you have cancer of any kind?** If YES answer questions 2a-2b. If NO, go to Question 3.	☐	☐
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head and neck?	☐	☐
2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	☐	☐
3.	**Do you have heart disease or cardiovascular disease? This includes coronary artery disease, high blood pressure, heart failure, diagnosed abnormality or heart rhythm.** If YES answer questions 3a-3e. If NO go to Question 4.	☐	☐
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
3b.	Do you have an irregular heartbeat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	☐	☐
3c.	Do you have chronic heart failure?	☐	☐
3d.	Do you have a resting blood pressure equal to or greater than 160/90mmHg with or without medication? Answer YES if you do not know your resting blood pressure.	☐	☐
3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	☐	☐

		YES	NO
4.	**Do you have any metabolic conditions? This includes Type 1 Diabetes, Type 2 Diabetes and Pre-Diabetes.** If YES answer questions 4a-4c. If NO, go to Question 5.	☐	☐
4a.	Is your blood sugar often above 13mmol/L? (Answer YES if you are not sure).	☐	☐
4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, OR the sensation in your toes and feet?	☐	☐
4c.	Do you have other metabolic conditions (such as thyroid disorders, current pregnancy related diabetes, chronic kidney disease, or liver problems)?	☐	☐
5.	**Do you have any mental health problems or learning difficulties?** This includes Alzheimer's, dementia, depression, anxiety disorder, eating disorder, psychotic disorder, intellectual disability and down syndrome. If YES answer questions 5a-5b. If NO go to Question 6.	☐	☐
5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
5b.	Do you also have back problems affecting nerves or muscles?	☐	☐
6.	**Do you have a respiratory disease?** This includes chronic obstructive pulmonary disease, asthma, pulmonary high blood pressure. If YES answer questions 6a-6d. If NO, go to Question 7.	☐	☐
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
6b.	Has your doctor ever said you blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	☐	☐
6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	☐	☐
6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	☐	☐
7.	**Do you have a spinal cord injury?** This includes tetraplegia and paraplegia. If YES answer questions 7a-7c. If NO, go to Question 8.	☐	☐
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	☐	☐
7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as autonomic dysreflexia)?	☐	☐

		YES	**NO**
8.	**Have you had a stroke?** This includes transient ischemic attack (TIA) or cerebrovascular event. If YES answer questions 8a-8c. If NO go to Question 9.	☐	☐
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking any medications or other treatments).	☐	☐
8b.	Do you have any impairment in walking or mobility?	☐	☐
8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	☐	☐
9.	**Do you have any other medical condition which is not listed above or do you have two or more medical conditions?** If you have other medical conditions, answer questions 9a-9c. If NO go to Question 10.	☐	☐
9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	☐	☐
9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, and kidney problems)?	☐	☐
9c.	Do you currently live with two or more medical conditions?	☐	☐
	Please list your medical condition(s) and any related medications here:		
10.	**Have you had a viral infection in the last 2 weeks (cough, cold, sore throat, etc.)?** If YES please provide details below:	☐	☐
11.	**Is there any other reason why you cannot take part in this exercise test?** If YES please provide details below:	☐	☐
12.	**Please provide brief details of your current weekly levels of physical activity (sport, physical fitness or conditioning activities), using the following classification for exertion level:** **L = light (slightly breathless** **M = moderate (breathless)** **V = vigorous (very breathless)** **Activity** **Duration (mins.)** **Level (L/M/V)** **Monday** **Tuesday** **Wednesday** **Thursday** **Friday** **Saturday** **Sunday**		

Please see below for recommendations for your current medical condition and sign this document:

✓ **If you answered NO to all of the follow-up questions about your medical condition, you are cleared to take part in the exercise test.**

✖ **If you answered YES to one or more of the follow-up questions about your medical condition it is strongly advised that you should seek further advice from a medical professional before taking part in the exercise test.**

SECTION 3: DECLERATION

Please read and sign the declaration below:

I, the undersigned, have read, understood and completed this questionnaire to the best of my knowledge.

NAME: ………

SIGNATURE: ………………………………………………………DATE: …………………………………..........

SIGNATURE OF PARENT/GUARDIAN: ………………………………………………………………………

This health questionnaire is based around the PAR-Q+, which was developed by the Canadian Society for Exercise Physiology www.csep.ca

Participant information sheet

School of Sport and Exercise Sciences, University of Kent, Medway Building,
Chatham Maritime, Kent. ME4 4AG.
Somruthai Poomsalood
Tel: 44 (0)1634 888903 email: sp620@kent.ac.uk

If you have any queries, please contact: **Somruthai Poomsalood (see above)**

Title: Effects of McConnell Taping and SERF Strap on Plantar Loading Pattern during Walking and Jogging

Invitation

You are being invited to take part in a research project. Before you decide if you wish to participate, it is important that you understand why this study is being conducted and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for your time and consideration.

Why is this study being done?

Many people suffer from patellofemoral pain syndrome (PFPS) or pain around the knee cap. Patellar taping is an effective treatment option in reducing pain in people with PFPS. However, there is a lack of research studies accessing effects of the patellar taping on foot pressures. The stability through external rotation of the femur (SERF) strap (Don Joy Orthopedics Inc, Vista, CA) has been developed to pull the thigh into outward rotation to support the knee joint, to reduce pain, and to improve lower limb motions during activities. However, there have been no studies considering an effect of SERF strap on plantar pressure.

What are the purposes of the study?

1. To investigate an effect of McConnell taping on foot pressures
2. To investigate an effect of SERF strap on foot pressures
3. To compare an effect between McConnell taping and SERF strap on foot pressures

Who are participants?

Healthy active individuals who are engaged in physical activities for 5 to 10 hours a week during the previous 12 months, aged between 18-35 years both males and females.

How long it will take?

You will come to the laboratory only 1 time and less than 2 hours.

What will happen to me in the study?

If you decide to take part in the study, you will be asked to walk and jog on a 2 m pressure plate with barefoot under 3 conditions: 1) no tape, 2) McConnell taping, and 3) SERF strap. McConnell taping and SERF strap will be applied on your right leg separately. We will record your foot pressures during the walk and the jog. See pictures below:

Figure 1 McConnell taping

Figure 2 SERF strap

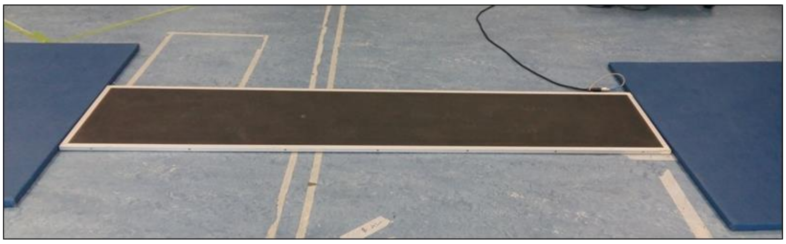


Figure 3 Pressure plate (2 meters)

Do I have to take part?

No, it is up to you and whether or not you decide to participate will not influence opinion of you in any way.

Who has reviewed the study?

The School of Sport and Exercise Sciences Research Ethics Committee, University of Kent

What are the risks related with the experiment?

There are no risks because you are only required to walk and jog at your natural speed.

What are the benefits of the study?

Once the study has been completed, you will (if you wish) be provided with a summary of the results and information about the plantar pressure.

Will my confidentiality be protected?

The researcher might use information gained from this study in scientific journal articles or in presentations. You will be identified by number only and none of the information will identify you personally. The data will be stored for a 5-year period at the School of Sport and Exercise Sciences (University of Kent) and will not be released without written permission or unless required by law.

If I decide to start the study can I change my mind?

Your decision to participate in this research is entirely voluntary and you can withdraw at any time without having to tell us why. If some of your data are already collected, we will delete them.

How can I get information about the study?

You will be able to get information about your results and the study findings by contacting Somruthai Poomsalood (sp620@kent.ac.uk).

What if I have questions?

If you have any questions about this research project, please contact the research investigator, Somruthai Poomsalood (sp620@kent.ac.uk) or Dr. Karen Hambly (K.Hambly@kent.ac.uk).

4. CHAPTER 6

Consent form

Title of project: Can stretch sensors measure knee range of motion in healthy adults?
Name of investigator: Somruthai Poomsalood, Karen Hambly, Karthik Muthumayandi

Participant Identification Number for this project:

Please initial box

1. I confirm I have read and understand the information sheet (version 1.0) dated 27/11/2017 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my right knee will be recorded by a mobile phone camera during the study. I give permission for members of the research to record my knee. ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason. ☐
4. I understand that my data will be anonymised before analysis. I give permission for members of the research team to have access to my anonymised data. ☐
5. I have already answered the health questionnaire truthfully and to the best of my knowledge and I agree to take part in the above research project. ☐

Name of participant	Date	Signature
Lead researcher	Date	Signature

Inclusion criteria questionnaire

Participant number……………………………………………………….

Age…..........years   Gender…………….

Weight…………………..kg   Height……….......………..cm

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you have all the inclusion criteria for the study

Please read the 6 questions below carefully and answer each one honestly: check YES or NO.	**YES**	**NO**
1. Are you a healthy person aged 18-40 years?		
2. Do you have any pain in your knees with activities? (If YES, please specify: …………………………………………………………… ……………………………………………………………………………………......)		
3. Have you had any surgery on your lower leg, ankle or foot in the last 12 months? (If YES, please specify: …………………………………………………………… ...………………………………………………………………………………………)		
4. Have you had any injury to the lower leg, ankle or foot within the last 6 months? (If YES, please specify: ………………………………………………………….... ……………………………………………………………………………………..)		
5. Do you adequately understand verbal explanation or written information given in English?		
6. Do you have any allergies to silicone or elastic tape?		

Participant information sheet

School of Sport & Exercise Sciences, University of Kent, Medway Building,
Chatham Maritime, Chatham, ME4 4AG.
Somruthai Poomsalood
Tel: 44 (0)1634 888903 email: sp620@kent.ac.uk
If you have any queries, please contact: **Somruthai Poomsalood (see above)**

Title: Can stretch sensors measure knee range of motion in healthy adults?

Invitation

We are inviting you to be part of a research project. Before you decide if you wish to join, it is important that you know why we want to do this study and what it will involve. Please take time to read the following information carefully and talk with others if you wish. Ask us if there is anything that is not clear or if you need more information. Take time to decide whether you want to join or not. Thank you so much for your time.

Why are we doing this study?

We are doing this study because we think that a stretch sensor (silicone) (Figure 1) will be very useful to measure knee movement. It is stretchable and can be placed on human body parts. We are hoping that if the sensor can be directly attached on the skin and can measure knee movement in the laboratory, we can use the sensor in a real environment in the future.

Figure 1 Stretch sensor

What is the aim of the study?

We want to find out how the sensor can be placed on human skin and to find out if the sensor can be used to measure knee movement during everyday activities.

Who are participants?

Healthy active people both men and women (age 18-40 years). Have no knee pain with any activities. Have no history of lower leg, ankle, or foot surgery in the last 12 months. Have no history of an injury to the lower leg, ankle, or foot within 6 months. Understand English in both listening and reading adequately.

How long it will take?

You will come to the laboratory only 1 time and less than 2 hours.

What will happen if you join the study?

If you decide to join our study, you will be asked to complete the health questionnaire, the inclusion criteria questionnaire, and sign the informed consent form. You will be tested for an allergy of an elastic adhesive tape (kinesiotape) by having a small piece of the tape on your knee for 30 mintues. You will have 3 stretch sensors applied to your right knee attached by kinesiotape and a battery box on your thigh held by an elastic bandage. (Figure 2). Three markers will be attached on the inside of your right ankle, knee, and thigh. You will be asked to sit on a seat of a Cybex dynamometer. You will have a seat belt across your waist and your right leg will be strapped to the dynamometer. You will relax your right knee and the dynamometer will move your knee slowly through a full knee bend and straighten. A mobile phone will be set up on your left side to video record your knee angles and the sensor system will record change of sensor length whilst your knee is moving. The video will only show your legs and your lower body and your face will not be recorded.

Figure 2 Stretch sensors covered by kinesiotape

Do you have to take part?

No, it is up to you and whether you decide to join or not and your decision will not affect our opinion of you in any way.

Who has reviewed the study?

The School of Sport and Exercise Sciences Research Ethics Committee, University of Kent

What are the risks related with the testing?

There are no risks because you are only required to sit on a seat and the dynamometer will move your knee automatically.

What are the benefits of the study?

Once we complete the study, we will (if you wish) provide you with a summary of the results.

Will your private information be protected?

We might use your information from this study in journal articles or in presentations. We will identify you by number only and none of the information will identify you personally.

If you decide to join the study can you change my mind?

Your decision to join this research is voluntary and you can leave the study at any time without having to tell us why. If you leave the study and some of your data are already collected, we will delete them.

How can you get information about the study?

You can get information about your results and the study findings by contacting Somruthai Poomsalood (sp620@kent.ac.uk).

What if you have questions?

If you have any questions about this research project, please contact us, Somruthai Poomsalood (sp620@kent.ac.uk) or Dr. Karen Hambly (K.Hambly@kent.ac.uk).

5. ARTICLE PUBLISHED

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Original Research Article

DOES MCCONNELL TAPING OR THE STABILITY THROUGH EXTERNAL ROTATION OF THE FEMUR (SERF) STRAP AFFECT REARFOOT PLANTAR LOADING PATTERNS DURING WALKING IN HEALTHY ADULTS?

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ABSTRACT

Background: Changes in patellofemoral joint biomechanics have the potential to influence function of the lower extremity. McConnell taping has been proposed to reduce pain in individuals with patellofemoral pain syndrome (PFPS). It is also believed to improve vastus medialis oblique (VMO) muscle, patellofemoral alignment, and stride length. The stability through external rotation of the femur (SERF) strap has been developed to pull the femur externally to stabilise the patellofemoral joint, in order to reduce patellofemoral pain and improve lower limb kinematics. A lack of literature has examined effects of these two treatment methods on plantar pressures. Therefore, the aim of this study was to investigate the effects of McConnell taping and the SERF strap on rearfoot plantar loading patterns during walking in healthy adults.

Materials and Methods: Twenty-three participants (12 males and 11 females, age: 26.52±6.4 years) were randomly tested under 3 conditions: 1) no tape, 2) McConnell taping, and 3) SERF strap. Each participant was instructed to walk on a 2 m pressure plate at their own natural pace. Three valid stance phases of the right foot were recorded for each condition. Maximum pressures of medial heel and lateral heel, contact area of medial heel and lateral heel, initial heel contact, foot axis angle, and centre of pressure were collected.

Results: There were significant differences of maximum pressures of lateral heel ($p = 0.011$) with McConnell taping condition and the SERF strap condition demonstrating higher pressures than the no-tape condition ($p = 0.042$, $p = 0.010$ respectively). However, significant differences of other variables were not found.

Conclusion: The differences of maximum pressures of lateral heel between the conditions could be a clinical role for McConnell taping or SERF strap use in reducing rearfoot pronation in individuals with lower extremity problems especially PFPS.

KEY WORDS: Patellofemoral pain syndrome, Plantar pressure, Foot pronation, Medial patellar taping, SERF strap

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INTRODUCTION

Changes in patellofemoral joint biomechanics have the potential to influence function of the lower extremity. Medial patellar taping is an inexpensive treatment option that has been proposed to immediately reduce pain following application in individuals with patellofemoral pain syndrome (PFPS) [1-3] . Patellar taping has become widely used since the introduction of the original approach by Jenny McConnell in

1984 [4]. It is believed that the reduction of pain following the medial tape application is associated with alterations in patellofemoral joint reaction forces [1]. In addition to pain reduction, medial patellar taping has also been proposed to improve the activity of vastus medialis oblique (VMO) and facilitating strengthening exercises of quadriceps femoris muscle [5-8]. Patellofemoral alignment [9-11] and stride length [12] during ramp ascent have also been shown to be improved after medial taping application. However, there is a lack of literature examining the effects of medial patellar taping on plantar pressures during walking.

Excessive and/or prolonged rearfoot pronation has been shown to lead to excessive medial rotation of the tibia and the femur in a closed kinetic chain [13]. When the femur rotates medially, the compression between the lateral side of the patella and the femur increases, resulting in increased patellofemoral joint stress [13-18]. The forces on the knee during weight-bearing activities are transmitted from the foot to the knee. Hence, loading of the knee and patellofemoral joint can be influenced by force and loading patterns at the foot [17]. By correcting excessive rearfoot pronation, external tibial rotation is increased, eliciting a relative medial patellar glide [19]. Higher loading on the medial areas of the plantar surface of the foot during running and other weight-bearing activities have been suggested to be important factors for lower limb injuries [14, 17]. Willems et al. (2006) [20] and Willems et al. (2007) [21] found increased pronation, accompanied with more pressure on the medial side of the rearfoot in healthy people who developed exercise-related lower leg pain during barefoot running. These findings are interesting because a greater medial foot-loading pattern may increase lateral force on the patellofemoral joint.

The Stability through External Rotation of the Femur ®(SERF) strap (Don Joy Orthopedics Inc, Vista, CA) has been developed to pull the femur into external rotation to stabilise the patellofemoral joint, in order to reduce patellofemoral pain and improve lower limb kinematics during dynamic activities [22-24]. Since it has been suggested that abnormal patellar tracking may be the result of excessive internal rotation of the femur and tibia from excessive rearfoot pronation, it is proposed that the application of the SERF strap should alter plantar loading patterns by pulling the femur laterally resulting in a reduction in medial tibial rotation and foot pronation. Although McConnell taping has become very popular for patellofemoral pain management, relatively little is known regarding its effect on rearfoot pressures [19]. Therefore, the aims of this study were to investigate the effects of both McConnell taping and the SERF strap on rearfoot plantar loading patterns during walking in healthy adults. On the basis of the review and the evidence that is presented, the McConnell taping has been associated with changing of patellofemoral joint reaction force and the SERF strap has been developed to pull the femur laterally so the hypotheses of this study were that both McConnell taping and the SERF strap would alter rearfoot plantar loading patterns during walking.

METHODOLOGY

Participants and study design: The sample size was calculated using G*Power 3.1.9.2 [25] with ANOVA repeated measures, within factors at the power of 0.85, medium effect size (0.3), and a 0.05 alpha level. A minimum sample size was 22 but 23 participants (12 males and 11 females) were recruited in this cross-sectional study. The average age of the participants was 26.5±6.4 years with an average weight of 69.7±14.8 kg and an average height of 171.7±8.9 cm. All participants were healthy individuals aged between 18 and 35 years who had engaged in physical activities for 2 hours or more per week during the previous 12 months before the beginning of the study with no discrepancy of 1 cm or greater in lower leg length [26] and normal arch of foot measured by using the plantar arch index (A/B) [27]. Participants had no history of surgery or injury involving the lower leg, ankle or foot in the last 12 and 6 months respectively [20] and no knee pain with activity [28].

Procedures: All participants were randomly tested in a walking activity under 3 conditions: 1) no tape, 2) McConnell taping, and 3) SERF strap. Starting with the participants lying on their back, a rolled-up towel was placed under the

right knee. Before the tape application, the participant's knee were shaved using a razor. During the tape application, an approximately 15 cm length of hypoallergenic tape (5 cm wide) was first applied on the knee with no tension to avoid allergic reactions [29]. A 10 cm length of zinc oxide tape (3.8 cm wide) as commonly used for McConnell taping was placed over the hypoallergenic tape on the lateral patellar border and the other end of the tape was medially pulled over the patella and secured near the medial femoral condyle [19]. Wrinkles of the skin at the inner aspect of the knee (Figure 1) were used as an indication that the patella had been moved medially. In the SERF strap condition, the SERF strap was applied on the right leg while the participants sat on a chair. The strap was wrapped around the lower limb from the knee to the waist (Figure 2). The tensioning of the strap and the direction of pull was to facilitate lateral rotation of the femur.

The participants gave written informed consent and the study was approved by School of Sport and Exercise Sciences Research Ethics and Advisory Groups (SSES REAG), University of Kent at Medway (Ethics reference: 143-2014_2015). Data were collected using a 2 m footscan pressure plate (RSscan International, Belgium). Before the testing started, all participants were acquainted with the data collection procedures including walking on the pressure plate (5-6 trials with no tape) until they felt comfortable [30]. During the study, each participant was instructed to walk on the pressure plate at their own natural pace while looking straight ahead and not towards the floor [15]. The participants were asked to start walking with their left foot first so that a completed right foot step was recorded. The participants performed all tests barefoot. The condition order (no tape, McConnell taping, and SERF strap) was assigned randomly between participants to control potential order effects. Three valid stance phases of the right foot were recorded for each condition. A trial was considered valid when the entire right foot was captured. Participants were given 3 minutes to recover between each of the conditions [22].

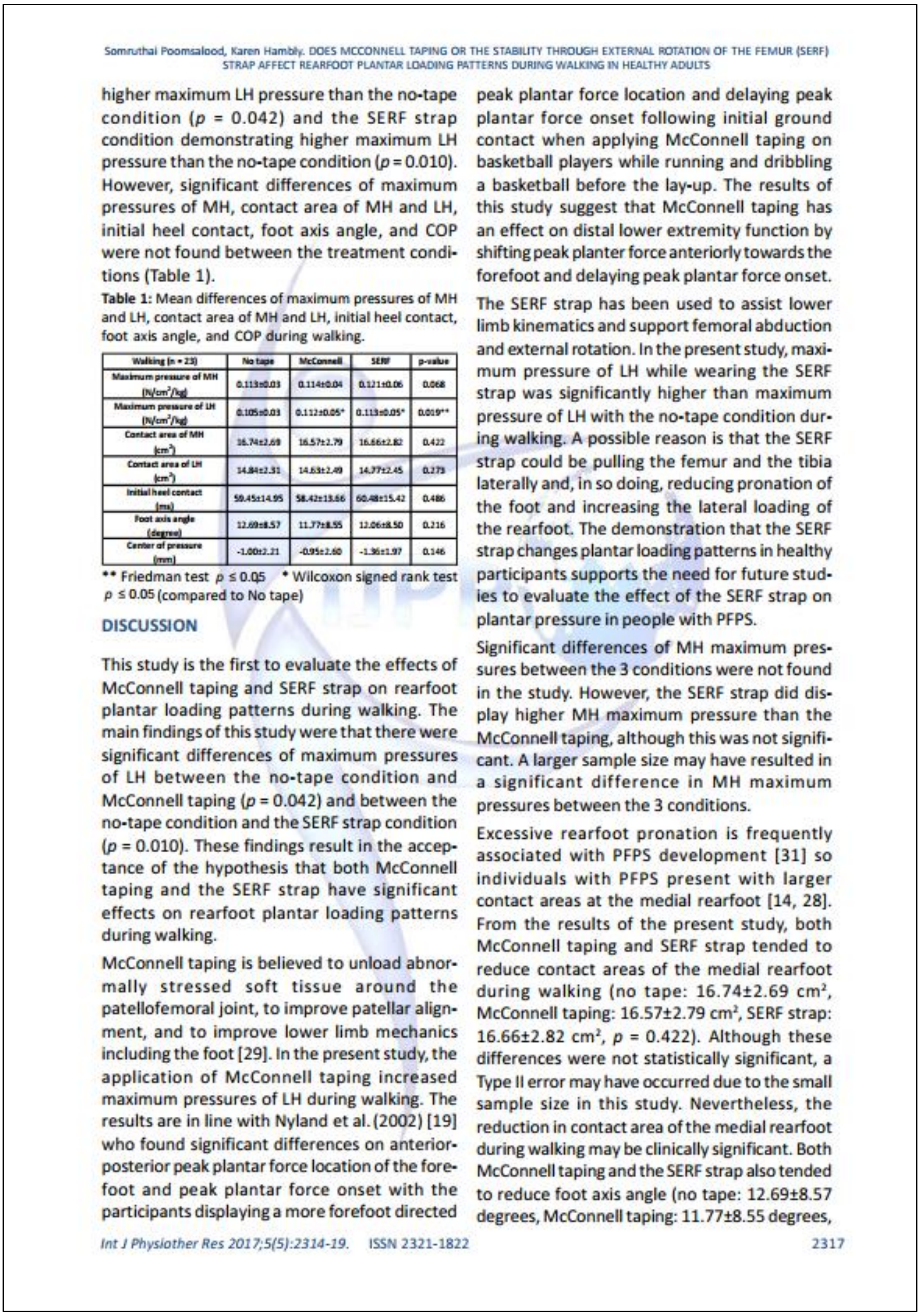
Statistical analysis: All rear foot plantar loading patterns were expressed as mean±standard deviation (SD). Maximum foot pressures of medial heel (MH) and lateral heel (LH) were normalised by the participants' body weight. The data were checked for normal distributions using Shapiro-Wilk test. Maximum pressures of MH and LH and initial heel contact were not normally distributed so they were analysed by Friedman test and Wilcoxon Signed Rank test. Contact area of MH and LH, foot axis angle, and centre of pressure (COP) were analysed by repeated measures ANOVA and Tukey's Post-Hoc test as the data were normally distributed. The data were analysed using SPSS 16.0 (Norusis/SPSS Inc., Chicago, IL, USA).

Fig. 1: Application of McConnell taping (medial patellar taping) on the right knee

Fig. 2: Application of the stability through external rotation of the femur (SERF) strap on the right knee.

RESULTS

Twenty-three participants' foot pressures (12 men and 11 women) were collected in this study. There were statistically significant differences of maximum pressures of LH (p = 0.019) with McConnell taping condition demonstrating



higher maximum LH pressure than the no-tape condition (p = 0.042) and the SERF strap condition demonstrating higher maximum LH pressure than the no-tape condition (p = 0.010). However, significant differences of maximum pressures of MH, contact area of MH and LH, initial heel contact, foot axis angle, and COP were not found between the treatment conditions (Table 1).

Table 1: Mean differences of maximum pressures of MH and LH, contact area of MH and LH, initial heel contact, foot axis angle, and COP during walking.

Walking (n = 23)	No tape	McConnell	SERF	p-value
Maximum pressure of MH (N/cm^2/kg)	0.113±0.03	0.114±0.04	0.121±0.06	0.068
Maximum pressure of LH (N/cm^2/kg)	0.105±0.03	0.112±0.05*	0.113±0.05*	0.019**
Contact area of MH (cm^2)	16.74±2.69	16.57±2.79	16.66±2.82	0.422
Contact area of LH (cm^2)	14.84±2.31	14.63±2.49	14.77±2.45	0.273
Initial heel contact (ms)	59.45±14.95	58.42±13.66	60.48±15.42	0.486
Foot axis angle (degree)	12.69±8.57	11.77±8.55	12.06±8.50	0.216
Center of pressure (mm)	-1.00±2.21	-0.95±2.60	-1.36±1.97	0.146

** Friedman test $p \leq 0.05$ * Wilcoxon signed rank test $p \leq 0.05$ (compared to No tape)

DISCUSSION

This study is the first to evaluate the effects of McConnell taping and SERF strap on rearfoot plantar loading patterns during walking. The main findings of this study were that there were significant differences of maximum pressures of LH between the no-tape condition and McConnell taping (p = 0.042) and between the no-tape condition and the SERF strap condition (p = 0.010). These findings result in the acceptance of the hypothesis that both McConnell taping and the SERF strap have significant effects on rearfoot plantar loading patterns during walking.

McConnell taping is believed to unload abnormally stressed soft tissue around the patellofemoral joint, to improve patellar alignment, and to improve lower limb mechanics including the foot [29]. In the present study, the application of McConnell taping increased maximum pressures of LH during walking. The results are in line with Nyland et al. (2002) [19] who found significant differences on anterior-posterior peak plantar force location of the forefoot and peak plantar force onset with the participants displaying a more forefoot directed peak plantar force location and delaying peak plantar force onset following initial ground contact when applying McConnell taping on basketball players while running and dribbling a basketball before the lay-up. The results of this study suggest that McConnell taping has an effect on distal lower extremity function by shifting peak planter force anteriorly towards the forefoot and delaying peak plantar force onset.

The SERF strap has been used to assist lower limb kinematics and support femoral abduction and external rotation. In the present study, maximum pressure of LH while wearing the SERF strap was significantly higher than maximum pressure of LH with the no-tape condition during walking. A possible reason is that the SERF strap could be pulling the femur and the tibia laterally and, in so doing, reducing pronation of the foot and increasing the lateral loading of the rearfoot. The demonstration that the SERF strap changes plantar loading patterns in healthy participants supports the need for future studies to evaluate the effect of the SERF strap on plantar pressure in people with PFPS.

Significant differences of MH maximum pressures between the 3 conditions were not found in the study. However, the SERF strap did display higher MH maximum pressure than the McConnell taping, although this was not significant. A larger sample size may have resulted in a significant difference in MH maximum pressures between the 3 conditions.

Excessive rearfoot pronation is frequently associated with PFPS development [31] so individuals with PFPS present with larger contact areas at the medial rearfoot [14, 28]. From the results of the present study, both McConnell taping and SERF strap tended to reduce contact areas of the medial rearfoot during walking (no tape: 16.74±2.69 cm², McConnell taping: 16.57±2.79 cm², SERF strap: 16.66±2.82 cm², p = 0.422). Although these differences were not statistically significant, a Type II error may have occurred due to the small sample size in this study. Nevertheless, the reduction in contact area of the medial rearfoot during walking may be clinically significant. Both McConnell taping and the SERF strap also tended to reduce foot axis angle (no tape: 12.69±8.57 degrees, McConnell taping: 11.77±8.55 degrees,

SERF strap: 12.06±8.50 degrees, $p = 0.216$) which means that foot abduction and pronation decreased. Barton et al. (2010) [32] evaluated the foot posture in 15 young healthy volunteers and 15 volunteers with PFPS and found that significantly greater pronated foot posture between subtalar joint neutral and relaxed stance were indicated in PFPS group compared to healthy group. Levinger and Gilleard (2007) [33] measured rearfoot, tibia motion, and ground reaction force during the stance phase of walking in patients with PFPS and healthy individuals. The results indicated prolonged rearfoot eversion during the stance phase of walking in PFPS participants. Since individuals with PFPS produce higher foot pronation than healthy individuals, McConnell taping and SERF strap could be choices for individuals with PFPS to reduce foot pronation.

CONCLUSION

The applications of McConnell taping and the SERF strap resulted in significantly higher LH maximum pressures compared to the no-tape condition during walking. These results suggest that there could be a clinical role for McConnell taping or SERF strap use in reducing rearfoot pronation in people with lower extremity problems especially PFPS. Further studies should focus on the effect of the SERF strap and McConnell taping on plantar pressures in patients with PFPS.

ABBREVIATIONS

PFPS – Patellofemoral pain syndrome
VMO – Vastus medialis oblique
SERF – The Stability through External Rotation of the Femur
MH – Medial heel
LH – Lateral heel
COP – Centre of pressure

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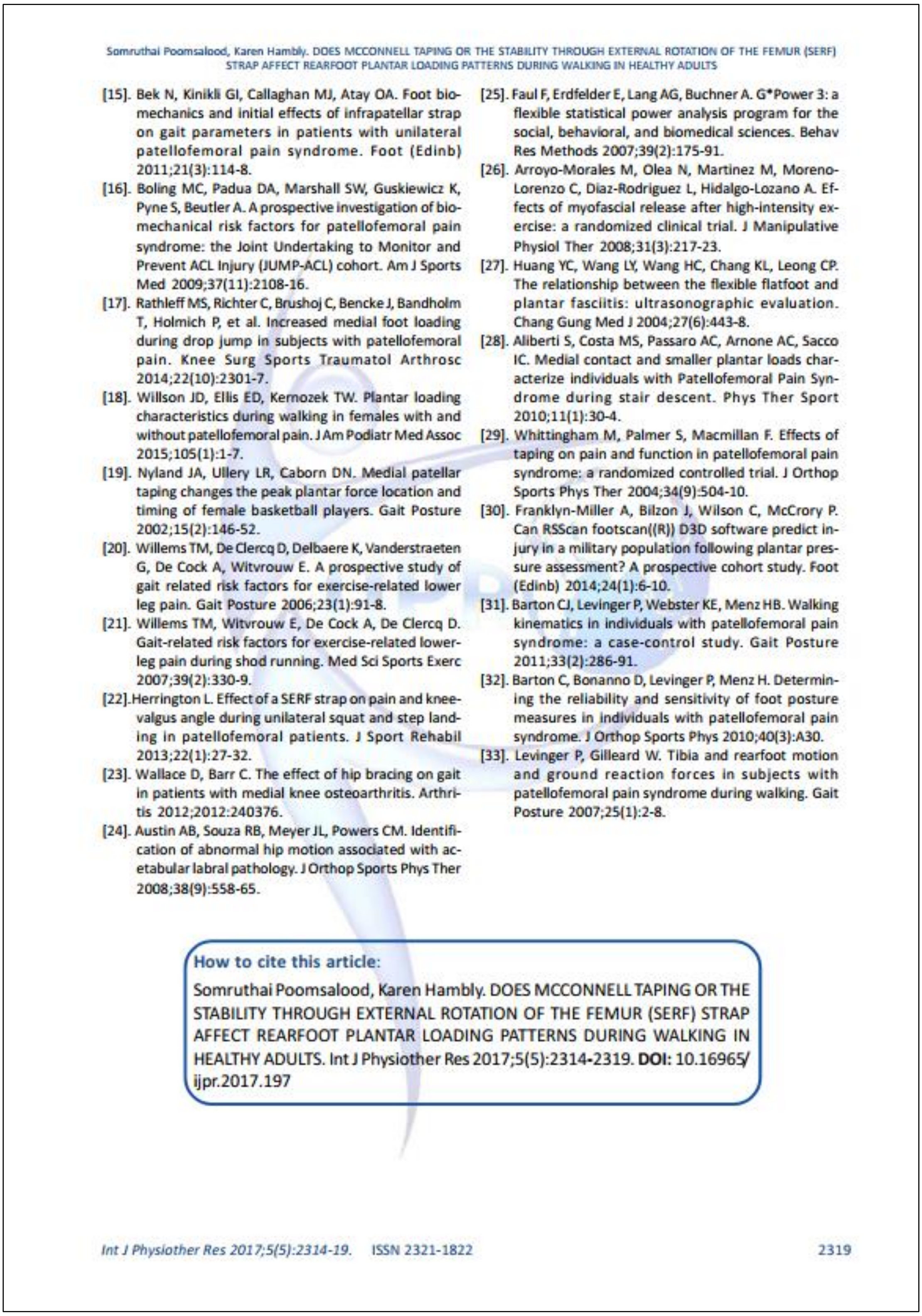
REFERENCES

[1]. Mostamand J, Bader DL, Hudson Z. Reliability testing of the patellofemoral joint reaction force (PFJRF) measurement during double-legged squatting in healthy subjects: a pilot study. J Bodyw Mov Ther 2012;16(2):217-23.
[2]. Callaghan MJ, Selfe J, McHenry A, Oldham JA. Effects of patellar taping on knee joint proprioception in patients with patellofemoral pain syndrome. Man Ther 2008;13(3):192-9.
[3]. Hinman RS, Bennell KL, Crossley KM, McConnell J. Immediate effects of adhesive tape on pain and disability in individuals with knee osteoarthritis. Rheumatology (Oxford) 2003;42(7):865-9.
[4]. Campolo M, Babu J, Dmochowska K, Scariah S, Varughese J. A comparison of two taping techniques (kinesio and mcconnell) and their effect on anterior knee pain during functional activities. Int J Sports Phys Ther 2013;8(2):105-10.
[5]. Christou EA. Patellar taping increases vastus medialis oblique activity in the presence of patellofemoral pain. J Electromyogr Kinesiol 2004;14(4):495-504.
[6]. Herrington L, Payton C. Effects of Corrective Taping of the Patella on Patients with Patellofemoral Pain. Physiotherapy 1997;83(11):566-72.
[7]. Kowall MG, Kolk G, Nuber GW, Cassisi JE, Stern SH. Patellar taping in the treatment of patellofemoral pain. A prospective randomized study. Am J Sports Med 1996;24(1):61-6.
[8]. Verma C, Krishnan V. Comparison between Mc Connell patellar taping and conventional physio-therapy treatment in the management of patellofemoral pain syndrome-A randomised controlled trial. JKIMSU 2012;1(2):95-104.
[9]. Larsen B, Andreasen E, Urfer A, Mickelson MR, Newhouse KE. Patellar taping: a radiographic examination of the medial glide technique. Am J Sports Med 1995;23(4):465-71.
[10]. Somes S, Worrell TW, Corey B, Lngersol CD. Effects of patellar taping on patellar position in the open and closed kinetic chain: a preliminary study. J Sport Rehabil 1997;6(4):299-308.
[11]. Worrell T, Ingersoll CD, Bockrath-Pugliese K, Minis P. Effect of patellar taping and bracing on patellar position as determined by MRI in patients with patellofemoral pain. J Athl Train 1998;33(1):16-20.
[12]. Powers CM, Landel R, Sosnick T, Kirby J, Mengel K, Cheney A, et al. The effects of patellar taping on stride characteristics and joint motion in subjects with patellofemoral pain. J Orthop Sports Phys Ther 1997;26(6):286-91.
[13]. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. J Orthop Sports Phys Ther 2010;40(2):42-51.
[14]. Aliberti S, Costa Mde S, Passaro Ade C, Arnone AC, Hirata R, Sacco IC. Influence of patellofemoral pain syndrome on plantar pressure in the foot rollover process during gait. Clinics (Sao Paulo) 2011;66(3):367-72.



[15]. Bek N, Kinikli GI, Callaghan MJ, Atay OA. Foot biomechanics and initial effects of infrapatellar strap on gait parameters in patients with unilateral patellofemoral pain syndrome. Foot (Edinb) 2011;21(3):114-8.

[16]. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. Am J Sports Med 2009;37(11):2108-16.

[17]. Rathleff MS, Richter C, Brushoj C, Bencke J, Bandholm T, Holmich P, et al. Increased medial foot loading during drop jump in subjects with patellofemoral pain. Knee Surg Sports Traumatol Arthrosc 2014;22(10):2301-7.

[18]. Willson JD, Ellis ED, Kernozek TW. Plantar loading characteristics during walking in females with and without patellofemoral pain. J Am Podiatr Med Assoc 2015;105(1):1-7.

[19]. Nyland JA, Ullery LR, Caborn DN. Medial patellar taping changes the peak plantar force location and timing of female basketball players. Gait Posture 2002;15(2):146-52.

[20]. Willems TM, De Clercq D, Delbaere K, Vanderstraeten G, De Cock A, Witvrouw E. A prospective study of gait related risk factors for exercise-related lower leg pain. Gait Posture 2006;23(1):91-8.

[21]. Willems TM, Witvrouw E, De Cock A, De Clercq D. Gait-related risk factors for exercise-related lower-leg pain during shod running. Med Sci Sports Exerc 2007;39(2):330-9.

[22].Herrington L. Effect of a SERF strap on pain and knee-valgus angle during unilateral squat and step landing in patellofemoral patients. J Sport Rehabil 2013;22(1):27-32.

[23]. Wallace D, Barr C. The effect of hip bracing on gait in patients with medial knee osteoarthritis. Arthritis 2012;2012:240376.

[24]. Austin AB, Souza RB, Meyer JL, Powers CM. Identification of abnormal hip motion associated with acetabular labral pathology. J Orthop Sports Phys Ther 2008;38(9):558-65.

[25]. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39(2):175-91.

[26]. Arroyo-Morales M, Olea N, Martinez M, Moreno-Lorenzo C, Diaz-Rodriguez L, Hidalgo-Lozano A. Effects of myofascial release after high-intensity exercise: a randomized clinical trial. J Manipulative Physiol Ther 2008;31(3):217-23.

[27]. Huang YC, Wang LY, Wang HC, Chang KL, Leong CP. The relationship between the flexible flatfoot and plantar fasciitis: ultrasonographic evaluation. Chang Gung Med J 2004;27(6):443-8.

[28]. Aliberti S, Costa MS, Passaro AC, Arnone AC, Sacco IC. Medial contact and smaller plantar loads characterize individuals with Patellofemoral Pain Syndrome during stair descent. Phys Ther Sport 2010;11(1):30-4.

[29]. Whittingham M, Palmer S, Macmillan F. Effects of taping on pain and function in patellofemoral pain syndrome: a randomized controlled trial. J Orthop Sports Phys Ther 2004;34(9):504-10.

[30]. Franklyn-Miller A, Bilzon J, Wilson C, McCrory P. Can RSScan footscan((R)) D3D software predict injury in a military population following plantar pressure assessment? A prospective cohort study. Foot (Edinb) 2014;24(1):6-10.

[31]. Barton CJ, Levinger P, Webster KE, Menz HB. Walking kinematics in individuals with patellofemoral pain syndrome: a case-control study. Gait Posture 2011;33(2):286-91.

[32]. Barton C, Bonanno D, Levinger P, Menz H. Determining the reliability and sensitivity of foot posture measures in individuals with patellofemoral pain syndrome. J Orthop Sports Phys 2010;40(3):A30.

[33]. Levinger P, Gilleard W. Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. Gait Posture 2007;25(1):2-8.

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