Strength and flexibility of the hip, knee and ankle associated with patellofemoral pain syndrome: A case-control study

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Declaration

Name of candidate: Naomi Helen Stuhlmann

This thesis entitled: 'Strength and flexibility of the hip, knee and ankle associated with patellofemoral pain syndrome: A case control study' is submitted in partial fulfilment for the requirements for the Unitec degree of Master of Osteopathy.

Candidates Declaration:

I confirm that:

- This thesis represents my own work;
- Research for this work has been conducted in accordance with the Unitec Research Ethics Committee Policy and Procedures, and has fulfilled any requirements set for this project by the Unitec Research Ethics Committee.
  Research Ethics Committee Approval Number: 2012-1054

Candidate Signature: Date:

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Introduction to Thesis

Patellofemoral pain syndrome (PFPS) is a condition defined by its symptoms of: anterior knee pain aggravated by physical activity, with no underlying pathology. Due to the multifactorial nature of this condition, standardised clinical diagnostic criteria and examination have yet to be agreed (Juhn, 1999; Zaffagnini, Dejour, & Arendt, 2010). Physical examination features of PFPS include: patella maltracking, decreased extensibility of the iliotibial band, a muscular imbalance of the quadriceps and hip stabilisers, and the presence of dysfunctional ankle mechanics. PFPS is generally considered to be an "overuse injury" (Thomeé, Augustsson, & Karlsson, 1999; Fredericson & Yoon, 2006), and therefore the condition can usefully be considered using an adapted version of the 'Dynamic, recursive model of aetiology in sport injury' Meeuwisse, Tyreman, Hagel, & Emery, 2007) to identify intrinsic risk factors which may predispose to the development of PFPS alongside interaction with other aspects of the model including extrinsic risk factors, adaptation to exercise or therapy, and various interventions. The investigation reported in this thesis employs a case-control design using physical examination measures for a selection of these intrinsic risk factors including: range of hip flexion, extensibility of the lateral structures of the hip and thigh, hip abduction strength, hip external and internal rotation strength, quadriceps length, and ankle dorsiflexion range. Comparisons in these physical examination measures were made between matched asymptomatic individuals and those with symptomatic PFPS. A reliability study of the physical examination measures was also conducted before data collection commenced.

This thesis is arranged in three sections. Section 1 is a review of the literature regarding PFPS, and the musculoskeletal components of the condition. An adaption of the 'Dynamic, recursive model of aetiology in sport injury' (Meeuwisse et al., 2007) has been used to contextualise the intrinsic risk factor contribution to PFPS. Section 2 contains a manuscript formatted in accordance with submission requirements for the journal of *Physical Therapy in Sport (*Appendix 4: Instructions for the Authors). Section 3: Consists of the Appendices including ethics documentation.

SECTION 1: Literature Review

Introduction

Patellofemoral pain syndrome (PFPS) is a common overuse injury which mainly affects young female athletes (Devereaux & Lachmann, 1984; Yates & Grana, 1986; Boling, Padua, Marshall, Guskiewicz, Pyne, & Beutler, 2010; Taunton, Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2002). The multi-causal aetiology of PFPS creates challenges in defining the basic epidemiology, establishing diagnostic criteria and identifying effective approaches to treatment. At present, there appears to be no objective examination approach for diagnosis and classification of the condition. PFPS is defined by symptoms of anterior knee pain present at rest and worsening with activities such as stair ascent or descent, with no obvious underlying pathology (Juhn, 1999; Zaffagnini, Dejour, & Arendt, 2010). Other factors that have been described as clinical features of PFPS include: a large Q-angle, an appearance of patella maltracking, decreased extensibility of the iliotibial band, a muscular imbalance of the quadriceps and hip stabilisers, the presence of dysfunctional ankle and foot mechanics, and overuse of the lower limb via physical activity (Thomeé, Augustsson, & Karlsson, 1999; Fredericson & Yoon, 2006). Of the studies that were investigated for this literature review, three of them found no significant link between these clinical features to PFPS (Powers, Ward, Chan, Chen, & Terk, 2004; Fulkerson & Buuck, 2004; Piva, Goodnite, & Childs, 2005). This emphasises the need to identify which factors are components of PFPS, and which factors are more likely to only develop into PFPS when in conjunction with an extrinsic risk factor.

Normal Structure and Function of the Patellofemoral Joint

The patellofemoral joint is the articulation between a sesamoid bone – the patella, and the patellar groove of the femur. The tibia is not considered part of the anatomical patellofemoral joint, as the patella only serves as a covering over the tibiofemoral joint (Tecklenburg, Dejour, Hoser, & Fink, 2006), for this reason, this will not be discussed in the following section. Due to the incongruent retro patellar cartilage and the bony contours of the patellar, stability is provided by the surrounding musculature and ligaments (Stäubli, Dürrenmatt, Porcellini, & Rauschning, 1999). The patella is able to move superiorly, inferiorly rotate and tilt within the sagittal plane of the trochlear groove. Initially the force created by the patella ligament of the patellofemoral joint was believed to act as a “frictionless pulley”, with the assumption the patella ligament force was equal to that of the quadriceps tendon. More recently, authors have expressed the opinion that multidirectional forces apply to the movement of the patella, this includes lateral tracking against the femur (Mason, Leszko, Johnson, & Komistek, 2008). Lateral tracking of the patella occurs most often at 20 degrees of knee flexion, when the medial patellofemoral ligament can no longer resist this movement

(Amis, Firer, Mountney, Senavongse, & Thomas, 2003). It could therefore be assumed symptoms of PFPS, due to lateral subluxation of the patella, are experienced during activities such as, sitting, or ascending or descending stairs.

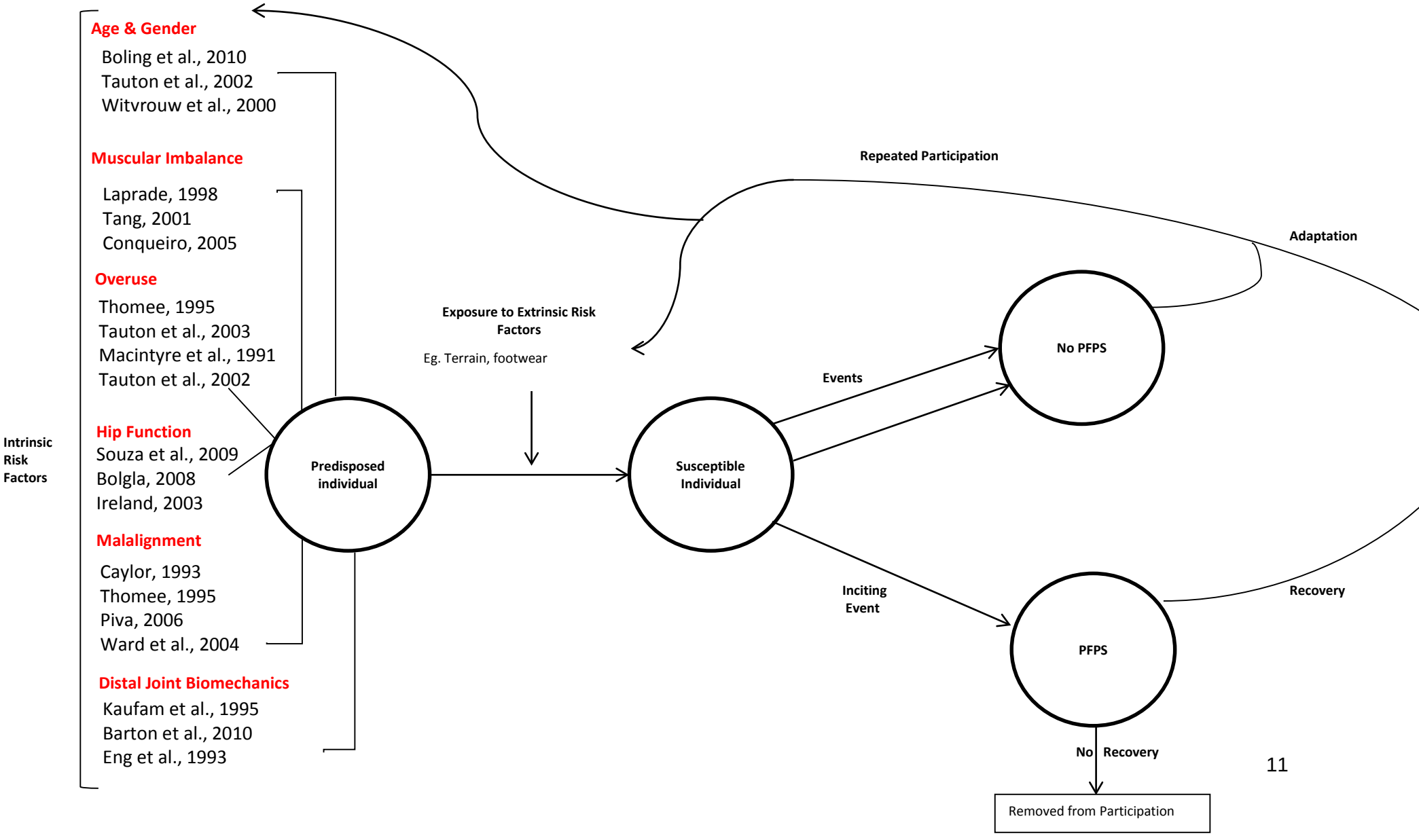
Aetiology of Overuse Injury

Defining injury proves to be difficult, as it occurs in all different contexts. Quinn and Fallon (1999), encompass the mental component of injury but lack in the biomechanical component, by defining injury as: *"a traumatic life event with physical and psychological ramifications"* (p.210). Whereas, Whiting and Zernicke (2008), emphasise purely the anatomical nature of injury, defining it as: *"the damage sustained by tissues of the body in response to physical trauma"* (p.2). Verghan and Mechelen (2009) expand on this definition with: *"Any physical complaint caused by a transfer of energy that exceeds the body's ability to maintain its structural and/or functional integrity"* (p.44). An overuse injury however is difficult to define, as it does not always present with gradual worsening of symptoms. For example, a patient may report knee pain proceeding a run, or sports game they played, however the actual process of the injury and poorly distributed forces may have been underway for a period of time before it exceeded the body's tolerance. For this reason an overuse injury is defined as; an injury caused by the repeated exposure to micro-trauma without an identifiable traumatic event (Fuller et al., 2006; Verhagen & Mechelen, 2009). Meeuwisse, Tyreman, Hagel, & Emery, (2007) have proposed a multifactorial model - the 'Dynamic, recursive model of aetiology in sport injury'. The model describes the types of factors involved in the development of an overuse injury. These factors include intrinsic risk factors (predisposing factors), extrinsic risk factors, exposure to 'inciting' event/s, adaptations to the environment and interventions (which could be preventive or therapeutic). The recursive nature of this model allows for repeat exposure to extrinsic risk factors, which may in turn influence the intrinsic risk factors. The cyclic nature of the model is unique in the fact that it illustrates that overuse injury need not be a result of a singular incident but, rather a number of incidents resulting in the inability of the body to sustain musculoskeletal integrity.

PFPS is multifactorial with many intrinsic risk factors thought to influence the condition (Thomeé et al., 1999; Fredericson & Yoon, 2006). It is categorised as an 'overuse injury' (Boling et al., 2010; Taunton et al., 2002), which has manifested due to a recursive exposure to a number of events and extrinsic risk factors (stair climbing, uneven terrain, inefficient footwear and so forth). This model is therefore appropriate to be used in the context of describing influential factors towards PFPS (see Figure 1).

Figure 1. Adaptation of Dynamic, recursive model of aetiology in sport injury' (Meeuwisse et al., 2007), for the condition of PFPS

The Intrinsic Risk Factors (listed below in red font) and their influence on PFPS are discussed in detail, in the following literature review. The components of the model are explained on the following page. The model is of a cyclic nature, and can be entered at any stage.



Considering PFPS in context of the "Dynamic, recursive model of sports injury"

The intrinsic risk factors

These factors differ depending on each individual. In the case of PFPS these could be age, gender, flexibility, muscular imbalance, strength, history of previous injury, malalignment of the lower limb, or distal joint biomechanics. This model suggests if there was an improvement of an intrinsic risk factor (for example, increased muscular strength), in turn the individual's susceptibility towards injury would decrease. This increase in muscle strength could come from repeated participation in an event (for example, a training programme). However, the opposite could also occur. If the training programme caused continual micro-trauma, this would have a negative effect on the intrinsic risk factor and lead to a 'susceptible to injury' individual.

The extrinsic risk factors

An extrinsic risk factor refers to an outside factor which could expose the individual to risk. This could be in the form of inappropriate foot wear, protective clothing available, difficult training terrain, an inappropriate ergonomic set up of a work place or a change in a gym programme. These extrinsic risk factors combine and interact with the intrinsic risk factors, this combination may have a detrimental effect on the 'predisposed individual', creating a 'susceptible to injury' individual.

The inciting event

The occurrence of a single or many events which lead to injury, no injury, or improved intrinsic factors. The event does not need to be monumental.

PFPS

The individual will re-enter the cycle if the recovery path is taken. If no recovery is made, or no medical intervention is implemented to aid recovery, the individual will be removed from the cycle.

No PFPS

If no injury is acquired the individual will continue in the cycle, however this model allows for adaptation to take place. This adaptation can influence the intrinsic risk factors, therefore making the individual more or less susceptible to injury. This path can also be taken if injury occurs but recovery is made.

The cyclic nature of this model allows an individual to enter it at any stage. The dynamic nature of this model allows for instability, or changes in risk factors occurring over time (Meeuwisse et al., 2007).

Methodological Discussion Regarding Establishment of a Cause-Effect Relationship between Risk Factors and PFPS

Ideally the causation or causative factors of PFPS would be established using randomised control trials (Solomon, Cavanaugh, & Draine, 2008). Ethically it is not appropriate to manipulate variables such as malalignment of the patella; therefore other research approaches to investigate aetiology are necessary.

Intervention studies to determine the aetiology of PFPS have been used as an alternative to randomised controlled trials. Systematic reviews of intervention studies have identified a strong association between iliotibial band tightness, decreased hamstring and quadriceps strength, patella tilting, and hip musculature weakness which could ultimately be related to PFPS (Arroll, Ellis-Pegler, Edwards, & Sutcliffe, 1997; Waryasz & McDermott, 2008).

The use of intervention methods such as orthotics, patella taping and mobilization could determine which method had the greatest effect on symptoms and therefore assume that the variable influenced could be deducted as the aetiology of the condition (Crossley, Bennell, Green, & McConnell, 2001). The limitation of this method lies in that improvement could be due to natural history of the condition.

Physical therapy intervention studies have also shown an improvement in PFPS symptoms, but without a comparison to a placebo control the results become inconclusive to which intervention was more significant in the decline in the symptoms (Crossley et al., 2001). Intervention studies can be difficult to run over a long period of time due to the financial costs (payments to practitioners) and the ongoing compliance cost (time) for subjects to complete the study. The challenges in using intervention studies to investigate PFPS aetiology have led to the use of case-control, or cross-sectional study designs (Thomee, Renström, Karlsson, & Grimby, 1995; Piva et al., 2005; Souza & Powers, 2009; Bolgla, Malone, Umberger, & Uhl, 2008; Ireland, Willson, Ballantyne, & Davis, 2003).

The case-control design has the advantage of studying multiple factors simultaneously. Although case-control designs cannot be used to define the cause of a condition, it can provide preliminary or foundational ideas about influential variables (Stommel & Willis, 2004). Case-control designs are also limited in the sense it can be challenging for investigators to ‘match’ cases and controls.

Cross sectional designs have been popular in previous investigations of PFPS (Laprade, Culham, & Brouwer, 1998; Ballas, Tytko, & Cookson, 1997) as the 'outcome' has already occurred and therefore these studies are efficient and cost effective.

Patellofemoral Pain Syndrome (PFPS)

Anterior knee pain in the absence of pathology, more commonly known as PFPS, has yet to be definitively defined. The clinical picture however, includes complaints of anterior knee pain, with insidious onset, worsening on activity or prolonged sitting, specifically aggravated by stair climbing or descending (Juhn, 1999). Poor muscle strength, aberrant motor control and limitations in joint range of motion of the lower extremity are also commonly cited in clinical teaching as being important contributors to PFPS (Frontera, Silver, & Rizzo, 2008; Ferri, 2011; Bope & Kellerman, 2012). These characteristics are not sufficient diagnostic criteria for PFPS, as they are also observed in people without PFPS (Thomee et al.,1995; Fulkerson & Buuk, 2004) .

The diagnosis of PFPS is most prevalent in adolescents and young adults (Witvrouw et al., 2014). It appears to be more common in females (Devereaux & Lachmann, 1984; Yates & Grana, 1986; Witvrouw et al., 2014). A recent study of United States Naval special operators (US Navy 'SEALs') supports previous epidemiological indications of a higher prevalence of PFPS occurring in females (Boling et al., 2010). Results revealed female US Navy SEALs were almost twice as likely (OR = 2.23; 95% CI: 1.19 to 4.20) to develop the condition than their male counterparts (Boling et al., 2010). Although not statistically significant the prevalence of PFPS on enrolment of the study, was higher in females (15%) compared to their male counterparts (12%). This could be attributable to the anatomical variation in Q-angle, between male and females (Boling & The University of North Carolina at Chapel Hill. Human Movement Science: Doctoral, 2008).

Although a number of predisposing structural and functional characteristics are thought to contribute to the aetiology of PFPS, the roles and interactions of these characteristics appear to be complex and it is not known to what extent these factors may contribute to the condition. Clinical studies are yet to show consistent results when assessing biomechanical differences in those with PFPS and those without (Fredericson & Yoon, 2006; Witvrouw et al., 2014; Rathleff, Rathleff, Crossley, & Barton, 2014).

Thomeé et al., (1999) suggests three general components of PFPS. These three components will provide the basic framework for consideration of literature in this review:

(i) "*malalignment of the lower extremity and/or the patella;*

(ii) *muscular imbalance of the lower extremity;*

(iii) *over-activity [physical activity]* " (p.1).

The aim of this section of the review is to identify the most important variables which should be included in future studies of contributing factors for PFPS.

i. Malalignment of the patella:

The biomechanics of the patellofemoral joint relies on the passive and dynamic stabilizers of the patella (Schepsis & Busconi, 2006). The patella is passively stabilized through the congruency of its shape within the trochlea groove of the femur, and the peripatellar retinaculum (Thomeé et al., 1999). Dynamically, it is supported by vastus medialis, vastus lateralis, vastus intermedius and rectus femoris (Thomeé et al., 1999). The Q-angle and extensibility of the iliotibial band can also influence the dynamic positioning, or movement of the patella within the trochlea groove. Dysfunction of this position or movement (especially within the lateral direction) has been clinically termed as "malalignment" or "maltracking" of the patella, and it has been considered by clinicians that this could be associated with the pain experienced with PFPS (Melchione & Sullivan, 1993).

The congruence angle of the patella is a measurement which is commonly used to assess patella subluxation (Chow, 2001) (Figure 2). A congruence angle of -6% to -8% is considered normal resulting in an asymptomatic knee (Chow, 2001). One of the earliest sources of data that supported the "maltracking" notion was reported by Insall, Aglietti, and Tria (1983). Here, they undertook a clinical study of surgical intervention to "realign" 75 symptomatic knees of which the patients complained of patella pain, or patella 'instability'. In a follow-up from two to ten years 91% of the participants were asymptomatic and their average congruence angle had regressed to -11%. This improvement was attributed to the correction of the congruence angle rather than the severity of chondromalacia found on surgery. Contrastingly, more recent research suggests maltracking of the patella may not directly cause the pain experienced by PFPS sufferers but supports the theory of patella congruency within the patellofemoral joint as a contributing factor.

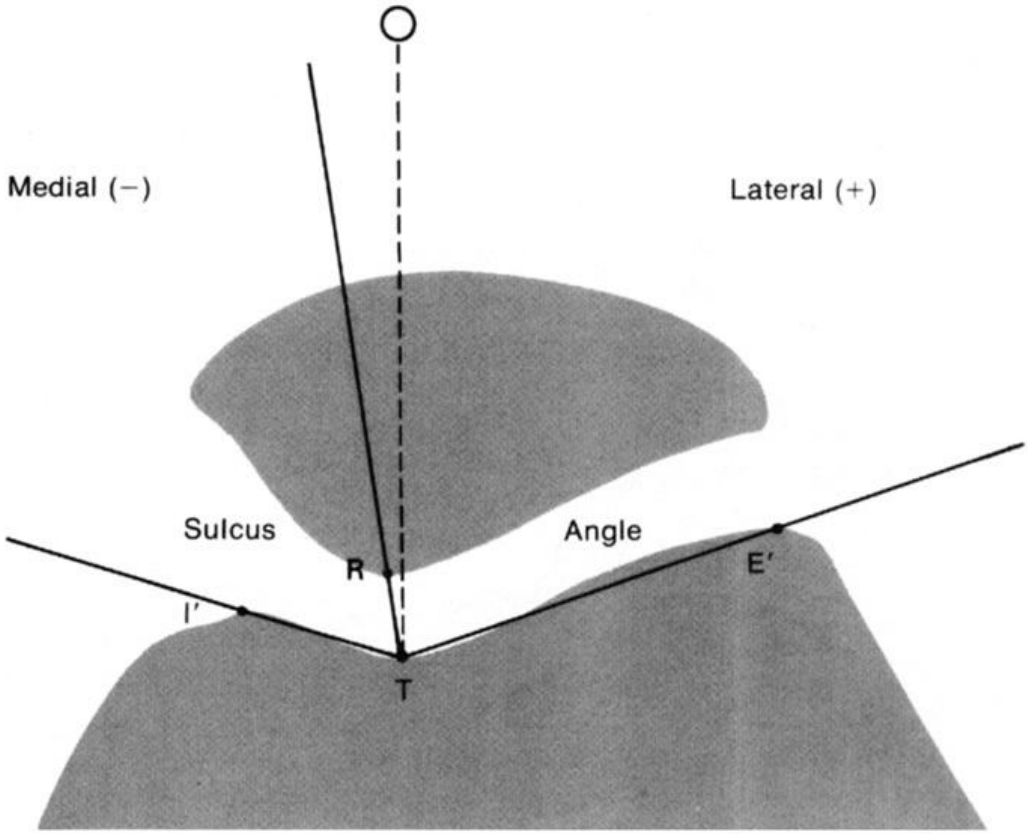


Figure 2. Congruence Angle of the Patella. Sulcus angle=E'TI', Neutral reference line=TO, Apex of the median patella ridge connected to the sulcus=RT. When RT is 'Medial (-)' to the neutral reference line the angle is given a negative value. When RT is 'Lateral (+) to the neutral reference line the angle is given a positive value. http://www.patellofemoral.org/pfoe/images/04_12.jpg Retrieved on the 20th of May 2014

Powers, Ward, Chan, Chen, and Terk (2004) investigated the relationship between lateral patella displacement, lateral patella tilt, patellofemoral joint contact area and experienced patellofemoral pain in an intervention study of fifteen participants. An 'On-Track Patellar Brace' (Don Joy Inc., Vista, CA), a 'Patellar Tracking Orthosis' (PTO; Breg Inc., Vista, CA) or 'patella taping' were used on the symptomatic knee. The participants reported a 50% decrease in patellofemoral joint pain when using the 'On-Track Patellar Brace' and 44% decrease in patellofemoral joint pain when using the 'Patellar Tracking Orthosis'. However, axial magnetic resonance imaging showed little change in lateral patella tilt and lateral patella displacement. The 'Patella Tracking Orthosis' and the 'On-Track Patellar Brace' did however significantly increase the patellofemoral contact area space by 21% and 24% respectively.

Although these results cannot describe the exact mechanism for the reduction of pain, they do suggest PFPS could in part be due to the congruency angle of the patella. This would cause abnormal loading of mechanical stress through the patellofemoral joint, rather than lateral maltracking of the patella. With contrasting results in regards to patella malalignment, investigations of further predisposing factors such as lower limb alignment, Q-angles, and muscular extensibility associated with PFPS could add insight to the aetiology of this condition.

Q-angle

The Q-angle is formed by a line from the anterior superior iliac spine to the centre of the patella and the tibial tubercle (Fulkerson & Buuck, 2004). There is reasonable consensus on what is considered a 'normal' Q-angle. Generally 14 to 20 degrees (95% CI) is considered normal with females usually exhibiting a larger angle (Fulkerson & Buuk, 2004). It is noteworthy that Q-angles outside the normal range do not necessarily result in symptomatic knees (Fulkerson & Buuk, 2004). Fulkerson and Buuk's (2004) findings are consistent with the 'Dynamic, recursive model of sport injury' (Meeuwisse et al., 2007) used, as a singular predisposing factor is not always sufficient to cause PFPS alone.

The Q-angle is an important determinant of the lateral movement of the patella during a quadriceps contraction. Excessive lateral patella movement is considered to be dysfunctional and is usually described as "maltracking" (Brown, Cui, Mihalko, & Saleh, 2009). Due to the high level of measurement error when measuring this angle, varied results occur. Olerud and Berg (1984), suggest having the patient standing when measuring the Q-angle as this will place the patella in the neutral position. If the tibia is rotated either internally or externally it will change the position of the tibial tubercle and therefore have an effect on the Q-angle (Olerud & Berg, 1984; Brown et al., 2009). Although the Q-angle gives insight into the lateral movement of the patella, it cannot be altered, unless by surgical intervention, and therefore is not of great interest from a physical therapists perspective.

A number of studies have considered the relationship of Q-angle between those with PFPS and asymptomatic individuals. Caylor, Fites, and Worrell (1993), reported no statistical significant difference in Q-angle between 50 asymptomatic (absence of anterior knee pain) and 52 symptomatic (presence of anterior knee pain) individuals. The average angle of symptomatic subjects was only 1.3 degrees more than the average angle for asymptomatic subjects. Thomee et al., (1995) also found no difference between the Q-angle of symptomatic and asymptomatic participants. However, the difference in activity level

between the two groups was noted - the symptomatic participants were on average more physically active (Thomee et al., 1995). The 'Dynamic, recursive model of aetiology in sport injury' (Meeuwisse et al., 2007) supports these results, as it demonstrates lateral tracking may be a strong intrinsic risk factor towards PFPS. However, the symptomatic participants could also have the intrinsic risk factor of 'overuse'. Together, and on their own, these intrinsic risk factors could lead to a "predisposing to injury" individual. The assessment of participants with similar physical activity level would give greater insight into whether or not lateral maltracking is a significant intrinsic risk factor (Witvrouw et al., 2014).

Iliotibial band

The iliotibial band (ITB) is considered an extension of the tensor fascia lata, with the distal end separating into two components. One component attaches to Gerdy's tubercle on the tibia where the other becomes the iliopatella band which integrates into the lateral retinaculum attaching onto the lateral aspect of the patella, influencing its positioning (Herrington, Rivett, & Munro, 2006). Tightening of this component has been cited as a cause of anterior knee pain, due to the lateral pull on the patella (Melchione & Sullivan, 1993).

As the flexibility of the ITB cannot be measured directly *in vivo*, a clinical test (Ober's test) is performed to measure the subjective length and tension of the ITB. The Ober's test however, is performed with the lower extremity in extension and this position does not reflect the positioning of the patella during gait. With the leg in extension the ITB is put under tension beyond what it would normally experience, therefore by flexing the knee to 90 degrees the patella will laterally glide to the extent it would during normal gait (Melchione & Sullivan, 1993). A modified version of the Ober's test (performed with the subject in a side lying position, with the test knee flexed to 90 degrees) has been shown to have excellent intra-tester reliability (ICC > 0.90; SEM = 1˚) (Reese & Bandy, 2003; Melchione & Sullivan, 1993). The modified Ober's test is more representative of normal functional activity, therefore should be used to assess the association between PFPS and lateral patella tracking. Piva et al., (2005) used this modified version of the Ober's test, when comparing ITB extensibility between those with PFPS and those without. There was no significant difference in ITB extensibility between the groups. These findings challenge the clinical belief that poor ITB extensibility has a negative influence on patellofemoral joint function and may be associated with PFPS (Hyde & Gengenbach, 2006; Norris, 2011).

ii. Muscular Imbalance:

Vastus medialis obliquus

Vastus medialis obliquus (VMO) is the name used to describe the obliquely oriented fibres of the vastus medialis muscle of the quadriceps. It is hypothesized that dysfunction of the vastus medialis obliquus has a direct link with the aetiology of PFPS (Hyde & Gengenbach, 2006; DeLisa, Gans, & Walsh, 2005; Chandler & Brown, 2008). Laprade et al., (1998), explained this idea by suggesting, due to the role VMO has on medial stabilisation of the patella, insufficient motor control of this muscle will lead to lateral deviation of the patella. With this malalignment the biomechanics of the knee joint become abnormal and force is no longer distributed appropriately, therefore causing stress to the joint. However, the results of Laprade et al., (1998) research contradict this theory. The ratio of contractile activity in vastus medialis obliquus to vastus lateralis (VMO:VL) was measured between participants with PFPS (n=9) and a control asymptomatic group (n=18) using electromyography. Results showed no significant difference of VMO:VL ratios between symptomatic and asymptomatic individuals (Laprade et al. 1998). Tang, Chen, Hsu, Chou, Hong, & Lew, (2001), found when studying the effects of open chain kinetic exercises, there was no significant difference of VMO:VL between the symptomatic and control group, however when the VMO maximal firing was induced by a closed chain kinetic exercise, from 0 to 60 degrees of knee flexion, the VMO:VL ratio was lower for PFPS participants. This discrepancy between the two research studies is not uncommon in the literature surrounding PFPS. It helps create a basis for further research around the importance of muscular imbalance as a contributing factor towards the syndrome.

Coqueiro, Bevilaqua-Grossi, Bérzin, Soares, Candolo, & Monteiro-Pedro (2005), found when comparing myoelectric activity of Vastus Lateralis Longus (VLL) and Vastus Medialis Obliquus of females with PFPS, during a double leg semi-squat (DLSS) exercise, VLL muscle's electrical activity was significantly higher than that of VMO. These results suggest a muscular imbalance between the medial and lateral compartment of the quadriceps femoris muscle in an individual with PFPS. However, these findings were not consistent when the females performed the DLSS with a hip adduction isometric contraction (DLSS-HA). This suggests the hip adductors influence the muscular balance of the VMO and therefore could also be considered an intrinsic risk factor towards PFPS. Magnetic resonance imaging (MRI) could more accurately discern a muscular imbalance rather than electromyography (Coqueiro et al., 2005). An MRI however is limited as it allows observation of muscle architecture only, and does not give insight into function and firing of the muscle. The function of the musculature would provide more insight into the role of dynamic stabilization of the patella.

Hip musculature

When considering muscular influence, as an intrinsic risk factor of PFPS, proximal muscle groups from the knee must be included, as they influence the biomechanics and force distributed through the patellofemoral joint itself. A number of studies (Bolgla et al., 2008; Souza & Powers, 2009; Ireland et al., 2003), and clinical observations (Chandler & Brown, 2008; Buschbacher, Prahlow, & Dave, 2008) suggest hip musculature could play a substantial role in the manifestation of PFPS.

Hip abduction can be an influential factor on the valgus angle of the lower limb. Without sufficient strength of the abductors the femur may adduct and internally rotate. This adduction and internal rotation generates abnormal compression and shearing forces through the lateral aspect of the patella. When participating in repetitive activities the malalignment of the patella with added forces may contribute to retro patellar articular damage (Ireland et al., 2003; Powers, 2003; Piva et al., 2006). Increased internal femoral rotation can also significantly increase patellofemoral joint contact pressures, which could contribute to PFPS (Lee, Morris, & Csintala, 2003).

Souza and Powers (2009) investigated the role of hip musculature on the patellofemoral joint when they compared hip kinematics in females with PFPS against asymptomatic controls. Peak hip abduction torque was shown to be significantly less in the symptomatic group (n=21) when compared to the controls (n=20) (mean ± SD, 1.39 ± 0.41 versus 1.62 ± 0.26 Nm/kg of body mass; *p = 0.02).*The results also demonstrated a greater amount of peak hip internal rotation within the symptomatic group compared to the asymptomatic group (mean ± SD, 7.6˚± 7.0˚ versus 1.2˚ ± 3.8˚, $p < .001$). However, due to the cross-sectional study design, cause-and-effect is not able to be established.

Similar findings were found in other cross sectional studies which assessed hip kinematics of women suffering from PFPS (Bolgla et al., 2008; Ireland et al., 2003). Bolgla et al., (2008) investigation showed symptomatic participants generated 24% less hip external rotation and 26% less hip adductor torque than asymptomatic women. In the study conducted by Ireland et al., (2003), isometric contractions of the hip musculature were assessed. Individuals with PFPS demonstrated 26% less hip abduction strength and 36% less hip external rotation strength than their asymptomatic matched controls. Both studies were limited to females, which is understandable on the basis of gender prevalence, however, further studies should include male to allow results to be more heterogeneous.

Dysfunction of the hip musculature and kinematics may be associated with patellofemoral pain, but whether the dysfunction causes the pain, or the pain causes the dysfunction cannot be determined from the studies reported (Bolgla et al., 2008; Ireland et al., 2003). From a clinical perspective however it is important to consider the significance of poor hip muscle function as an intrinsic risk factor of PFPS. In doing so, the 'Dynamic, recursive model of sport injury' (Meeuwisse et al., 2007) can be used by clinicians to instil appropriate therapeutic interventions and eliminate exposure to extrinsic risk factors, focusing treatment on strengthening hip musculature in an aim to alleviate PFPS.

iii. Increased Physical Activity

Repetitive physical activity is widely understood to be an important contributing factor to PFPS (Thomee et al., 1995; Taunton, Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2003; Macintyre, Taunton, Clement, Lloyd-Smith, McKenzie, & Morrell, 1991; Ballas, Tytko, & Cookson, 1997). The 'Recursive Model of Sport Injury' (Meeuwisse et al., 2007), describes this process. Intrinsic risk factors such as malalignment, muscular imbalance or change in distal biomechanics can increase the pressure between the patella and contact with the femur during gait. When an individual is *repeatedly* exposed to extrinsic factors such as stair climbing, running and/or uneven surfaces (Rest, 1999) this can lead to the intrinsic risk factor of overuse, which in turn can predispose to a "susceptible individual" for PFPS.

Investigations into sporting groups and training programmes indicate a similar association between 'overuse' and PFPS. Tauton et al., (2003) studied seventeen training clinics in Vancouver for running injuries. The training clinics ran for 13 weeks. Of the 844 recreational runners participating in the study, the knee was reported as the most vulnerable site of injury (36% of men and 32% of women reporting pain in this area). 29% of the participants reported running at least twice a week. However baseline characteristics were not equal, as 42% of the participants reported they had previous injury from which they had not fully recovered.The knee pain therefore experienced could purely be a reoccurrence of the old injury (an "overuse" injury) not a development of PFPS. Further research should include a control group with no pre-existing injuries to validate results (Witvrouw et al., 2014).

Retrospective studies of running injuries show a similar association between overuse and PFPS. A less recent study of 4,173 running injuries seen at a sports medicine clinic over a four year period identified the knee to be the most common site of injury and PFPS the common diagnosis (Macintyre et al., 1991). More recently Taunton et al., (2002), studied data recorded from running injuries, over a two-year period from the Allan McGavin Sports Medicine Centre. 331 cases were diagnosed with PFPS out of 2002 cases observed. The

authors reported this as the most common overuse injury. Given the nature of these studies, unfortunately and understandably so, these findings do not have comparable non-injured subjects with documentation of their everyday activity. For this reason it is difficult to determine whether physical activity may have influenced the development of PFPS.Research determining contributing factors of PFPS should establish an even baseline of the individual's participation in physical activity (Witvrouw et al., 2014).

Thomee et al., (1995) undertook a case control study of 40 females, 20 individuals who were suffering from PFPS and 20 asymptomatic individuals. The symptomatic individuals were significantly more involved in physical activity compared to the control group and had a significantly lower "pain-free activity level" threshold than the controls. These results suggested PFPS was associated with long-term overloading of the patellofemoral joint (Thomee et al., 1995). Further research directed towards identifying the most influential intrinsic risk factors contributing to PFPS needs to match symptomatic and asymptomatic cases by physical activity participation. This will enable results to be less influenced by the variance in this factor.

Role of Ankle Mechanics

Earlier literature has neglected investigation into ankle stability as an intrinsic risk factor to PFPS. More recently however research has reported the role of the ankle to be influential (Barton, Bonanno, Levinger, & Menz, 2010). Change in ankle biomechanics due to muscular or ligamentous integrity can lead to a change in alignment, or decreased flexibility. During gait, excessive subtalar pronation causing internal rotation of the tibia may be a likely influential factor towards PFPS (Nigg, 2001). For normal sagittal plane knee mechanics to continue in this situation, the femur could compensate by internally rotating. Dynamically a greater knee valgus would result. The increase in knee valgus could contribute to symptoms of PFPS (Nigg, 2001). It is therefore necessary to investigate the influence that the ankle may have on the development of PFPS.

To determine whether a relationship existed between static foot structure and the development of musculoskeletal overuse injuries (inclusive of PFPS), Kaufam, Brodine, Shaffer, Johnson, & Cullison (1995) completed a study on Navy SEALs. Static ankle dorsiflexion was among the measurements taken of 449 trainee Navy SEALs before commencing a rigorous physical training course. Of the 449 individuals studied, 42 suffered from PFPS. However the incidence for PFPS to have developed in the 128 individuals that tested positive for 'tight' dorsiflexion (less than 11.5 degrees of dorsiflexion with the knee extended) was only 7.0 %, and the risk ratio was RR = 0.86 (95% CI = 0.37 to 2.00). This

study therefore does not support the association between decreased ankle dorsiflexion and PFPS, as a significant relationship could not be identified. Prediction of PFPS associated with decreased dorsiflexion in this study via static range of motion requests insight into an assessment of dynamic range of motion, as you could assume these would be closely linked. As PFPS is a condition that usually occurs from physical activity it would be appropriate to replicate a dynamic movement for a true relationship to be determined.

More recently, Barton et al., (2010), undertook a case control study and a study of the reliability of measurements, of foot and ankle characteristics between those with and without PFPS. Measurements were all of a weight bearing nature. Inter-rater reliability across all three raters was “good” with ICC of 0.75 to 0.9 ranging to “excellent” with ICC above 0.90. The strong level of reliability suggests that a clinician is highly likely to have accurate and dependable results when using these measurements to re-assess their patient’s foot and ankle characteristics each session. Cases and controls were also matched via gender, age, height, and body mass index.

Findings indicated that those with PFPS had a significant increase in foot pronation when measuring the Longitudinal Arch Angle (effect size, 0.90) and Foot Posture Index (effect size, 0.71). Greater ranges of motion in all foot posture measures were also detected in all those with PFPS. Subtalar Joint Neutral was used as a reference posture (effect sizes 0.75-1.02). These findings suggest that a change in foot or ankle mechanics can have a significant effect on the patellofemoral joint. What cannot be deducted from this study is whether the change in foot and ankle biomechanics has led to PFPS, or if the condition has caused a compensatory change in the foot and ankle.

In support of the findings of Barton et al., (2010), is Eng and Pierrynowski’s (1993) intervention study to attempt to correct subtalar pronation. Participants were females aged 13-17, all diagnosed with PFPS. From the 20 participants, 10 were assigned to the treatment group and ten to the control (this was done randomly). Both groups participated in a home exercise program consisting of varying quadriceps strengthening exercises, as well as participating in physical activity they would normally do. The treatment group received fitted orthotics in order to correct the pronation. The Visual Analogue Scale (VAS) was used to measure the pain experienced. Both groups reported a decreased pain level on the VAS during walking, running, stairs ascent, stairs descent, sitting for 1 hour, and squatting, however, the cases reported experiencing the greatest reduction of pain during the weight bearing activities. This suggests the orthotic may have altered the patellofemoral joint mechanics with the result of less nociception generation at the patellofemoral joint.

These studies (Eng & Pierrynowski, 1993; Kaufam et al., 1995; Barton et al., 2010) illustrate a further need to investigate the role of ankle mechanics involvement in PFPS. Despite that static and weight bearing measurements have been shown to be reliable and appropriate for clinical use, dynamic measurements may add insight into how the change in ankle mechanics influences gait. Further intervention studies, could assess differing footwear and the effect on PFPS although this would require considerable financial sponsorship.

Rationale for Further Studies

The use of the 'Dynamic, recursive model of sport injury' (Meeuwisse et al., 2007) allows us to view PFPS as a multifactorial condition. Reviewing the above literature illustrates that there is little validation of exactly which structural and functional impairments have the strongest association with PFPS. There is also little investigation into intra- and interrater reliability for physical examination measures of intrinsic risk factors of PFPS.

By adapting the Dynamic, recursive model of aetiology in sport injury' (Meeuwisse et al., 2007) to correspond specifically to PFPS, further investigation can be narrowed in to specific areas of interest. In this case, attention to the intrinsic risk factors which are most significant to the condition could add evidence and rationale for clinical diagnosis, examination and treatment.

Measurements which are to be used within a clinical setting must have a certain degree of reliability to produce accurate findings. An intrarater reliability study of any measures used to test intrinsic risk factors should therefore be done prior to any investigation of the chosen contributing factors of PFPS. This leads to the research question of *"What are the physical examination variables associated with patellofemoral pain syndrome when compared to matched asymptomatic patients?"*

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SECTION 2: Manuscript

Note:

This manuscript has been prepared in accordance with the Guide for Authors for the journal: *Physical Therapy in Sport* [see Appendix 4].

Strength and flexibility of the hip, knee and ankle associated with patellofemoral pain syndrome: A case-control study

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Abstract

Background: Patellofemoral pain syndrome (PFPS) has been defined as anterior knee pain in the absence of pathology, and a complex multifactorial aetiology. The identification of modifiable intrinsic factors variables which can be measured in a clinical setting would be useful for practitioners who manage people with PFPS. **Objectives:** To identify intrinsic variables associated with PFPS using physical examination measures of known reliability. **Design:** Cross sectional, case-control. **Setting:** laboratory. **Participants:** Twenty participants (n=10 symptomatic, n=10 asymptomatic). Asymptomatic participants were matched to symptomatic participants by age, gender, height, weight and level of recent physical activity (RPAQ). **Main Outcome Measures:** Participants were assessed for hip flexion, quadriceps length, iliotibial band length, isometric hip internal and external rotation strength, and the range of ankle dorsiflexion during weight bearing. **Results:** Isometric strength measures (hip internal and external rotation strength) were significantly different between symptomatic and asymptomatic participants and were associated with 'very large' effects (d>2.5). **Conclusions:** The strong association between hip weakness and PFPS, indicates the importance of considering this factor in a clinical setting. Measures used in this research were clinically appropriate and reliable to assess strength and flexibility measures associated with PFPS.

[189 words]

Key words: *anterior knee pain, hip internal rotation, hip external rotation, knee, patella*

1. Introduction

Patellofemoral pain syndrome (PFPS) is a debilitating condition that is prevalent among young athletes (Boling, Padua, Marshall, Guskiewicz, Pyne, & Beutler, 2010; Taunton, Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2002). The condition has been categorised as an 'overuse injury' (Thomeé, Augustsson, & Karlsson, 1999; Fredericson & Yoon 2006), however, it lacks a well-defined aetiology (Rest, 1999; Fulkerson & Buuck, 2004). At present PFPS is defined as "anterior knee pain in the absence of pathology" (Zaffagnini, Dejour, & Arendt, 2010). The clinical picture of PFPS includes anterior knee pain of insidious onset, worsening on activity or prolonged sitting, and is typically aggravated by stair climbing or descending. These symptoms, however, are not of themselves sufficient diagnostic criteria for PFPS, as symptoms can vary in each individual, making it challenging to identify the main contributing factors (Juhn, 1999). Previous studies have sought to identify predisposing structural and functional characteristics associated with PFPS including muscular imbalance (Tang, Chen, Hsu, Chou, Hong, & Lew, 2001; Coqueiro, Bevilaqua-Grossi, Bérzin, Soares, Candolo, & Monteiro-Pedro, 2005; Bolgla, Malone, Umberger, & Uhl, 2008; Souza & Powers, 2009), increased physical activity (Thomee, Renström, Karlsson, & Grimby, 1995; Tauton , Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2003; Wills, Ramasamy, Ewins, & Etherington, 2004), patellofemoral alignment (Caylor, Fites, & Worrell,1993; Powers, Ward, Chan, Chen, & Terk 2004; Piva, Goodnite, & Childs, 2005), and altered ankle mechanics (Nigg, 2001; Barton, Bonanno, Levinger, & Menz, 2010). The roles and interactions of these characteristics appear to be complex and the extent to which different intrinsic risk factors may contribute to aetiology of the condition is not clear.

Modifiable intrinsic risk factors, which can be identified clinically and influenced through treatment interventions such as therapeutic exercise and manual therapy, are of particular interest to practitioners consulting people diagnosed with PFPS. Intrinsic risk factors such as muscular extensibility and weakness have previously been of interest, with evidence supporting an association between these factors and PFPS (Hyde & Gengenbach, 2006; Bolgla et al., 2008; Norris, 2011).

A recent systematic review reported moderate evidence from cross-sectional studies that both men and women with PFPS have decreased isometric hip muscle strength when compared to asymptomatic individuals (Rathleff, Rathleff, Crossley, & Barton, 2014). The latest cross-sectional studies show an association between hip strength and PFPS (Ireland, Willson, Ballantyne, & Davis, 2003; Bolgla et al., 2008).This decrease in hip strength could

be a consequence of PFPS, rather than a risk factor for PFPS. Whatever the nature of the association, rehabilitation of muscle strength deficits remain an important therapeutic goal of intervention (Ferri, 2012).

Although studies are able to link PFPS to several intrinsic risk factors (for example iliotibial band extensibility, hamstring extensibility, hip strength, and ankle mechanics), to date, there appears to be no study that has employed reliable physical examination style measures which require low technology and can be routinely applied in a clinical setting. This study will therefore include an intra-tester reliability study of the measures used to assess the variables.

Recent reviews of PFPS have highlighted limitations in previous literature and made several recommendations for further research in this area including: (1) investigating the role of hip musculature in PFPS (Witvrouw et al., 2014); (2) that measurements used should be reliable and easily replicated by investigators to reduce inconsistencies (Rathleff et al., 2014; Witvrouw et al., 2014); (3) Clinically relevant measurements should be used in biomechanical studies if possible (Witvrouw et al., 2014); and (4) Participation in physical activity should be taken into account when undertaking case-control studies (Rathleff et al., 2014). Therefore, the aim of this study was to employ clinically relevant physical examination measures to identify strength and flexibility characteristics of the hip, knee and ankle between people with PFPS compared to matched controls.

[620 words]

2. Methods

2.1 Study Design

A case-control design was used to identify physical examination findings that may be associated with PFPS by comparing a symptomatic case group with an asymptomatic control group. Case control study methodology is suited for investigation of factors which may contribute to aetiology of a specific condition (Lewallen & Courtright, 1998).

2.2 Reliability of physical examination measures

Prior to the main study a preliminary intra-tester reliability study was undertaken for each measure by the primary researcher. The right and left leg, of 12 asymptomatic participants were tested. Of these 12, n=3 were also participants in the main study. Five repetitions of each measure were undertaken and reliability coefficient (ICC [model 2,1]) and 95%CI calculated for each variable. In addition, the Typical Error of Measurement (TE) was calculated for each variable using a customised Excel spreadsheet (Hopkins, 2000) (see Table 1).

2.3 Sample Size

There are few previous studies from which to draw effect sizes to determine statistical power *a priori*, therefore, given the limitations of available funding a group sequential approach to sampling (Hopkins, 2006) was employed in which an initial sample of n=10 cases and matching controls were recruited and analysed for differences between groups. No further sampling was undertaken when a clear difference was obtained for one of the physical examination measures.

Participants

Participants were recruited from the local community, through advertising posters, word of mouth, and online social media. Ten ‘cases’ (symptomatic participants) who matched the criteria for PFPS were recruited. Ten ‘controls’ (asymptomatic participants) were matched to the ‘cases’ according to age, gender, height, weight, and recent physical activity. Physical activity was measured by the Recent Physical Activity Questionnaire (RPAQ) (Wareham, Jakes, Rennie, Mitchell, Hennings, & Day, 2002). The RPAQ has established validity for reported time participating in vigorous-intensity activity and overall daily energy expenditure (Besson, Brage, Jakes, Ekelund, & Wareham, 2010). All participants gave written informed consent and the study was approved by the Unitec Research Ethics Committee (UREC No.: 2012-1054).

The methods for matching cases with controls followed Bolgla et al. (2008) study. In the case of bilateral symptoms, the symptomatic leg identified as being of greater severity by the participant was used (Piva et al. 2006). Both groups were assessed for factors which have been clinically related to patellofemoral pain syndrome (Thomeé et al., 1999; Fredericson & Yoon, 2006). Inclusion criteria for both symptomatic and asymptomatic groups were based on those described by Bolgla et al., (2008).

Inclusion Criteria

Symptomatic

The inclusion criteria for symptomatic participants included; between 18 and 60 years of age, male or female, presence of knee pain for a minimum of one year since first onset, crepitus of the patellofemoral joint during movement and pain during at least two of the following activities: stair ascent or descent, squatting, kneeling, or prolonged sitting

Asymptomatic

The inclusion criteria for asymptomatic participants included; no history of diagnosis of knee pathology, no pain on rest, squatting, sitting, kneeling, or passively flexing or active compression during a quadriceps contraction and are able to be matched with a symptomatic participant

Exclusion criteria

Exclusion criteria for both symptomatic and asymptomatic groups were based on those described by Witvrouw, Werner, Mikkelsen, Van Tiggelen, Vanden Berghe, & Cerulli (2005). The exclusion factors include; a history of knee surgery for previous patellar dislocation, knee surgery within previous 24-months, known or suspected diagnosis of peripatellar bursitis or tendonitis, internal knee derangement, systemic arthritis, ligamentous knee injury or laxity, plica syndrome, Sinding-Larsen-Johansson's disease, Osgood Schlatter's disease, infection or malignancy, any neurological lower extremity involvement that interferes with physical activity and/or pregnancy.

Data Collection

The RPAQ was administered prior to measuring the physical examination variables of each participant. All physical examination measures were undertaken in one session.

Physical Examination Measures

Hip flexion via Straight Leg Raise test

The range of hip flexion was recorded using a passive straight leg raise (SLR) test (Piva et al., 2006). An electrogoniometer (Software: iSetSquare v1.3 on iOS; http://www.plaincode.com) was used to record angle. The goniometer was zeroed on the distal aspect of the anterior border of the tibia on the symptomatic limb. The researcher performed a passive supine straight leg raise. Once the limb had reached passive end of range the angle was recorded. Five repetitions of the SLR were undertaken with a 5 s interval between repetitions. Poor extensibility or 'tight' hamstrings has been defined as a straight leg raise angle of less than 80 degrees (Göeken & Hof, 1993). This study will also use this to qualify poor extensibility. The intra tester reliability ICC was 'excellent' (Table 1).

Extensibility of the lateral structures of the thigh via passive hip adduction range

Measuring the length of the iliotibial band can be difficult, due to the inability to directly measure it without the combined influence of other lateral thigh structures (Melchione & Sullivan, 1993). Therefore, passive adduction range was used to represent the extensibility of the lateral structures of the thigh including iliotibial band and others. The participant was assessed supine. The participant 'neutralised' their pelvis by lifting it off the plinth and then placing it back down. An electrogoniometer was zeroed on the horizontal surface and then placed over the anterior aspect of the tibia. Melchione & Sullivan (1993), highlights the importance of a stable pelvis position during measures of hip adduction, therefore a self-adhesive circular sticker was placed on the anterior superior iliac spine and a laser pointer was positioned directly above and was shone onto it. The researcher passively adducted and elevated this leg over the participant's other leg. The end point was determined when the light contacted the edge of the adhesive and the skin. Five measurements were taken with a 5 s interval. The intra tester reliability ICC was 'excellent' (see Table 1).

Hip abduction strength

The participant was positioned side lying and a hand-held dynamometer (model: Chatillon, Ametek, Inc., Largo, Florida, USA) was positioned just proximal to the lateral malleolus. The participants were instructed to exert an isometric contraction of the hip abductors for 5 s. To minimize the activation of the hip flexors during abduction the thigh was stabilised by the examiner during abduction (Bolgla et al., 2008). Five measurements were taken with a 5 s interval. The intra-tester reliability coefficient of this test was ICC = 93.0 (95% CI = 0.83 to 0.97). As the lower boundary of the CI for intra tester reliability was lower than the other variables, and the measure was technically difficult to perform by one researcher it was eliminated from the variables to be measured on the sample participants.

Hip external rotation strength and internal rotation strength

The participant was seated with the lower limbs suspended over the side of the plinth such that their feet could not touch the ground, to avoid generating more force by using the opposite leg to push against the ground. Hands were rested in lap, with no contact on the plinth. The dynamometer was applied just proximal to the medial malleolus (to measure external rotation strength) and to the lateral malleolus (to measure internal rotation strength). The participant was instructed to exert an isometric contraction of either the external rotators of the hip or internal rotators of the hip. Five measurements were taken with a 5 s interval. The reliability of this method of measuring strength of hip external and internal rotation was nearly perfect (see Table 1). Due to the differences in each participant's mass, strength data were normalised for body weight using the following formula: normalised value = [(kg force/kg body mass) × 100]. (Piva et al., 2005). Force was measured rather than torque as this is more useful clinically (Piva et al., 2005; Robinson & Nee, 2007).

Quadriceps extensibility

The length of the quadriceps muscle group was measured by passively flexing the knee of the participant lying in a prone position. The angle of the knee flexion was measured using a gravity goniometer (this was zeroed between each measurement on a horizontal plane), by placing it over the distal tibia. A dynamometer was also placed over the anterior distal tibia, to gauge the force exerted by the examiner to achieve end of range movement. The force used during the first repetition was used for all trials of this measure. Five measurements were taken with a 5 s interval. The average of these five measurements was used for analysis. This measuring tool had an intra-tester reliability co-efficient of ICC = 0.97 (95% CI: 0.93 to 0.99).

Range of weight bearing ankle dorsiflexion

Ankle dorsiflexion in weight bearing was measured as the *angle* between the tibial shaft and the vertical using an electrogoniometer strapped to the distal tibia. The participant was instructed to stand with their first metatarsal touching a vertical wall (to ensure no lifting of the toes during the measuring). A pressure switch was placed under the subject's heel, which illuminated a light visible to the researcher. The subject was instructed to slowly perform ankle dorsiflexion until the light turned off (this indicated the heel had lifted from the floor). The intra-tester reliability was 'nearly perfect' (see Table 1).

Data Analysis

Raw data was tabulated in Microsoft Excel. All statistical analysis was conducted using SPSS (v20, IBM Corp., SPSS). Raw data was checked for assumptions of normality using

visual inspection of P-P and Q-Q plots and the Shapiro-Wilk statistic. Differences in matching of height, age, body weight, Scores of Reported Activities were analysed using independent samples *t*-tests. Differences between symptomatic and asymptomatic groups for each of the physical examination measures (hip flexion using straight leg raise (hamstring length), extensibility of lateral thigh structures, hip abduction strength, hip external rotation strength, hip internal rotation strength, quadriceps muscle length, ankle dorsiflexion range in weight bearing) were compared using independent samples *t*-tests. Levene's test of equality of variances between groups was satisfied for each comparison. Differences between groups for each physical examination measure were quantified using Cohen's effect size (*d*), and the 95% confidence intervals calculated for mean differences. Effect size descriptors were interpreted using Hopkins' descriptors (Hopkins et al., 2009).

[1647 words]

3. Results

The first eligible 10 respondents who matched the criteria for a symptomatic participant were enrolled in the study. Ten control participants were matched for eligibility (See Table 2. for characteristics). All participants completed data collection and were analysed. There was no missing data.

Differences between characteristics of cases and controls are displayed in Table 2. There were no significant differences between cases and controls for any of the physical examination measures related to range of motion (Hip adduction range, hip flexion, extensibility of lateral structures of the thigh, quadriceps length and weight bearing ankle dorsiflexion,). However, strength measures (hip internal and external rotation strength) showed a significant weakness in cases when compared to controls (Table 3) and were associated with 'very large' effects (d>2.5).

[115 words + Tables]

Table 1.

Test-retest reliability of physical examination measures

Physical Examination Measure	ICC(2,1)	95% CI	Descriptor	Typical Error of Measurement (95%CI)
HipAddRange (deg)	1.00	1.0-1.0	“perfect”	0.04 (0.03-0.05)
Ham (deg)	0.99	0.98-1.00	"nearly perfect"	0.1 (0.08-0.14)
Quad (deg)	0.99	0.97-0.99	"nearly perfect"	0.13 (0.10-0.18)
IntRot (N/kg)	1.00	1.00-1.00	“perfect"	0.05 (0.04-0.06)
ExtRot (N/kg)	1.00	1.00-1.00	"perfect"	0.05 (0.04-0.07)
AD (deg)	1.00	0.99-1.00	"nearly perfect"	0.07 (0.05-0.09)
HipAbd* (N/kg)	0.78	0.57-0.90	“large”	0.49 (0.40-0.68)

Notes: HipAddRange= Hip Adduction Range, Ham=Hamstring length, Quad=Quadriceps Length, IntRot= Hip Internal Rotation Strength, ExtRot=Hip External Rotation Strength, AD= Ankle Dorsiflexion (weight-bearing), HipAbd*=Hip Abduction Strength (shown here but not included in analysis); Descriptors for ICCs are from Hopkins (2009).

Table 2.

Participant characteristics

	Group	n	Mean	SD	p-value	Mean Difference	95% Confidence Interval for mean difference	
							Lower	Upper
Height (cm)	Asymptomatic	10	174.9	9.75	.960	.2	-8.1	8.5
	Symptomatic	10	174.7	7.83				
Weight (kg)	Asymptomatic	10	78.6	14.21	.879	-1.0	-14.6	12.6
	Symptomatic	10	79.6	14.68				
Age (y)	Asymptomatic	10	28.1	9.22	.982	-1.0	-9.1	8.9
	Symptomatic	10	28.2	9.87				
Score of Reported Activities (Met-h/day)	Asymptomatic	10	32.8	17.75	.790	2.1	-14.3	18.5
	Symptomatic	10	34.9	17.10				

Notes: p-value from an independent samples t-tests

Table 3.

Difference in physical examination measures between symptomatic and asymptomatic group

	Group	N	Mean	SD	p-value	Mean difference	95% Confidence Interval		Effect Size	Effect Descriptor
							Lower	Upper		
HipAddRange Av (deg)	Asymptomatic	10	17.80	5.9	.521	-1.73	-7.28	3.82	0.29	“small”
	Symptomatic	10	19.20	5.9						
Ham Av (deg)	Asymptomatic	10	72.10	9.4	.157	6.35	-2.68	15.39	0.66	“moderate”
	Symptomatic	10	65.70	9.8						
Quad Av (deg)	Asymptomatic	10	35.29	8.9	.130	6.88	-2.23	16.0	0.71	“moderate”
	Symptomatic	10	28.41	10.47						
IntRot Av (kg/kg)	Asymptomatic	10	0.29	0.07	< 0.001	0.14	0.09	0.20	2.58	“very large”
	Symptomatic	10	0.15	0.04						
ExtRot Av (kg/kg)	Asymptomatic	10	0.26	0.07	< 0.001	0.12	0.06	0.17	2.46	“very large”
	Symptomatic	10	0.15	0.02						
AD Av (deg)	Asymptomatic	10	30.73	9.9	.288	-4.11	-12.0	3.78	0.50	“small”
	Symptomatic	10	34.84	6.5						

Notes: HipAddRange Av=Hip Adduction Range Average, Ham Av=Hamstring Extensibility Average, Quad Av=Quadriceps Length Average, IntRot Av= Hip Internal Rotation Strength Average, ExtRot Av= Hip External Rotation Average, AD Av= Ankle Dorsiflexion Average; p-value derived from an independent samples t-test; Descriptors for ICCs are from Hopkins (2009)

4. Discussion

The aim of this study was to compare physical examination measures between people with symptomatic PFPS and matched asymptomatic participants. The main finding of this study was a deficit of hip, external and internal, rotation strength in those with PFPS compared to matched controls. However, small non-significant differences were found between symptomatic and asymptomatic participants for physical examination measures of hip adduction range, quadriceps length, hip flexion, and ankle dorsiflexion. The relationship between hip rotation strength and symptomatic status is consistent with other authors who have identified an association between PFPS and weakness of the hip (Ireland et al. 2003; Robinson & Nee 2007; Fredericson et. al, 2006). The methods of the present study follow recent recommendations for PFPS research, which implore the use of clinically applicable, and reliable, physical examination measures (Witvrouw, 2014; Rathleff, 2014).

A very 'large' effect size for differences in hip strength between participants with PFPS and controls was identified in the current study. Hip strength deficit findings of a similar magnitude to this study, were reported in Ireland et al.'s case control study (Ireland et al. 2003). Likewise Ireland et al. 2003) used the same basis for matching criteria (including age, body weight, and physical activity participation) for symptomatic participants and controls. Similarly, Robinson & Nee (2007) also conducted a cross sectional study of PFPS, once again noting a 'large' difference of hip strength between people with PFPS (n=10) and the dominant limb of asymptomatic participants (n=10). Both of these studies (Ireland et al., 2003; Robinson & Nee, 2007), however, recruited only female participants. Although literature is clear that PFPS is more prevalent in females (Devereaux & Lachmann, 1984; Yates & Grana, 1986; Boling et al., 2010; Taunton et al., 2002), males with PFPS also present in clinic. Although there are many similarities between the two sexes when investigating PFPS (Nakagawa, Moriya, Maciel, & Serrão, 2012), there may be significant anatomical differences to consider in future studies It has been suggested further research should include male participants (Witrouvw, 2014), therefore the current study included a balanced number of both female and male participants.

In contrast to Ireland et al (2003), Robinson & Nee (2007) and this present study, Piva et al. (2005) did not identify weakness of hip external rotation strength and hip abductor strength between symptomatic PFPS and asymptomatic controls. These contradicting results could be related to the assessment position used to measure hip strength. Piva et al (2005) had their participants lie prone, with the hip extended and knee flexed to 90˚. This position effectively reduces the influence of gravity and allows recruitment of accessory movements

to perform hip knee flexion, abduction and external rotation (Clarkson, 2000). In the present study, and those of Ireland et al, (2003) and Robinson & Nee (2007), the sitting position was selected as it is more functional to assess hip external rotation strength and a more accurate representation of how the lower limb is used during gait.

McMoreland, O'Sullivan, Sainsbury, Clifford, & McCreesh (2011) also found contrasting results when studying hip strength and endurance deficits in female participants with PFPS. Once again no significant difference was found between the asymptomatic group and the symptomatic group when comparing internal rotation strength, external rotation strength and abduction strength. McMoreland et al. (2011) has suggested the insignificant differences could be due to the symptomatic participants only rating an average of 1.3cm on the Numerical Rating scale for pain.

It is well accepted that the action of the posterior portion of the gluteus medius is to extend, abduct and laterally rotate the hip (Gray & Williams, 1998). It has been argued that this posterior portion can become excessively lengthened or weakened and this state may be associated with an increased lumbar lordosis with a posterior pelvic tilt (Sahrmann, 2002). This leads to a clinical reasoning hypothesis for the role of hip function and its association to PFPS (Sahrmann, 2002). Without efficient stability of the hip joint, the femur will tend to internally rotate which in turn causes the knee to increase its valgus angle, creating dysfunction at the patellofemoral joint (Nguyen, Shultz, Schmitz, Luecht, & Perrin, 2011). This observation is supported, at least in part, by Ireland et al. (2003) who also proposed that those with PFPS may have insufficient hip strength to control external valgus and internal rotation forces. Due to this motion pattern, lateral patella tracking occurs, increasing retro patella contact (Piva et al., 2006). The present study demonstrates an association between weakness of hip strength and PFPS that is, within the limitation of the design, supportive of this observation. A strength of this study is the close matching of the participants by age, recent physical activity, gender, weight and height, thereby reducing the likelihood of other influential factors confounding the association (Hulley, Cummings, Browner, Grady, & Newman, 2011). Close matching did, however, result in a restriction of age (mean ± SD age, 28.2 ± 9.87 years; age range, 19-52 years) which limits the extent to which these results may be generalised to older age groups.

There are several limitations of this study. Firstly, the primary examiner was not blinded to symptomatic status. Logistical and financial constraints limited the recruitment of a blinded examiner. Expectation bias could therefore have been unintentionally introduced during data

collection. The use of blinded examiner measurements would have avoided this potential source of bias.

Secondly the present study evaluated all passive movements separately and statically. To understand the kinematics of the lower extremity and determine if there is a relationship with patellofemoral pain syndrome, measurements of a more dynamic nature need to be addressed. Internal and external rotation strength of the hip was limited to isometric strength testing. Assessing other indices (muscle activation, eccentric strength, muscle force development and endurance) in future investigations could add more insight into the role of the intrinsic risk factors of PFPS (Witvrouw et al., 2014) but these measures were beyond the intention of this study to employ clinically applicable methods.
Thirdly, although our findings suggest that hip weakness is associated with PFPS, the cross sectional design does not inform the nature of any cause and effect interaction. It is not understood whether hip function deficits occur as a consequence of knee pain, or whether the deficit causes the knee pain. In considering PFPS in the context of the 'Dynamic, recursive model of aetiology in sport injury' (Meeuwisse et al., 2007) it is apparent that hip function should be considered an intrinsic risk factor of PFPS. Meeuwisse et al. (2007) dynamic model describes how multiple intrinsic and extrinsic risk factors, repetitive events and adaptation may all contribute to the development of PFPS symptoms rather than a single isolated factor. Weakness and instability of the hip joint may not be the primary influential intrinsic risk factor, as participants could have other musculoskeletal dysfunction contributing to the development of PFPS (Dierks, Manal, Hamill, & Davis, 2008). Hip weakness may be a cause of PFPS (as proposed in Sahrmann's explanation (Sahrmann , 2002)), or, the presence of knee pain may result in altered neuromuscular control at the hip. It is well established that pain impairs motor control (Hodges & Tucker, 2011) and this impairment may also arise as a consequence of pain at a distal joint (Friel, McLean, Myers & Caceres, 2006). Nakagawa et al. (2012) supported this with findings of less activation of the gluteus medius during a single leg squat, of female subjects with patellofemoral syndrome, when compared to females without. Overall, symptomatic males and females from this study had 17% less hip external rotation strength when compared to their asymptomatic controls. However, Bolgla et al. (2008) found participants with patellofemoral syndrome had less hip strength but no change in kinematics at the hip or knee.

Further, it is not clear whether hip function deficits are either necessary, or sufficient for development of PFPS (Witrouvw, 2014; Rathleff, 2014). The practical application of this present study lies in the clinician identifying influential and modifiable intrinsic risk factors, to inform development of a treatment plan of PFPS. Regardless of the mechanisms causing

PFPS, the literature is clear that when treatment is focused at improvement of hip muscle function, symptoms of PFPS will also improve (Witvrouw, Lysens, Bellemans, Peers, & Vanderstraeten, 2000; Mascal, Landel, & Powers, 2003; Tyler, Nicholas, Mullaney, & McHugh, 2006). Results from this study emphasize the limitation inherent in a clinical approach limited to isolated joints. The present study supports assessment of kinematically related joints (such as the hip) to inform therapeutic decision making and management of this condition.

[1227 words]

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SECTION 3: Appendices

Appendix 1: Participant Information Sheet

RESEARCH INFORMATION FOR PARTICIPANTS

Strength and flexibility of the hip, knee and ankle associated with patellofemoral syndrome: A case control study

You are invited to participate in our research investigation. Please read carefully through this information sheet before you make a decision about volunteering.

Researcher

My name is Naomi Stuhlmann and I am a Master of Osteopathy student at Unitec New Zealand. As part of this programme I am conducting a research project.

Purpose of the study

Anterior knee pain, also known as patellofemoral joint syndrome, has yet to be accurately defined. The factors which specifically cause this condition are under discussion. Therefore to achieve further insight into this condition measurements will be taken from those who meet the criteria for having anterior knee pain and those who meet the criteria for having no knee pain. These measurements will then be compared.

The aim of this study is to identify measurements which may influence this condition. By doing so, more efficient physical examination and treatment may be achieved.

What the study involves

If you volunteer to take part in this project, you will either meet the criteria of a participant with anterior knee pain, or meet the criteria of having no anterior knee pain. Your age, gender, height, weight and level of physical activity will be recorded. You will then be asked to participate in a number of procedures of which muscle flexibility, strength, and length will be measured. These procedures consist of:

1.Straight leg raise test

A goniometer will be required to be placed on the lower limb. The participant will be lying on their back on a plinth, and the practitioner will lift the chosen leg. The leg will be kept from

bending during the lift. The end of range measurement will be recorded. This will be repeated to determine an accurate measurement.

2. Iliotibial Band length

The participant will be required to on their back on a plinth. A LED light will be shone onto the front of the hip to determine any movement. A gravity goniometer will be required to be placed on the chosen leg. The leg will be abducted away from the mid line and supported by the practitioner. Measurements will be recorded. This will be repeated for an accurate measurement.

3. Hip Internal Rotation Strength

The participant will be required to sit on the plinth, without their feet touching the floor. A dynamometer will be required to be placed on the ankle. The participant will be instructed to internally rotate their thigh (this will be shown how to do by the practitioner). This will be repeated for an accurate measure.

4. Hip External Rotation Strength

The participant will be required to sit on the plinth, without their feet touching the floor. A dynamometer will be required to be placed on the ankle. The participant will be instructed to externally rotate their thigh (this will be shown how to do by the practitioner). This will be repeated for an accurate measure.

5.Quadriceps muscle Length

The patient will be required to lie on the plinth in a prone positon. A gravity goniometer and a dynamometer will be required to be placed on the participant's leg. The choosen knee will be flexed. Measurement will be taken. This will be repeated for an accurate measurement.

6. **Range of weight bearing ankle dorsiflexion**

This will be measured two ways: 1) the distance from the great toe to the wall and 2) the angle between the tibial shaft and the vertical using an inclinometer.

7. Physical Activity Questionnaire (EPAQ)
You will be required to complete a questionnaire, directed at your participation in physical activity in everyday life. The questionnaire will take approximately 10 minutes to answer.

Taking part in this study will require you to attend 1 session at the Osteopathic Clinic at Unitec Institute of Technology on Carrington road. This session will last approximately 2 hours. Clothing worn will need to consist of wearing shorts which will enable full movement of the hip, leg and expose the knee. You will not be asked to disrobe in any way.

Your voluntary participation

Your participation in this study is entirely voluntary and you may withdraw anytime up until 24-hrs after the conclusion of the data collection session by letting the researcher know by phone or email or in person.

Who may participate?

You are eligible to participate if you:

- Are aged between 18 and 60 years of age.
- Are willing to give informed written consent.

Unfortunately you are unable to participate if you:

- A history of knee surgery previous patellar dislocation
- Knee surgery over the past 2 years
- Known or suspected diagnosis of: peripatellar bursitis or tendonitis, internal knee derangement, systemic arthritis, ligamentousknee injury or laxity, plica syndrome, Sinding-Larsen-Johansson's disease, Osgood Schlatter's disease, infection, malignancy,
- Any neurological lower extremity involvement that interferes with physical activity
- Pregnancy
- Unable to perform any of the procedures stated above.

Please inform the researcher if any of the above pertains to you. As a participant you may ask any questions, and may discuss any cultural concerns that you may have.

What we do with the data and results, and how we protect your privacy.

Personal information is collected and stored under the guidelines provided by the Privacy Act 1993 and the Health Information Privacy Code 1994. For information collection your identity will remain anonymous and you will simply have an identification number. If the information you provide is reported or published, this will be done in a way that does not identify you as its source. All the data recorded will be stored in a password-locked computer and archived in a locked file room and will be stored for a minimum of 5 years. Access to this data will be limited to the principle researcher, the research supervisor, and yourself.

Compensation may be available in the unlikely event of injury of negligence

Should you incur a physical injury as a result of your participation in this study, you may be covered by ACC under the Injury Prevention, Rehabilitation and Compensation Act 2002. You may or may not be entitled to ACC compensation, depending on several factors such as whether or not you are an earner. ACC will usually cover a proportion of income lost due to a physical injury, this does not cover mental injury unless as a direct result from a physical injury. ACC cover may affect your right to sue. Please contact your nearest ACC office for further information (0800 735 566) or visit their website: www.acc.co.nz

You have the right to withdraw your data from this project at any time up until 24-hrs after the conclusion of the data collection session. This can be done by contacting the researcher below.

A summary of the final report will be available to you if you are interested. Please contact me if you require further information about the study.

Contact Details

Naomi Stuhlmann

Phone: 021 173 0410

Email: naomibubbles@hotmail.com

Supervisor Details

Rob Moran

Phone: 021 073 9984

Email: rmoran@unitec.ac.nz

This study has been approved by the Unitec Research Ethics Committee from (XX-XX-2012) to (31-12-2012). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (Ph: 09 815 4321 ext.7254). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 2: Participant Consent Form

Participant consent form

Strength and flexibility of the hip, knee and ankle associated with

patellofemoral syndrome: A case control study

Name of Participant: ……..

This form is to ensure that you understand the requirements of your participation and that you aware of your rights. Please read carefully through the points below. If you are happy and agree with the points then please sign at the bottom of the page. If you have any questions at all please ask the researcher before signing this form.

- I have had the research project explained to me and I have read and understood the information sheet given to me.
- I understand that I don't have to be part of this if I don't want to and I may withdraw myself (or any information I have provided) at any time anytime up until 24-hrs after the conclusion of the data collection session by letting the researcher know by phone or email or in person.
- I understand that everything I say and the information I provide will be collected in accordance with the Health Information Privacy Code 1994 and kept confidential and in accordance with the Privacy Act 1993. I understand that the only persons who will have access to my information will be the researchers and relevant clinical staff.
- I understand that all the information I give will be stored securely on a computer at Unitec for a period of 5 years.
- I understand that I can see the finished research document.
- I have had time to consider the information provided, to ask questions, and to seek any guidance.
- I give my consent to be a part of this project

Participant Signature: …….. Date: …….

Principal Researcher: …….. Date: …….

This study has been approved by the Unitec Research Ethics Committee from (XX-XX-2012) to (31-12-2012). If you have any complaints or reservations about the ethical conduct of this research, you may contact the Committee through the UREC Secretary (Ph: 09 815 4321 ext.7254). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

Appendix 3: UREC Approval Letter

Naomi Stuhlmann
118 St Heliers Bay Road
St Heliers
Auckland

23.8.12

Dear Naomi,

Your file number for this application: **2012-1054**
Title: **Strength and flexibility of the hip, knee and ankle associated with patellofemoral syndrome: A case control study**

Your application for ethics approval has been reviewed by the Unitec Research Ethics Committee (UREC) and has been approved for the following period:

Start date: 13.8.12
Finish date: 13.8.13

Please note that:

1. **The above dates must be referred to on the information AND consent forms given to all participants.**
2. **You must inform UREC, in advance, of any ethically-relevant deviation in the project. This may require additional approval.**
3. **Organisational consent/s must be cited and approved by your primary reader prior to any organisations or corporations participating in your research.**

You may now commence your research according to the protocols approved by UREC. We wish you every success with your project.

Yours sincerely,

Gillian Whalley
Deputy Chair, UREC

CC: Rob Moran
Cynthia Almeida

Appendix 4: Instructions for Authors

Physical Therapy in Sport

Retreieved from http://www.physicaltherapyinsport.com/authorinfo 11 July 2013

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All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or anaylsis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

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Clinical Trials that commence after 1st June 2013 must be registered to be considered for publication in *Physical Therapy in Sport*. Authors will be asked to state the trial registration number during the submission system as well as at the end of the manuscript file. From January 2014 *Physical Therapy in Sport* will not be able to accept any unregistered Clinical Trial papers. By 2015 the journal will not be able to publish any Clinical Trials that are unregistered prior to recruitment of the first participant.

All randomized controlled trials submitted for publication in *Physical Therapy in Sport* should refer to the Consolidated Standards of Reporting Trials (CONSORT) flow chart. Please refer to the CONSORT statement website at http://www.consort-statement.org for more information. It may be helpful to authors to complete the CONSORT checklist.

Physical Therapy in Sport has adopted the proposal from the International Committee of Medical Journal Editors (ICMJE) (see a recent Editorial in *Manual Therapy* Editorial: Clinical trial registration in physiotherapy journals: Recommendations from the International Society

of Physiotherapy Journal Editors), which require, as a condition of consideration for publication of clinical trials, registration in a public trials registry. Trials must register at or before the onset of patient enrolment. The clinical trial registration number should be included at the end of the abstract of the article. For this purpose, a clinical trial is defined as any research project that prospectively assigns human subjects to intervention or comparison groups to study the cause and effect relationship between a medical intervention and a health outcome. Studies designed for other purposes, such as to study pharmacokinetics or major toxicity (e.g. phase I trials) would be exempt. Further information can be found at http://www.icmje.org.

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