Kinetic and 3D Kinematic analysis of netball movements: with and without prophylactic knee bracing

by

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STUDENT DECLARATION FORM

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Abstract

Background: Patellofemoral pain is one of the most common musculoskeletal pain conditions, with a multifactorial aetiology. It is reported that young females are at high risk of developing patellofemoral pain. During dynamic, fast-paced games athletes are exposed to high ground reaction forces, contributing to lower body injury occurrence during landing and high patellofemoral loads. Knee braces, such as knee sleeves, are commonly used for patellofemoral pain; however the underlying mechanisms on the patellofemoral joint remain unclear. An increase in understanding of joint mechanics during sporting and functional tasks could help our understanding of injury mechanisms and preventative interventions.

Aim: To identify any changes in the kinetics and kinematics of the tibiofemoral joint and the patellofemoral loading experienced in healthy subjects during a range of functional movements with and without a prophylactic knee sleeve.

Method: Twenty female netball players aged between 18 and 30 years old (age = 20.95 ± 1.76 years, height = 1.67 ± 0.04 m, mass = 61.45 ± 7.04 kg) volunteered to participate in the study. Participants were asked to perform four tasks; running, cutting manoeuvre, countermovement vertical jump and a step-pivot movement, with and without the Trizone knee sleeve. Comparisons were made between the brace and no brace conditions, and between tasks. The right foot, shank, thigh and pelvis were modelled using the calibrated anatomical systems technique (CAST). Kinematic and kinetic data were recorded using 8 Oqus motion cameras and 1 Kistler force platform.

Results: The trizone sleeve led to a significant reduction in the knee peak range of motion in the transverse plane ($P< .05$), specifically in the run ($P< .001$), cut ($P< .05$) and pivot turn ($P< .05$). Significant differences were found in the transverse plane in the minimum knee angle during the run ($P< .05$), cut ($P< .05$) and pivot turn ($P<.05$). The trizone sleeve showed a

significantly greater knee maximum abduction moment in the coronal plane ($P < .05$), specifically in the pivot turn ($P < .05$). The results show there was no significant difference in the patellofemoral contact force when wearing the knee sleeve in all movements ($P = .06$). There was a significant interaction in the patellofemoral force between the knee sleeve and movement ($P < .05$), with an increase in patellofemoral force in the brace condition during the jump movement ($P < .05$). Chi-squared test results reported a significant increase in perceived stability during the run ($P < .05$), jump ($P < .05$) and pivot ($P < .01$) movements when wearing the brace.

Discussion: Changes in knee mechanics in the coronal and transverse planes between bracing conditions emphasises the importance of studying movement as a 3D examination. This study identified potentially important improvements in knee stability. However, further work is needed to identify the additional mechanical, neuromotor and proprioceptive effects. In the sagittal and coronal plane of movement, the cutting manoeuvre displayed higher moment loading, whereas in the transverse plane the pivot turn movement is vulnerable to excessive moment loading. Therefore, it can be proposed the cut and pivot turn movements may increase the risk of developing patellofemoral pain. No previous studies have looked at different functional movement tasks, however changes in patellofemoral loading and movement kinematics provides insight into the aetiology of potential injury patterns that could increase the risk of patellofemoral pain in female netball players.

Conclusion: In conclusion this study demonstrated significant improvement on the coronal and transverse mechanics of the knee when wearing a prophylactic knee brace. The current investigation provides insight into the aetiology of potential injury patterns and patellofemoral loading between different movement tasks that could increase the risk of patellofemoral pain development in female netball players.

Table of Contents

List of tables and illustrative material

List of tables

CHAPTER 4 – RESULTS

List of figures

CHAPTER 2- LITERATURE REVIEW

CHAPTER 3- METHODS

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Abbreviations

ACL – Anterior cruciate ligament

ANOVA – Analysis of Variance

AP - Anterior-Posterior

ASIS - Anterior superior iliac spine

BOLD – Blood-oxygen-level dependent

CAST - Calibrated anatomical systems technique

FM – Rectus femoris

fMRI – Functional magnetic resonance imaging

GCS – Global coordinate system

JCS – Joint coordinate system

KFA – Knee flexion angle

KN – Constant

KOOS - Knee injury and Osteoarthirtis Outcome Score

KXT – Knee extensor moment

LCL – Lateral collateral ligament

MCL – Medial collateral ligament

ML – Medial-lateral

PAR-Q – Participant activity readiness questionnaire

PCF – Patellofemoral contact force

PCL – Posterior cruciate ligament

PFJ – Patellofemoral joint

PFP – Patellofemoral pain

PP – Patellofemoral pressure

PSIS – Posterior superior iliac spine

QF – Quadriceps force

QMF - Quadriceps effective moment arm

QTM - Qualisys Track Manager

SCS – Segment coordinate system

SI - Superior-Inferior

VAS – Visual Analogue Scale

VI - Vastus intermedius

VL – Vastus lateralis

VM – Vastus medialis

VML -Vastus medialis longus

VMO - Vastus medialis obliques

Appendices

CHAPTER 1

INTRODUCTION

This chapter examines the terminology and prevalence of patellofemoral pain (PFP) from previous studies. A brief outline of the function of the patella is presented. This leads into an overview of how knee function is thought to affect the patellofemoral joint (PFJ) and considers why knee braces, such as knee sleeves, are proposed for this painful condition.

1.1. Patellofemoral Pain

Anterior knee pain, PFP and chondromalacia are all terms that are used interchangeably to describe multiple conditions that occur in the same anatomic region (Atanda et al., 2012). Although there is no consensus on the terminology, it is well discussed and agreed in the literature that PFP is the more flavored term, therefore the term PFP will be used throughout this thesis. PFP describes the development of pathologies or anatomical abnormalities leading to anterior and retropatellar knee pain (Salsich et al., 2002). Overall, it is reported to be one of the most common musculoskeletal pain conditions seen in orthopaedic, general practice and sports medicine clinics (Ireland et al., 2003; Fredericson & Yoon, 2006).

According to McConnell (1996), PFP affects one in four of the general population in Australia. Following this, Callaghan and Selfe (2007) conducted a review into the occurrence of PFP; despite the estimated figures of the prevalence of PFP in the adult general population, the incidence rate in the general population is unknown with source data only focused on sport-medicine or military settings. Many studies have reported the condition is most common among active young females (Barton et al., 2009), along with athletic and military populations (Nejati et al., 2011). Brechter and Powers (2002) suggested that one in four of the sporting population might be affected by this disorder. Specifically, runners have been reported to be vulnerable to this common overuse injury where approximately 2.5 million runners will be diagnosed with PFP in a given year (Taunton et al., 2002).

Studies have identified the increased risk of developing PFP among active young females (Barton et al., 2009), including Wilson (2007) who showed females (62%) are significantly more at risk of experiencing PFP than males (38%). Powers et al., (2012) proposed it is important to identify physically active people who are at high risk to avoid the development of chronic PFP. Netball has increased in popularity among the female population who are participating in physically demanding movements (Williams & O'Donoghue, 2005). The nature of the sport has led to the sport being associated with a reputation for a high incidence of knee injuries (Ferreira & Spamer, 2010) with hospital reports identifying the knee as one of the most commonly injured body regions in both recreational and high performance netball players (Flood & Harrison, 2009). The limited aetiological literature available on the incidence of injuries in netball players and the risks associated, with no studies looking at PFP specifically, provides an area of interest to identify the potential risk of PFP in healthy netball players to aid the development of a preventive mechanism of this hindering condition.

The patella has an important mechanical function to displace the quadriceps tendon forwards, thereby improving its leverage. Ward et al., (2012) reported the role of the patella is to improve the quadriceps efficiency and provide mechanical advantage to the quadriceps muscles used to extend the knee, by increasing the patellar tendon moment arm. This is supported in an earlier study, which advocated that the increased moment arm of the quadriceps improves the ability of the anterior thigh muscles to extend the knee (Wilson & Davis, 2008). However the precise role of the patella is still not determined among authors, some claim it acts as a “fulcrum for the extensor mechanism of the knee”, while others suggest there is a “balance beam for the patella tendon force and the quadriceps force” (Richards, 2008). The patella is described as a dynamic lever acting as the fulcrum, which is exposed to the greatest patellofemoral ground reaction forces during normal motion; ranging from approximately 0.5 times body weight for walking and up to 7 times body weight for squatting (Powers et al., 2012).

The PFJ has to deal with loads that exceed the body weight which can reach as high as 20 times body weight during intensive sporting activities (Lee et al., 2003; Schindler & Scott, 2011). The normal functioning of the PFJ relies on static and dynamic stabilisers surrounding the joint; static stabilisers such as the ligaments and cartilage maintain the joints stability whereas the muscles involved in patellar tracking are recognised as the dynamic stabilisers (Palastanga & Soames, 2012). Repeated forceful loading of the PFJ causes forces on the patella to range from between one third and one half of a person's body weight during walking, to three times body weight during stair climbing (Reilly & Martens, 1972). Similarly, Richards (2008) reported the knee demonstrated 33% higher compressive forces compared to the hip during walking, which further increased to three times body weight during stair climbing.

1.2. Patellofemoral Pain and Knee Function

Previous literature has considered the most important aetiological mechanism for the development of PFP is an abnormal tracking of the patella in the femoral groove during flexion and extension of the knee joint (McNally, 2001; Elias & White, 2004). Earl et al (2005) stated dynamic malalignment during functional tasks might lead to improper tracking of the patella within the femoral trochlea. Likewise dysfunctions and alterations in the alignment of the proximal and distal segments of the lower extremity, namely at the hip, ankle and foot, may cause biomechanical changes at the PFJ, that could possibly lead to PFP (Lee et al., 2003; Powers, 2003). Powers (2003) reported femoral adduction and tibial abduction produce greater knee valgus resulting in greater loading stress on the PFJ. Whereas, Barton et al (2012) reported positive correlations in PFP patients between peak rearfoot eversion and peak tibia internal rotation, and rearfoot eversion range of motion and hip adduction range. Tibia internal rotation and hip adduction are likely to increase knee valgus and PFJ stress.

1.3. Role of Knee bracing in Patellofemoral Pain

With previous attention focused on patellar taping, known as a recognised technique in clinical practice, knee bracing is now a frequently used therapeutic intervention to treat knee pain (Warden et al., 2008). Nadler and Nadler (2001) reported the purpose of patellofemoral braces have been designed to centralise the patella within the trochlea groove and to reduce compression of the patella. Exclusively, Palumbo (1981) reported that that 93% of patients with PFP had a reduction in pain. Selfe (2008; 2011) examined the influence of patellar bracing during step-down tasks, which lead to increased dynamic control of the knee by displaying significant reductions in coronal and transverse planes of motion. Although wearing a brace has been shown to reduce PFP, the exact underlying mechanisms behind the effect of bracing on the PFJ remains uncertain. Selfe (2004) knee pain review identified significant limitations in research involving knee bracing with only 6% of studies involved gait or objective movement analysis and only 7% involved knee braces.

Richards et al., (2015) recent investigation into the potential 'ladder of effectiveness' among conservative treatments for PFP found changes in knee mechanics providing possible evidence about the proprioceptive and mechanoreceptive effects, as well as reporting great knee control with the knee brace. The majority of clinical research on the effect of knee bracing has been limited by either focused simply about the movement in the sagittal plane or used very simple biomechanical models (Salsich et al., 2002; Crossley et al., 2004). Therefore, accurate measures of movement and moments around the ankle, knee and hip joints in the coronal and transverse planes cannot be investigated. The effects of knee bracing are important because it is possible altered biomechanics of the joints of the lower extremities (ankle, knee, and hip) are associated with knee injury. Biomechanically the body is a kinetic chain, and altered biomechanics of one joint, in theory, affects the biomechanics of other nearby joints.

Recent advances in knee brace design have led to further developments in types of knee bracing. Previous studies have shown improvements in knee mechanics when wearing prophylactic knee bracing during tasks such as step down, which supports the notation of improved neuromuscular control (Richards et al., 2015). However no further investigations have determined the size and nature of the biomechanical effects in more dynamic tasks using proprioceptive knee bracing.

1.4. Rationale

PFP is now one of the most common musculoskeletal disorders (Bergman et al., 2001; Tallay et al., 2004). Previous studies have investigated conservative treatment methods, specifically patellar taping (Baker et al., 2002; Callaghan et al., 2002; Aminaka & Gribble, 2005, Balachandar, Barton & Morrissey, 2011) and knee bracing (Nadler & Nadler, 2001; Warden et al., 2008; Selfe et al., 2008; Draper et al., 2009; Selfe et al., 2011). However, significant limitations occur in research involving knee bracing, where only 6% of studies involved gait or objective movement analysis and only 7% involved knee braces (Selfe, 2004). This creates an area to further investigate the effect of knee bracing in different functional movements related to sports performance.

Interest in the game of netball amongst female players has gained popularity in recent years, which has highlighted the effect of the physically demanding sport placing great demands on the body leaving players vulnerable to injury (Williams & O'Donoghue, 2005). Players are specifically vulnerable to developing PFP due to the nature of the sport involving excessive loading during jumping, cutting and pivot movements (Witvrouw et al., 2000) As a female-dominated sport it has a reputation for a high incidence of knee injuries (Ferreira & Spamer, 2010). Studies have investigated kinetic and kinematic differences between males and females; both Kernozek et al., (2005) and Malinzak et al., (2001) studies found females exhibited greater knee valgus angles during landing tasks involving high external knee joint loads (Boden et al., 2000; Hewett et al., 2005). Overall, research has found the prevalence of PFP is greater in young females who are physically active (Boling et al., 2010).

1.5. Ethical Approval

The STEMH ethics committee at the University of Central Lancashire provided ethical approval for this investigation (Appendix A/B). The unique reference number for ethical approval was STEMH 278.

1.6. Thesis structure

Chapter 1: Introduction

This chapter outlines the findings of previous work from patellofemoral studies and links this with knee function, to demonstrate how the present study will contribute to knowledge in this area.

Chapter 2: Literature Review

This chapter includes a review of the epidemiology of PFP and details the incidence rates in female netball players. Information is provided on the anatomy and function of the PFJ during functional movements. The use of conservative treatments is discussed and how the risk of PFP has been measured previously, including the influence of knee proprioception and assessment of pain. The initial aim and objectives of the present study are stated.

Chapter 3: Methodology

This chapter presents the methods used in the present study to compare kinetic and kinematic data, with and without prophylactic knee sleeve, in 20 healthy female netball players. The equipment is specially developed for this work detailed, before the procedures undertaken by the subjects are presented.

Chapter 4: Results

This chapter displays the kinetic and kinematic data; comparing the differences in functional movements with and without the prophylactic knee sleeve, and highlights any significant differences the knee sleeve makes on knee mechanics.

Chapter 5: Discussion

This chapter discusses the results of the healthy netball players, comparing the differences in knee kinematic and kinetic results including patellofemoral loading; with and without the prophylactic knee sleeve. Following, the limitations of the present study will be stated and considerations made for the direction of potential future research. The final overall conclusion will be presented.

CHAPTER 2

LITERATURE REVIEW

2.1. Definition of Patellofemoral Pain

Patellofemoral pain is a term for a variety of pathologies or anatomical abnormalities leading to anterior and retropatellar knee pain (Salsich et al., 2002). It is one of the most common musculoskeletal pain conditions seen in orthopaedic, general practice and sports medicine clinics (Ireland et al., 2003; Fredericson & Yoon, 2006; Wood et al., 2011). Research has found the prevalence of PFP is greater in young females who are physically active (Boling et al., 2010), particularly during loaded knee flexion activities such as descending stairs, squatting and running (Näslund, 2006). Despite the high incidence of PFP, the basic aetiology of this syndrome is still unknown, but numerous predisposing factors have been reported in the literature including patellofemoral malalignment and maltracking, gait abnormalities and elevated PFJ stress (Goodfellow et al, 1976; MacIntyre et al., 2006; Dixit et al., 2007).

2.2. Epidemiology of Patellofemoral Pain

Many authors claim that PFP is one of the most common musculoskeletal disorders (Bergman et al., 2001; Tallay et al., 2004). According to McConnell (1996), PFP affects one in four of the general population. In England alone, it was reported the population estimate of the adult population who have/had PFP, between 19 to 50 years old, is over 25 million (ONS, 2007). This is supported by Saxena and Haddad (2003) who showed patients can range from their early teens into their eighties, with PFP affecting up to 45% of teenagers and 33% of adults (Näslund, 2006). However, despite the estimated figures of the prevalence of PFP in the adult general population, the incidence of PFP in the general population is unknown with source data only focused on sport-medicine or military settings (Callaghan & Selfe, 2007). As a common overuse injury, Wilson (2007) found among 2002 of people with running injuries, PFP accounted for 7% of cases. In addition, based on the data of Taunton et al., (2002), approximately 2.5 million runners will be diagnosed with PFP in a given year.

Many studies have reported the condition is most common among active young females (Barton et al., 2009), along with athletic and military populations (Nejati et al., 2011). Boiling et al., (2010) reported females were 2.23 times more likely to develop PFP compared with males. Similarly, Wilson (2007) showed that females (62%) have a higher incidence of experiencing PFP than males (38%). It has been postulated that anatomical, neuromuscular and hormonal influences contribute to the enhanced incidence of patellofemoral disorders in females (Robinson & Nee, 2007). With the increased risk of developing overuse injuries such as PFP in young, active females it is important to identify physically active people who are at high risk to avoid the development of chronic PFP and recurring pain seen in 70-90% of individuals with PFP (Powers et al., 2012).

Risk of developing overuse injuries can be defined as complex interactions between internal and external risk factors. Internal factors such as age, sex, and body composition, in addition external factors such as shoe traction and floor friction may influence the risk of sustaining injuries, predisposing the athlete to injury, and are therefore by definition risk factors. It is the presence of both internal and external risk factors that renders the athlete susceptible to injury, but the mere presence of these risk factors is not sufficient to produce injury. The sum of these risk factors and the interaction between them ‘prepares’ the athlete for an injury to occur in a given situation (Bahr & Krosshaug, 2005). In order to address the potential for prevention of injury, previous injury prevention research has emphasised a critical step to establish the cause of injuries (van Mechelen et al., 1992). This includes obtaining information on why a particular athlete may be at risk in a given situation, defined as the risk factors, and gaining understanding of how the injuries happen, known as the injury mechanism. Firstly, the magnitude of the problem must be identified and described in terms of the incidence and severity of sports injuries (van Mechelen et al., 1992).

2.2.1. Incidence Rate in Female Netball Players

Netball is a physically demanding sport involving rapid acceleration, quick changes in direction, sudden breaking, pivots, jumps and balance, placing great demand on the body leaving players vulnerable to injury (Williams & O’Donoghue, 2005). Reviewing the limited aetiological literature available on netball injuries suggests that the sport is associated with a greater risk of injuries, specifically to the lower extremities. However, no studies have currently reported the incidence rate for specifically PFP in netball players.

Previous aetiological analyses have indicated the majority of injuries occur in the lower extremities and that a high proportion of these are chronic pathologies that relate to over utilization of the musculoskeletal structures during netball specific motions (McManus et al., 2006). The seriousness of the occurring injury problem has previously been highlighted by Egger (1990), who reported 20% of all injuries among netball players were injuries to the knee joint. This is further supported by Hopper and Elliot (1993) who showed that 52 of the 213 (24%) netball competitors sustained either a lower limb or back injury during the course of a netball tournament. Likewise, Hume & Steele (2000) documented the occurrence of 238 injuries per 1000 playing hours during a three-day tournament. More recent evidence has documented injury rates that range from 66.7 – 71.4 per 1000 participants, obtained from three seasons of league competition (Saunders and Otago, 2009). As a female-dominated sport it has a reputation for a high incidence of knee injuries (Ferreira & Spamer, 2010) with hospital reports identifying the knee as one of the most commonly injured body regions in both recreational and high performance netball players (Flood & Harrison, 2009).

The nature of netball and similarly in other team sports, up to 70% of knee injuries occur as a result of non-contact movements (Boden et al., 2000). Specifically these tend to occur during the landing or stance phase of a high impact task, that incorporates sudden deceleration and/or rapid changes in direction (Griffin et al., 2006). The majority of non-contact injuries have specifically focused on anterior cruciate ligament (ACL) injuries. This is due to the nature of the movements that create excessive external knee valgus moments thought to play a significant factor in increasing the risk of ACL injuries at the knee. Also, the risks of sustaining non-contact ACL injuries are two to eight times greater compared to male athletes (Hootman & Dick, 2007). However, demanding and dynamic movements requiring female athletes to change their direction of motion and involve rapid, high impact landing, such as a side stepping cutting manoeuvre, are high susceptible to injuries at the knee (Greene et al., 2014).

2.3. Anatomy of the Patellofemoral Joint

The PFJ is the articulation between the patella and the femoral trochlea (Dixit et al., 2007). It is a synovial joint with six degrees of freedom of motion; three translating and rotational motions around the *x*, *y* and *z* axes respectively, that is capable in dealing with large forces of multiple times of the body applied rapidly through a wide range of motion during functional activities (Selfe, 2010). The PFJ can be exposed to force values between 0.5 to 9.7 x body weight during normal daily activities and as high as 20 x body weight during intensive sporting activities (Schindler & Scott, 2011). The patella is a small, triangular, sesamoid bone located anterior to the knee joint, where the broad proximal end develops within the quadriceps muscle tendon (Tortora & Derrickson, 2011). The patella tendon located at the distal end of the quadriceps muscle tendon, extends from the apex of the patella and inserts on the tuberosity of the tibia. The main function of the patella is to improve the quadriceps efficiency and provide mechanical advantage to the quadriceps muscles used to extend the knee, by increasing the patellar tendon moment arm (Ward et al., 2012).

The stability of the knee joint is dependent upon static and dynamic stabilisers. The static stabilisers are passive structures such as the retinaculum, ligaments, cartilage and bone, while the dynamic stabilisers are the muscles involved in moving and positioning the patella, referred to as patellar tracking (Palastanga & Soames, 2012). Compromise of either the static of dynamic stabilisers of the knee will increase a burden on the other ligamentous structures that provide knee stability during functional movements, therefore may increase the likelihood of functional deficits and impair movement of the knee. To ensure stability in the three planes of motion: sagittal, coronal and transverse, the knee joint has four major ligaments split into two groups, collateral ligaments and cruciate ligaments each responsible for certain stabilisation in the joint.

2.3.1. Static Stabilisers

The collateral ligaments involve the lateral collateral ligament (LCL) and the medial collateral ligament (MCL) that run along the inside and outside of the knee. The LCL helps stabilise the knee laterally by preventing the knee from bending to the outside, therefore being a major static support to varus stress. It stretches from the lateral epicondyle of the femur down towards the head of the fibula. Whereas the MCL is situated on the medial side of the knee joint, slightly posterior connecting the femur to the tibia. It acts as a counterpart to the LCL by resisting forces that cause the knee to move inwards causing valgus stress. At 25 ° of knee flexion, the MCL provides 78% of the valgus-restraining force primarily due the decrease in contribution from the posterior medial part of the capsule during flexion (Grood et al., 1981). Structurally the collateral ligaments differ, the MCL is a broad, membranous band as more stability is required on the medial side, whereas the LCL is thinner and more flexible therefore less prone to injury. Both ligaments are tight during knee extension and become lax with increased flexion.

The cruciate ligaments sit within the middle of the knee joint and consist of the ACL and the posterior cruciate ligament (PCL). The ACL runs diagonally connecting the medial front of the tibia (anteromedial) to the lateral back of the femur (posterolateral), in counterpart with the PCL that stretches from the lateral edge of the medial femoral condyle to the posterior surface of the tibia. The ACL is the primary static stabiliser that controls tibial anterior displacement in the unloaded knee, as well as providing joint stabilisation as the ACL tightens against rotational moments (Fu & Zelle, 2007). Whereas the PCL prevents posterior translation by providing 95% of the total constraint during a range of flexion angles and is most important due to its cross-sectional area, tensile strength and location in the central axis of the knee joint (Margo, Radnay & Scuderi, 2010).

Passive stabilisation is primarily offered by the medial and lateral retinacula that is composed of various fascial layers, which extends from surrounding musculature, in particular the vastus lateralis (VL) muscle, and attaches to the patella margin (Dixit et al., 2007). Other attachments associated with the retinaculum include to the lateral epicondyle of the femur and to Gerdy's tubercle of the tibia (Merican & Amis, 2008). The medial patellofemoral ligament originates from the femoral medial epicondyle to the medial edge of the patella (Amis et al., 2003). Even though it is only a thin ligament, it is a major soft-tissue restraint to lateral patellar translation (Dopirak et al., 2008). Other static structures include the bony ridges of the trochlea, especially the lateral condylar ridge that mechanically stops the patella from dislocating laterally.

2.3.2. Dynamic Stabilisers

Surrounding the knee joint, a range of muscle complexes work together providing lower extremity stability and locomotion. The quadriceps muscle consists of the vastus medialis (VM), vastus intermedius (VI), VL and rectus femoris (FM), where the VM muscle acts as the main dynamic stabilizer of the patella. It acts at the main medial dynamic stabilizer to the patella due to the orientation of its fibres at a 55-degree angle to the rest of the quadriceps muscles, which stabilises the patella medially during extension (Tabassum & Prosenjit, 2014). The VM is described as being divided into two sections, the vastus medialis oblique's (VMO) and vastus medialis longus (VML) (Lieb and Perry, 1971).

Muscular balance of the medial and lateral quadriceps muscles surrounding the PFJ are important in assisting in maintaining the patella's position within the femoral trochlea. Quadriceps weakness/tightness has been identified as a potential risk factor in the development and persistence of PFP (Cowan et al., 2001): however these investigations provide conflicting findings. Dynamic imbalance of the PFJ has been studied by several authors which have assessed the changes in activity of the VM and VL muscles, confirmed as the primary dynamic stabilisers of the patella (Lin et al., 2004).

The strength of the main active stabiliser of the patella (VM) can be overpowered by tightness of the lateral retinaculum or VL, which can exert excessive lateral force on the patella and cause a timing deficit with delayed onset of the VM compared to the VL. In this instance, imbalances in activation patterns exist in the VM and VL (Cowan et al., 2001). This can alter patellofemoral alignment and cause weak knee extensor strength, which appears to be a risk factor for PFP (Lankhorst et al., 2012). In addition, quadriceps tightness is known to increase the contact pressure between the articular surfaces of the femur and patella hence increasing the risk of PFP. Elias et al, (2009) reported a link between VM function and pressure applied to lateral patellofemoral cartilage indicating improved VM function reduces the load carried by the PFJ cartilage. The study was performed to characterise how improving VM strength and activation time influences the pressure applied to the patellofemoral cartilage.

During a step descent movement, Bennett and Stauber (1986) found PFP patients failed to produce quadriceps eccentric control. Reductions in force producing capabilities and atrophy of the quadriceps muscles are major factors that can alter lower body kinematics and increase the risk of PFP (Dixit et al., 2007). Netball players with quadriceps weakness or tightness may contribute to patellar malalignment resulting in change in technical performance. Deficits in knee kinematics during functional activity have been associated with decreased VM activity (Crossley et al., 2004).

2.4. Biomechanics of the Patellofemoral Joint

The PFJ reaction force is the compressive force acting on the patella. It is defined as the force that is equal and opposite to the resultant of the patellar tendon and quadriceps force (Reilly & Martens, 1972). The resultant force helps to keep the patella in the trochlear groove as the knee flexion angle varies, displayed in the coronal view below (Figure 2.0).

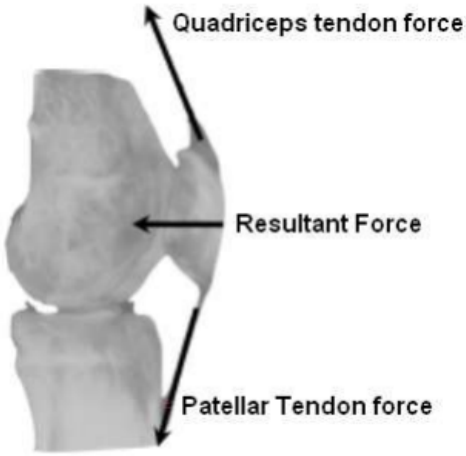

Figure 2.0. Resultant forces on the patella in the coronal view.

The articular cartilage at the PFJ is adapted with hyaline cartilage to bear the high compressive forces with minimal friction. In case there is any damage or loss to the cartilage of the patella, it can result in excessive forces on the patella causing pain. However recent evidence now suggests that PFP may be a pre-cursor to other conditions later in life, particularly patellofemoral arthritis (Thomas et al., 2010).

2.4.1. Lower extremity mechanics during functional movements

In recent years there has been an increase in studies that have focused on movement of the lower body extremities during functional movements, particularly looking at the differences between males and females. Kernozek et al., (2005) examined males and females to determined gender differences in ankle, knee and hip joint kinematics and kinetics in the front and sagittal planes during a landing task. They found females displayed significantly greater peak ankle dorsiflexion, peak foot pronation and peak knee valgus angles. Similarly, Malinzak et al., (2001) found females exhibited greater knee valgus and less knee flexion during landing tasks and this is further evident during landing tasks that involve high external knee joint loads (Boden et al., 2000). Overall during landing tasks, the literature is consistent in reporting that females display greater knee valgus angles (Malinzak et al., 2001; Kernozek et al., 2005) and higher vertical ground reaction forces (Hewett et al., 2005; Kernozek et al., 2005). Furthermore, male and female movement patterns have been compared when performing cutting manoeuvres. Results showed females typically perform cutting tasks with less knee flexion (Malinzak et al., 2001; James et al., 2004) and greater knee valgus (McClean et al., 2004; Sigward & Powers, 2006). In Beaulieu et al., (2008) study, male and female elite soccer players performed cutting manoeuvres and it was reported females had greater knee valgus angles at initial contact and greater peak knee valgus angles.

2.5. Intrinsic and extrinsic risk factors in PFP

2.5.1. Development of PFP

The aetiology of PFP remains controversial and it is generally agreed PFP can be considered as a multifactorial problem, resulting from multiple risk factors at a given time (Cheung & Chen, 2006). This is presented in a multifactorial model by Meeuwisse

(1994), which describes how multiple factors, intrinsic and extrinsic, can interact to produce an injury (Figure 2.1).

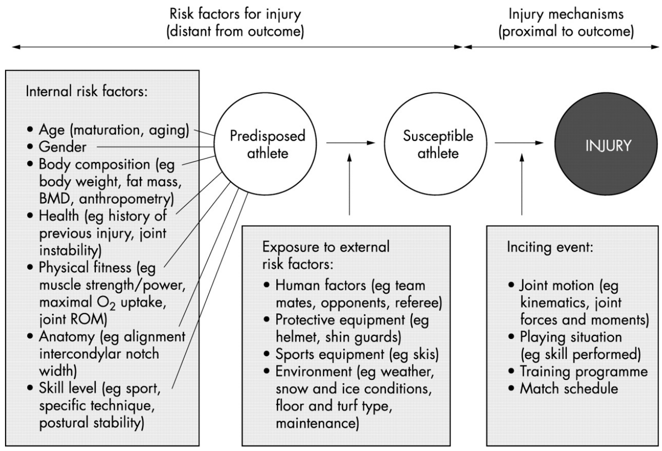

Figure 2.1. Multifactorial Model of sports injury etiology. (Adapted from Meeuwisse, 1994).

Previous literature has considered the most important aetiological mechanism for the development of PFP is an abnormal tracking of the patella in the femoral groove during flexion and extension of the knee joint (McNally, 2001; Elias & White, 2004). Dynamic malalignment is a term used to describe faulty movement patterns of the lower extremity during functional tasks that may lead to improper tracking of the patella within the femoral trochlea (Earl et al., 2005). For normal tracking of the patella in the trochlear groove of the femur, it is imperative the static and dynamic stabilisers are functioning correctly. Otherwise, if the stabilisers malfunction this will result in the maltracking of the patella, which significantly decreases the load tolerance of the PFJ (Dye, 2005) and thereby increases the risk of patellofemoral overuse.

Malalignment of the PFJ

The origin of possible malalignment within the PFJ can be distinguished into static (non-muscular) and dynamic (muscular) stabilisers. Bony abnormalities include femoral trochlear dysplasia, hypoplasia of the medial patellar facet and the presence of a shallow trochlear groove, which have been identified as possible causes of patella malalignment relating to PFP and instability. In addition, Kasim and Fulkerson (2000) stated 'the cause of PFP involves excessive pressure on the patella as well as patellar subluxation or tilt due to imbalance of the retinacular restraints.' Dysfunction of the lateral retinaculum can also result in patella hypermobility, therefore acting as a risk factor of PFP (Dixit et al., 2007).

In patients with PFP, it is common to have dysfunction of the dynamic stabilisers surrounding the knee joint, including loss of knee extensor strength. Retrospective studies have reported significant loss of quadriceps strength, specifically observed during eccentric contraction. A significant strength deficit in the quadriceps explosive strength was considered as a risk factor for the development of PFP (Witvrouw et al., 2000). As well as muscle weakness, dysfunction of the quadriceps includes various patterns of selective hypertrophy of the VM and neuromuscular timing dysfunction between the VM and VL (Witrouw et al., 2005). In addition to strength and neuromuscular dysfunctions of the quadriceps muscle, tightness of the lateral muscles specifically the iliotibial band (Hudson & Darthuy, 2008), causes lateral tracking and tilting of the patella. All these factors related to dysfunction of the quadriceps have been closely linked to patellar maltracking and the development of PFP.

An important concept in PFJ function is the quadriceps angle (Q-angle) as a greater q-angle (more than 15°) has previously been suggested as a risk factor for PFP (Mizuno et al., 2001). The q-angle is the angle between a vector connecting the anterior superior iliac spine (ASIS) to the patella and a vector connecting the patella to the tibial tuberosity (Livingston & Spaulding, 2002). The first vector represents the quadriceps muscle and the second vector represents the patellar tendon. There is evidence that the q-angle increases with increased knee flexion angles (Livingston and Spaulding, 1999), which may predispose women to greater lateral displacement of the patella during functional activities that require high levels of quadriceps activation (Lathinghouse and Trimble, 2000). This is only limited to flexion angles less than 60°, for example Powers and colleagues (2004) found PFJ contact forces increases linearly from 0 to 30 degrees of knee flexion, remains unchanged 30 to 60 degrees and decreases slightly from 60 to 90 degrees. In further clinical studies, Selfe (2000) confirmed that in a group of health volunteers a critical angle occurred, where there was a sudden reduction in eccentric control at 61° of flexion during a step down task. In a later study on a group of patients with PFP, the critical angle was observed to occur earlier at 58° of knee flexion (Selfe et al., 2001). This helps to confirm that patients with impairment in their extensor mechanism function may have particular problems during step descent.

Malalignment outside the PFJ

Much of the previous research has focused on the PFJ itself and used interventions, such as patellar taping and bracing, in order to influence patellar mobilization. However, it has been recognised that the mechanics of the PFJ can also be influenced by segmental interactions of the lower extremity (Duffey et al., 2000). The Kinetic Chain Theory suggests the lower limbs involve a complex, multi-segmented system involving the trunk, pelvis and lower extremities (Griffin et al., 2006). According to the kinetic chain theory, dysfunctions and alterations in the alignment of the proximal and distal segments of the lower extremity, namely at the hip, ankle and foot, may cause biomechanical changes at the PFJ, including malalignment, that could possibly lead to PFP (Lee et al., 2003; Powers, 2003).

Intrinsic imbalances of the ankle and foot have been linked to be predisposing factors in the development of PFP (Lun et al., 2004). These indirect factors include tibial varum, external tibial torsion and varus deformities of the forefoot and rearfoot, which are all likely to cause an increase in pronation at the subtalar joint (Tiberio, 1987). Knee valgus is often seen in individuals who exhibit increased eversion; this consequently leads to greater medial displacement of the foot, contributing to tibial abduction (Williams et al., 2001). It has been reported, in addition to femoral adduction, that tibial abduction can produce greater knee valgus (Powers, 2003) causing greater loading stress on the PFJ. Evidence has shown peak rearfoot eversion positively correlates with peak tibia internal rotation in patients with PFP, while rearfoot eversion range of motion positively correlates with hip adduction range in PFP and control groups (Barton et al., 2012). This adds greater implications for PFJ loading, as tibia internal rotation and hip adduction are likely to increase knee valgus and PFJ stress.

Considering the segments proximal to the PFJ, the kinetic chain theory suggests that proximal core hip strength is needed for control of distal segments (Niemuth et al., 2005). Clinical evidence provided by Mascal and colleagues (2003), found after a 14-week hip muscle-strengthening program, patients with PFP increased hip muscle strength leading to improved hip kinematics. However, a limitation of this study is that knee kinematics were not examined so the effect of hip muscle weakness on knee valgus remains unclear. It was hypothesised in Irelands' et al., (2003) study that the force of the hip muscles may play an important role in controlling the movement of the knee in the frontal and transverse planes. The authors found 26% less hip abduction strength and 36% less hip external rotation strength in individuals with PFP and concluded that hip muscle weakness may result in greater femoral adduction and internal rotation leading to an increase in PFJ stress. Similarly, increased hip internal rotation has been observed in females with PFP during functional tasks (Souza & Powers, 2009).

PFP is a common pain disorder experienced by young adult and adolescent athletes who participate in jumping, cutting and pivoting sports, all vulnerable to excessive loading (Witvrouw et al., 2000). Another main risk factor than can contribute to PFP is repeated forceful loading of the PFJ where forces on the patella range from between one third and one half of a person's body weight during walking, to three times body weight during stair climbing and up to seven times body weight during squatting (Reilly & Martens, 1972). This is supported by clinical observation that PFP typically is reproduced with activities that require quadriceps contraction. Dye (2005) stated the function of the PFJ can be characterised by a load and its' frequency of application, known as the "envelope of function" which defines a range of painless loading. If excessive loading is placed across the joint, loss of tissue homeostasis can occur resulting in pain (Witvouw et al., 2005). In addition to joint reaction forces, Heino-bretcher and Powers (2002) found higher PFJ stress in the PFP group was the result of diminished contact area. The combination of reduced contact area and elevated joint reaction forces is most detrimental with respect to PFJ loading.

2.5.2. Clinical Subgroups

Latest discussions among expert groups have highlighted the need for a classification system (Figure 2.3) to allow targeted intervention for patients with PFP. In recent high quality studies (Crossley et al., 2002; Collins et al., 2008), it has been proposed that a targeted intervention approach for specific subgroups of patients with PFP may produce improved patient outcomes and allow more specific treatments to be designed. The idea of clinically subgrouping patients with PFP and then delivering targeted treatment emerged from the First International PFP Research Retreat (Davis & Powers, 2010). This model identifies six subgroups identifying different clinical signs that have previously been proposed to cause PFP, which categorizes quadriceps weakness (Fredericson & Yoon, 2006), decreased flexibility of the lower extremity (Piva et al., 2005), patellar malalignment (Powers, 2003) and overuse and muscle imbalance (Thomee et al., 1995; 1999). The most widely accepted theory postulates that abnormal patellar tracking leads to elevated PFJ stress and articular cartilage degeneration (Fulkerson & Shea, 1990).

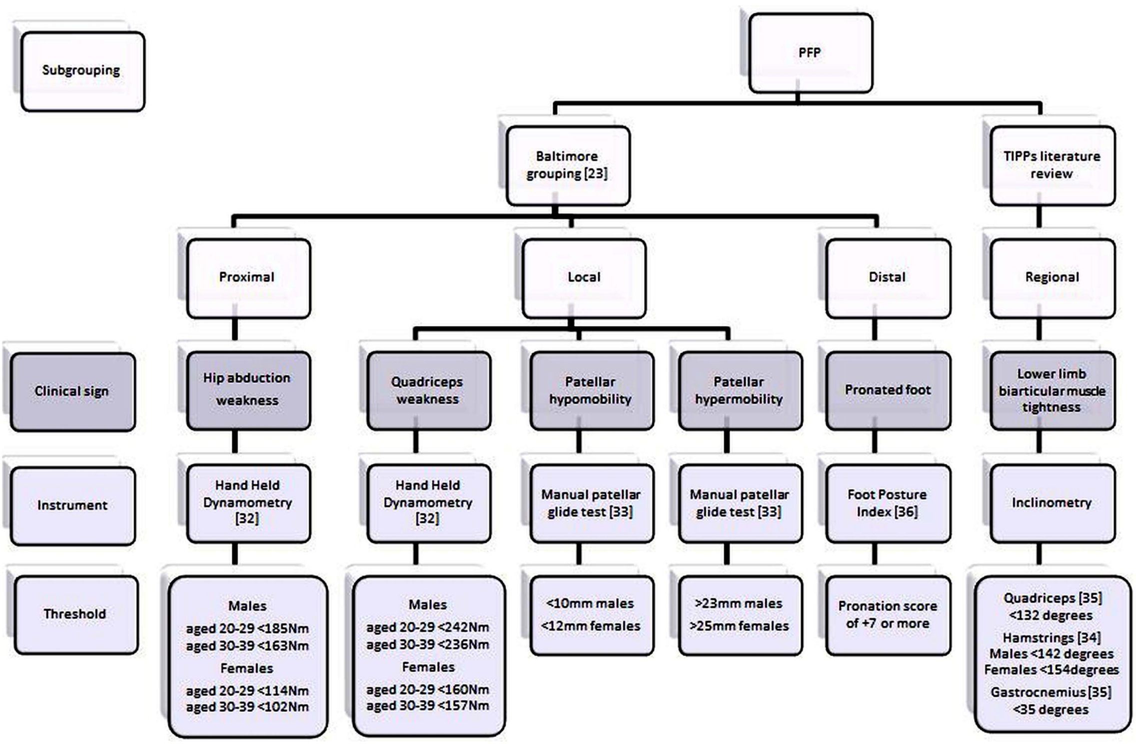

Figure 2.3. Targeted interventions of patellofemoral pain groups.

2.6. Conservative Treatment Methods

The goals of conservative treatment of PFP include improve patellar tracking and maintain patellar alignment thereby reducing pain and improving functional ability (Van Tiggelen et al., 2004). A range of conservative treatments for PFP often consists of a variety of components designed to improve patellar alignment. McConnell (1986) revolutionised rehabilitation of PFP patients with the introduction of taping concepts. Since this landmark paper, patellar taping has attained widespread acceptance and now recognised as part of the clinical standard practice. Whilst the concept of taping has received considerable attention in clinical and biomechanical literature, the effects of knee bracing have received far less attention by comparison even though the limited results are encouraging in the treatment of PFP (Nadler and Nadler, 2001).

2.6.1. Patellar Taping

Patellar taping has received far greater attention as taping techniques are now recognised as a standard clinical practice and readily used my physiotherapists in the treatment of PFP. Adhesive, rigid taping is designed to correct abnormal patellar alignments using McConnell (1996) tailored taping techniques to reduce excessive lateral glide, tilt, and rotation of the patella (Cowan et al., 2002). The physical correction of malalignment is one of the reasons it can be beneficial for PFP patients by establishing proper patellar tracking within the patellofemoral groove to ensure functional efficacy (Aminaka & Gribble, 2005).

Many studies have been performed to investigate the effects of patella taping in PFP patients. Balachandar, Barton and Morrissey (2011) concluded that patellar taping has effects on pain, neuromuscular control, and/or PFJ kinematics in individuals with PFP.

Previous studies have reported improvement in knee stability with the alteration of patellofemoral kinematics (Desasari et al., 2010); as an example Selfe et al., (2011) found patellar taping improved knee stability in the coronal and transverse planes during a step descent by reducing the range of motion and moments at the knee which can infer an improvement in knee control. Recent work has highlighted the importance of the potential proprioceptive effects of taping (Baker et al., 2002; Callaghan et al., 2002).

Malalignment of the patellar has been reported to be a predisposing factor for PFP with some studies showing patellar taping can help to decrease pain in patients with PFP (Cerny, 1995; Warden et al., 2008). Appropriate taping techniques have been reported to aim to decrease pain by at least 50% during relevant functional activity allowing for more intensive quadriceps rehabilitation (Crossley et al., 2000). In a recent systematic review of the literature, it can be concluded that patellar taping may be an effective intervention to reduce painful systems for the treatment of PFP (Aminaka & Gribble, 2005).

2.6.2. Knee Bracing

A frequently used therapeutic intervention to treat knee pain, along with knee taping, is the use of knee bracing (Warden et al., 2008). Numerous braces have been designed with the purpose of centralising the patella within the trochlear groove. As well as preventing excessive lateral shifting of the patella, patellofemoral braces have also been designed to reduce compression of the patella (Nadler & Nadler, 2001). In addition, knee braces have been advocated because several investigations have shown that wearing a brace alleviates symptoms and reduces PFP, for example Palumbo (1981) reported that 93% of patients with PFP had a reduction in pain. The pain-relieving effects have been attributed to an increased stabilisation of the joint, which reduces muscle force generation (Nadler & Nadler, 2001). Although wearing a brace has been shown to reduce PFP, the exact underlying mechanisms behind the effect of bracing on the PFJ remains uncertain.

Selfe et al., (2008) examined the influence of a patellar brace on the three-dimensional kinematics of the knee during a controlled step down task. It was shown that the brace condition significantly reduced peak coronal plane knee angle and also produced significant reductions in both coronal and transverse plane knee moment range. It was concluded that bracing leads to increased dynamic control of the knee in the coronal and transverse planes. Selfe et al., (2011) investigated the effect of patellar bracing on the three-dimensional mechanics of the knee in PFP patients during a step descent task. They showed that significant reductions in both coronal and transverse plane range of motion were mediated by the knee brace, which they believed was clinically relevant and lead to an increased stability at the knee. Draper et al., (2009) examined the effects of knee bracing in females with PFP. The effects of knee braces on patellofemoral flexion/extension motion were investigated using magnetic resonance imaging (MRI). Their results showed that bracing significantly reduced lateral translation of the patella near full extension, which Draper et al., (2009) concluded may be effective in reducing patellar maltracking.

Previously, BenGal et al., (1997) investigated the role of knee bracing in preventing PFP whilst performing increasingly intensive exertion exercises. They found as the exercise intensity increased, PFP symptoms appeared more frequently and those wearing knee bracing had significantly less incidence of PFP than those without knee bracing. It was concluded the use of knee bracing might be an effective way in reducing the onset of PFP. There are significant limitations in research involving knee bracing; in a knee pain review by Selfe (2004) it was reported only 6% of studies involved gait or objective movement analysis and only 7% involved knee braces. Richards et al., (2015) recently has investigated a potential 'ladder of effectiveness' among conservative treatments for PFP. It was found changes in knee mechanics between patients with and without PFP provide important evidence about possible proprioceptive and mechanoreceptive effects of different treatments. Knee bracing was found to provide the greatest knee control compared to neutral taping and a neoprene sleeve during a slow step down task. Particularly, no further investigations have looked at the effect of knee bracing in different functional movements related to sports performance. Overall, the majority of clinical research on the effect of knee bracing have either focused on the sagittal plane or used very simple biomechanical models, which do not allow accurate measures of the movement and moments about the foot, ankle and knee joints in the coronal and transverse planes (Salsich et al., 2002; Crossley et al., 2004).

2.7. <u>Knee Proprioception</u>

Proprioception is thought to play a more significant role than pain in preventing acute injury and in the evolution of chronic injury and degenerative joint disease (Lephart, 1995). Three main components provide the basis of proprioception: static awareness of joint position, kinaesthetic awareness of joint position and closed loop efferent neural pathways (Lattanzio and Petrella, 1998). Information obtained through senses is vital to the initiation of protective muscular reflexes. These protective reflexes can help prevent an injury to an articular joint or perhaps minimize the extent of an injury. Sensation arises through activity in the sensory neurons in the skin, muscles and joint tissue

(Grigg, 1994). Kinaesthetic awareness of joint position deals with the detection of movement and acceleration of the related joint and limbs.

Proprioceptive deficiency has been shown to cause abnormal stress accumulation in the surrounding tissue by obstructing movements and consequently contributes to the occurrence of further problems in the joint (Baker et al., 2002). It is not clear if proprioceptive deficiency causes the injury or if the injury causes the proprioceptive deficiency. Limited previous studies have investigated knee proprioception in patients with PFP and normal control patients. Akseki et al., (2008) found patients with a clinical diagnosis of unilateral PFP have impaired proprioception in their pathologic and normal knees compared to the normal controlled group. Similarly, Jerosch et al., (1996) studied the proprioceptive status in 43 patients with unilateral PFP and in 30 normal volunteers with the technique of detection of threshold of movement, and found deterioration in pathologic and normal knees. Baker et al., (2002) compared joint position sense in 20 PFP patients and 20 matched healthy control subjects. The results showed that the PFP patients were significantly less accurate and less consistent than the healthy control subjects.

In conjunction with reported mechanical effects of knee bracing, it has been shown that wearing a knee brace has significant consequences on the proprioceptive capacity. Knee sleeves are commonly considered the simplest form of knee brace as they simply provide a compressive force to the entire knee joint. Studies have suggested that therapeutic effects seen with these braces are due to enhanced sensory feedback rather than effects on patellar movement (Cherf & Paulos, 1990). The term ‘increased sensory feedback’ is used to depict an alteration in proprioception and muscular control, important in patients with PFP that have been shown to have abnormal knee joint proprioception. (Baker et al., 2002).

Evidence displays use of braces may be effective in the treatment of PFP by improving knee proprioception and muscular recruitment. (Birmingham et al., 2000). Interestingly, Prymka et al., (1998) showed that an elastic knee bandage improved patients' proprioceptive status significantly. The proposed mechanism for this finding was that the bandage stimulated rapidly adapting superficial receptors in the skin during joint motion and increased pressure on the underlying muscles and joint capsule. (Perlau et al., 1995). The importance of the effects of knee proprioception has been evident with previous studies proposing proprioceptive effects as one mechanism for pain reduction with patellar stabilization braces. (Lun et al., 2005; Selfe et al., 2008). During functional movement, it has been shown good proprioception leads to a decrease in injury rate. (Van Tiggelen et al., 2004).

Selfe et al (2008) was the first paper to determine the biomechanical effects on 3-dimensional movement and control of the knee when using taping and bracing during step down tasks. This work highlighted improvements in knee control and demonstrate a link to clinically important proprioceptive deficits (Callaghan et al., 2008). Higher levels of neuromotor and proprioceptive function with the application of a brace or sleeve have been significant, respectively than without a brace or sleeve (Thijs et al., 2010). The effect of neoprene knee sleeve application during open and closed kinetic chain tests has previously been evaluated in Birmingam' et al., (1998) study, which concluded the knee sleeve positively affected performance with 72% of participants reporting an improvement in performance. However, this study is limited in the fact patients had disorders in their proprioception, for example arthritis and anterior cruciate ligament tears, so it was expected a significant improvement in knee control would occur.

More recently, the use of functional magnetic resonance imaging (fMRI) has emerged as a favourable technique in order to provide an indirect measure of neuronal activity and detects regional mapping of human cognitive functions, such as motor and memory, by identifying associated changes in blood flow (Callaghan et al., 2012). Previous studies have demonstrated even though patella taping may not significantly alter patella alignment, it can improve proprioceptive in healthy individuals (Callaghan et al., 2002) and patients with PFP (Callaghan et al. 2008). However, the majority of proprioception studies have been limited, in terms of the variables measured and have only assessed the final outcome of muscle activation and joint movement (Riemann et al., 2002). Thijis et al., (2010) was the first to conclude both a knee brace and sleeve increase brain activation as a result of increased proprioceptive input, but it should be noted the multi-joint task performed was a non-proprioceptive task with knee flexion limited to 0 to 90 degrees. Furthermore, proprioception and simple non-proprioception tasks performed with and without patella taping have been found to alter brain response in healthy individuals (Callaghan et al., 2012). The interaction between the task and tape condition revealed a mix pattern of blood oxygenation level-dependent (BOLD) responses and brain activity, but the increases in brain activity and positive BOLD responses reveal the potential non-biomechanical effect of patella taping during knee movement.

2.8. Assessment of Pain

The International Association for the Study of Pain (IASP) (Merskey et al., 1979) has defined pain as, 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or describe in terms of such damage.' The pain intensity is a subjective sensation and a correlation is not uncommon between the amount of pain (sensation) and the degree of injury/disease (nociception). PFP is a diagnosis based primarily on a patient's complaint of pain or perceived loss of function. Clinicians routinely assess these parameters using a 10-cm or 20-cm visual analog scale (VAS) and an anterior knee pain scale (Kujala et al., 1993), which are tools capable of providing reliable and valid outcome measures (Crossley et al., 2004).

It has been demonstrated that there is an immediate decrease in pain during a provocative task, measured using the VAS following application of patellar taping. Whittingham et al., (2004) investigated the effect of patellar taping on pain between three groups: patella taping combined with a standardized exercise program, placebo patella taping and exercise program, or exercise program alone. The outcome was measured using a 10-cm VAS where 3 measures were used in this case: average pain over the previous 24 hours, and pain on performance of an aggravating activity (step-down task) both with and without taping over a period of four weeks. Results found improvements statistically significant reductions in pain in all groups, specifically the taping-and-exercise group compared with the placebo group, with pain initially reported as 3.6 ± 0.4 and reducing to 0.0 ± 0.0.

Similarly, patellar taping was found to significantly decrease perceived pain in patients with PFP during Herringtons' (2001) investigation when performing an isokinetic quadriceps strength test. It was proposed the reason for this is that taping of the patella medially repositions it in the trochlear groove (McConnell, 1996), meaning not only would it relieve pain by altering joint loading and relieving pressure on overloaded structures, but increased leverage provided by the patella and increased the quadriceps force potential. Overall it was concluded taping has the potential to increase quadriceps peak force either through repositioning of the patella to increase mechanical leverage or through a reduction of pain inhibition of the quadriceps.

Other studies have also assessed the effect of patellofemoral bracing on knee pain using the VAS. Powers et al., (2004) focused on the effect of two types of similar knee bracing where subjects rated their perceived pain on a VAS whilst doing a unilateral squat or deep knee bend. Out of a possible score of 10, the pain score significantly reduced comparing from having no knee brace (4.6 ± 1.9) to the application of the knee bracing (2.3 ± 1.8 and 2.6 ± 1.9). The results indicated small changes in patellar displacement form bracing could induce large increases in PFJ contact area, which could lead to reduced knee pain. Whereas, in Muhle and colleagues' study (1999), despite no statistically effect of the knee bracing on patellar displacement, patients reported subjective pain relief and comfort with the patellar realignment brace. They proposed the reason for the reduced pain could possibly be from altered feedback mechanisms related to neurophysiologic imbalance between the quadriceps muscles, rather than actual patellar kinematics. Neurophysiological imbalances between the VM and VL muscles have been reported in PFP patients (Cowan et al., 2001; Witrouw et al., 2005). Muhles' theory could be supported by a recent functional MRI study (Thijs et al., 2010), which reported that wearing a knee brace or sleeve could alter brain activation during knee movement by providing different intensities of peripheral inputs to the skin.

The collected findings suggest that bracing may employ different strategies to reduce PFP symptoms besides correction of patellar tracking. Thus, it is clinically important to understand the effect of different types of braces on the reduction of knee pain during functional tasks since various types of patellofemoral bracing products exist and each employs a different strategy to relieve PFP symptoms during functional tasks (Powers et al., 2004; Wilson et al., 2010).

2.9. Aims and Objectives

The aim of this study is to investigate the effect of a patellofemoral knee sleeve in different functional movements in healthy netball players, in order to assess knee mechanics relevant to potential PFP risk. This combines the clinical relevance of knee alignment and the influence bracing has on proprioceptive awareness and adjustments made in the different movements with the bracing.

The objectives of this study are:

- To conduct a literature review to determine appropriate kinetic and kinematic variables for analysis prior to full experimental protocol.
- To identify any changes in movement of the knee joint between the two interventions: with knee bracing and without knee bracing.
- To identify changes in the patellofemoral loads between the two interventions: with and without the prophylactic knee sleeve.
- To discover any differences between the four functional movements: run, cut, jump and pivot and how it may relate to the risk of injury or pain.
- To review participant subjective opinion based on the feasibility of the prophylactic knee sleeve, in terms of perceived comfort and stability.

CHAPTER 3

METHODS

3.1. Introduction

The purpose of this study was to investigate the effects of prophylactic knee sleeve on lower extremity kinematics and kinetics during four different movements that are commonly identified in the game of netball. Additionally, differences in the netball-specific movements were analysed to identify any potent variables that may contribute to an increased risk of PFP therefore developing further discussion. All instrumentation for this study were chosen in order to provide a comprehensive picture of knee joint biomechanics as well as descriptive and exploratory purposes.

3.2. Quantitative method of analyses

The review of previous literature demonstrates research that has investigated the effect of conservative intervention methods on PFP, is inconsistent with the limited studies that investigates the effect of knee bracing in dynamic movements that reflect sports performance.

A hypothesis is a tentative explanation created using plausible factual knowledge about a problem (Currier, 1990; Muijs, 2011). In this study, the experimental hypothesis to be investigated is as follows:

Experimental Hypothesis:

H1 – The hypothesis is that there will be a significant difference between the four movements (run, cut, vertical jump and pivot) and between the two conditions: with and without prophylactic knee sleeve, in all four movements.

Null Hypothesis:

H0 – The null hypothesis is that there will be no significant difference between the four movements (run, cut, vertical jump and pivot) and between the two conditions: with and without prophylactic knee sleeve, in all four movements.

Variables

The independent variables are the one to be manipulated. The variable, which may change as a result of our manipulation of the independent variables, is called the dependent variable.

To decrease the risk of error in the results, it is important that the researcher ensures that the measurement tools are valid and reliable. Validity is enduring that the researcher is measuring what is intended to be measured. Reliability is the ability to reproduce the results.

The variables being manipulated in this study are:

- Independent variables: Condition (Sleeve vs. No sleeve), type of movement (run, cut, jump, pivot).
- Dependent variables: Measured kinetic and kinematic variables.

Controlled variables:

- Standardised testing protocol.
- Correct sizing of the knee sleeve for each participant.

3.3. Participant Recruitment

Twenty female netball players aged between 18 and 30 years old (age = 20.95 ± 1.76 years, height = 1.67 ± 0.04 m, mass = 61.45 ± 7.04 kg) were recruited to participate in this study. The participants were recruited from the University of Central Lancashire student and faculty population, particularly the University Netball Club, and local surrounding netball clubs.

3.3.1. Sample Size

Based on the sample size calculations performed in previous studies (Wilson & Davis, 2008; Powers et al., 2004), it was found a sample size of 20 was sufficient to provide a statistical power of 80% ($P < 0.05$) and to ensure reasonable protection from type II errors.

3.4. Eligibility Criteria

To be eligible for the study, participants were required to be healthy individuals who haven't obtained any knee or ankle injuries within the last six months; with an injury defined as any incident that required medical attention, swelling or bruising visible or limited physical activity. Additionally, participants were required to be physically active at the time of testing, specifically involved in training or playing netball at least twice a week.

3.4.1. Screening Process

To ensure technical ability is controlled at a competitive playing standard, participants will be required to perform the movements prior to testing during a screening process to decide whether the participant continues onto the testing procedure.

3.5. Ethical Approval and Consent

The University of Central Lancashire ethical panel approved all procedures for this study. Prior to data collection, participants will be given a Participant Information Sheet (Appendix C) and will be required to complete a written informed consent form (Appendix D) and Physical Activity of Readiness Questionnaire (PAR-Q) (Appendix E).

3.6. Instrumentation

3.6.1. Patellofemoral Knee Bracing

One type of prophylactic knee bracing design was utilized in the study, named the Trizone knee sleeve (Figure 3.0), which came in three different sizes; small, medium and large to accommodate for all participants. The order in which participants performed in the two conditions were counterbalanced, with half performing movements with knee bracing initially, followed by performing movements without knee bracing and vice versa. Additionally, the order of the four movements; run, cut, pivot and jump, for each condition were randomised. This was conducted using a random number generator in Microsoft Excel 365.

Figure 3.0. Trizone knee sleeve.

3.6.2. 3D motion capture system

Kinematic data was captured at 250Hz using an eight-camera (Oqus 310 series) motion analysis system. The Qualisys motion capture (Qualisys Medical AB, Goteburg, Sweden) uses passive infrared technology to capture retro-reflective markers positioned on the body.

<u>*Camera Placement*</u>

The eight-camera motion system was configured in order to track the kinematic motions of all four movements. The data collected image was checked for each camera to determine the anticipated movement volume and the key aspects of each movement task could be seen from each camera.

Calibration

Prior to each data collection session, to identify the camera pose in respect to the lab co-ordinate system (Richards et al., 2008) calibration of the Qualiysis^{TM} system was performed. The lab global coordinate system (GCS) must be defined; where X is forward/backward direction, Y is vertical gravitational axis, and Z is the left/right (medial/lateral) axis. This is accomplished using a static reference L-frame (Figure 4.0) that is placed on the force platform and aligned along the X and Z -axis, which defines the origin of the GCS (Richards et al., 2008). In addition to the reference L-frame, a T-shaped wand (Figure 3.1) is used to provide dynamic calibration as it is moved through the anticipated movement volume. It is a fundamental requirement the whole volume is covered and that the orientation of the wand is varied to ensure accurate calibration in all three cardinal planes. The 3D coordinate data points collected from the camera system are determined by a Bundle adjustment, which is a nonlinear transformation technique from the Qualisys Track Manager software, to obtain the position and orientation of the camera's and wand (Triggs et al., 2000).

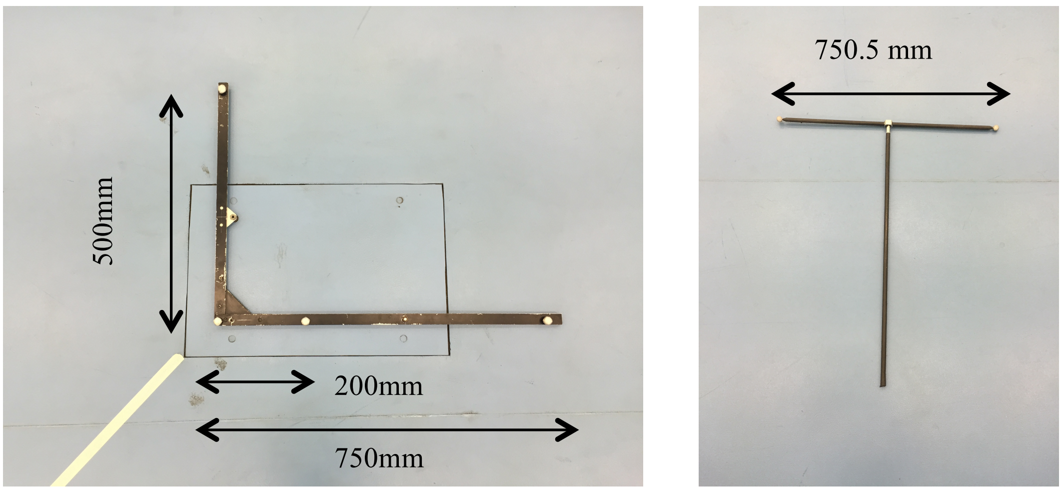

Figure 3.1. a) Calibration L-shaped frame. b) Calibration wand.

The purpose of the anatomical calibration process is to find the relation between the marker axes and the anatomical axes. Each calibration allows the two key factors to be calculated. Firstly, the norms of residuals are calculated which refers to the error associated with the camera system. Secondly, the standard deviation of the known wand length provides information regarding the potential errors in the quantification and representation of spatial marker position. Prior to data collection, an accepted calibration had to achieve values of less than 0.85mm for the number of residuals for each camera when using a 750.5 mm wand length and points in excess of 4000 to ensure data quality.

3.6.3. Kinetic Data Collection

Force Platform

The piezoelectric force platform utilized throughout the study is a Kistler 9281CA model (Kistler Instruments Ltd., Alton, UK) with dimensions of 60cm length by 40cm width. It is embedded in the floor (Altrosports 6mm, Altro Ltd.,) of a 22m biomechanics laboratory, located at the University of Central Lancashire, UK. All force platform data were obtained at 1000Hz.

3.7. Procedure

Participants performed four movement tasks under two conditions, namely unbraced (normal) and braced (wearing one knee sleeve on the right leg). For each participant, data collection for both conditions was conducted on one day. For the braced condition, participants wore a Trizone prophylactic knee sleeve on the right dominant knee.

Participants tried on the different sized bracing to ensure they wear the correct sized brace that restricts enough to provide support, within comfort levels.

Participants were informed of the location of the biomechanics lab (DB018) in Darwin Building at the University of Central Lancashire. All were instructed to report to testing wearing their own athletic clothes and shoes, providing they wore shorts with a length above the mid-thigh and a relatively tight fitting top to reduce the risk of marker tracking issues. On arrival, participants were introduced to the researcher(s) present and informed as to the study's purpose, and were then asked to complete the required documentation providing informed consent and completing the PAR-Q.

Anthropometric measurements were then taken which included the height (m) and weight (kg) of each participant, measured and recorded by the researcher using SECA scales. After the measurements were taken, the researcher conducted a brief 5-minute. This consisted of low intense heart raising exercises (jogs, star jumps, high-knees, heel-flicks) and dynamic stretching (lunges, squats). To ensure technical ability and the netball performance standard in all players is consistent, the researcher will demonstrate the required four movements that need to be performed and participants will have to replicate the desired movements as they would when playing netball. If the researcher felt the participant couldn't naturally perform the netball-specific movements, testing was terminated. This was stressed to participants during recruitment and at the initial welcome on arrival.

Once the participant is accepted to continue the testing process, fitting of the knee bracing is necessary before markers are placed on the body. The correct-sized knee sleeve for the right knee is selected and is then either removed or remained fitted depending on what condition is being tested first. Anatomical markers and tracking clusters were placed on the pelvis and segments of the lower extremities on each participant using the calibrated anatomical systems technique (CAST; Cappozzo et al., 1995).

Once all markers were positioned correctly, the previous warm-up was repeatedly conducted with participants allowed as much time as they desired. The researcher explained details of the tasks involved before commencing the testing procedure. A static calibration trial was captured with the participant standing in the anatomical position prior to each condition (with and without bracing) to allow the 3D cameras to capture the anatomical markers and reference in relation to the tracking clusters to define segment end points (Richards & Thewlis, 2008). After the first calibration trial, the lateral and medial femoral epicondyle markers were removed. Following completion of the first condition, the two markers were then repositioned for the second calibration trial before being removed again. Before actual data collection, participants had the opportunity to practice the movements and practice striking the force platform to become more accustomed and to allow the movement to be performed more naturally.

3.7.1. Run movement

When performing the running movement, participants' velocity was assessed at 4.0 m/s ± 10% by tracking the xiphoid retro-reflective marker. Participants struck the force platform with their right foot. After each trial the speed was checked and feedback was given to the participant to either maintain the speed, speed up or slow down.

3.7.2. Cutting manoeuvre

The cutting movement followed the same principle as the running movement, with the speed monitored at 4.0 m/s ± 10% by tracking the xiphoid retro-reflective marker at initial contact on the force platform. Participants were instructed to run forwards, strike the force platform with their right foot and perform a 45° forward v-cut movement (Figure 3.2) in the left direction (Sinclair et al., 2015). In accordance with McLean, Huang, Su, and Van Den Bogert (2004) cut angles were measured from the centre of the force plate using a goniometer and the corresponding line of movement was delineated using masking tape so that it was clearly evident to participants.

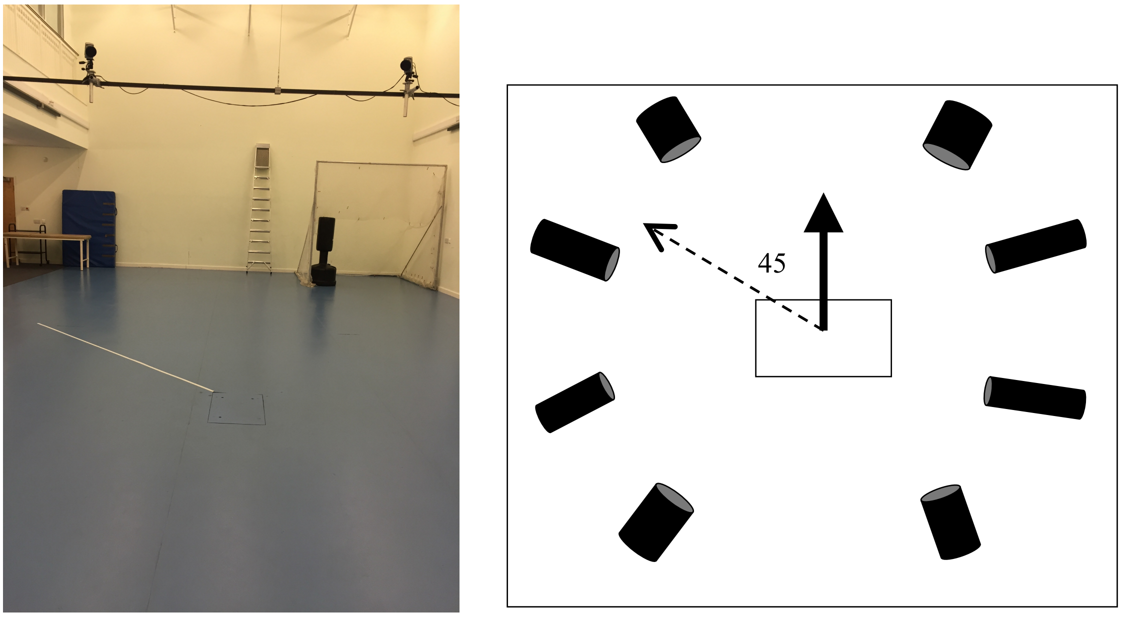

Figure 3.2. Direction of 45 ° of cut movement.

3.7.3. Countermovement jump

Participants started off the platform initially. The countermovement jump involved stepping onto the force platform with the right foot only and the left foot at the side of the force platform. Participants were instructed to perform a maximum two-foot landing jump involving an arm swing. Even though no specific jump height was measured, this was instructed to accurately replicate what would occur in a netball game.

3.7.4. Pivot movement

The final movement conducted was a pivot movement where the participant was instructed to perform a jog towards the force platform and land on their right foot, ensuring the foot is flat, and performing a pivot movement anti-clockwise at 180 degrees (Greig, 2009). Throughout the movement the left foot doesn't touch the ground until the participant is facing the direction they initially started from and can continue the movement by performing a slow jog away from the platform to the marked starting position.

These four movements are repeated for both conditions (with and without bracing) with three successful data trials completed for each individual movement. Once all data collection was completed the markers were removed and participants were required to complete the subjective feedback form.

3.7.5. Subjective Feedback questionnaire

Participants were given a feedback questionnaire (Appendix F) once all data collection was completed which asked to subjectively rate the Trizone knee sleeve in terms of stability and comfort, as well as provide further comments in relation to wearing the bracing when playing netball.

3.8. Calculation of 3D Kinematics

3.8.1. 3D Kinematic Marker Placement

The marker configuration utilized throughout the study to allow 3D tracking/modelling of specific segments was based on the CAST (Cappozzo et al., 1995). The CAST offers the ability to model each body segment in six degrees of freedom (6 DOF). The six ways of movement include: three linear or translational movements, vertically, medio-laterally and anterior-posterior, and three rotational movements in the sagittal, coronal and transverse planes.

For each lower-body segment, the CAST technique involves defining an anatomical reference frame based on palpable anatomic landmarks, which is then calibrated with respect to corresponding arrays of technical tracking clusters (Richards and Thewlis, 2008).

Anatomical Frame

The positioning of anatomical markers defines the proximal and distal ends of each segment, providing an anatomical coordinate system for each segment (Figure 3.3). The origin of the segment coordinate system is defined as the midpoint between the medial and lateral anatomical landmarks. A joint is identified when two segments endpoints meet. Once the anatomical segment coordinate axes have been defined for each segment, a static calibration of the model allows the segment coordinate system to be referenced in relation to the positioning of the tracking clusters (Richards & Thewlis, 2008). In this study, the anatomical frame of the lower extremity segments was defined as below.

Foot

The foot segment was modelled and tracked as a single rigid segment. Both the left and right foot segments were modelled and tracked. To identify the anatomical axes of the foot, retro-reflective anatomical landmarks were placed over the 1st metatarsal and 5th metatarsal to define the distal end, and to define the proximal end markers were placed over the medial and lateral malleoli. The segment co-ordinate system axes for the foot orientation were defined as the mid-point between the malleoli markers.

Shank

To define the distal end of the shank, anatomical landmarks were placed over the medial and lateral malleoli and at the proximal end; markers were placed at the medial and lateral femoral epicondyles. The segment co-ordinate system was defined as the mid-point between the femoral epicondyle markers.

Thigh

The thigh segment was defined using the hip joint centre at the proximal end and by the medial and lateral femoral epicondyles at the distal end. Prediction of hip joint centre location from external landmarks was based on anatomical regression equations proposed by Bell et al. (1989). Based on recommendations of Bell et al., (1989) in defining the hip joint, the anatomical technique was used which places the hip joint centre 14% medial, 22% posterior and 30% distal from the right anterior superior iliac spine (ASIS) markers (Sinclair et al., 2013). The segment coordinate system axes origin for the thigh segment was at the hip joint centre located midway between the ASIS anatomical landmarks. The three axis was positioned in all three planes of motion .The

Medial-Lateral (ML) axis was positioned from the left to the right ASIS marker. The Anterior-Posterior (AP) axis was constructed from the midpoint between the two posterior superior iliac spine (PSIS) landmarks, positioned perpendicular to the ML axis. The Superior-Inferior (SI) axis was generated as the cross product between the AP and ML axis.

Pelvis

The pelvis was constructed using the CODA option in Visual 3D software via the left and right ASIS, and left and right PSIS markers. The segment coordinate system axes origin was defined as the midpoint between the ASIS markers.

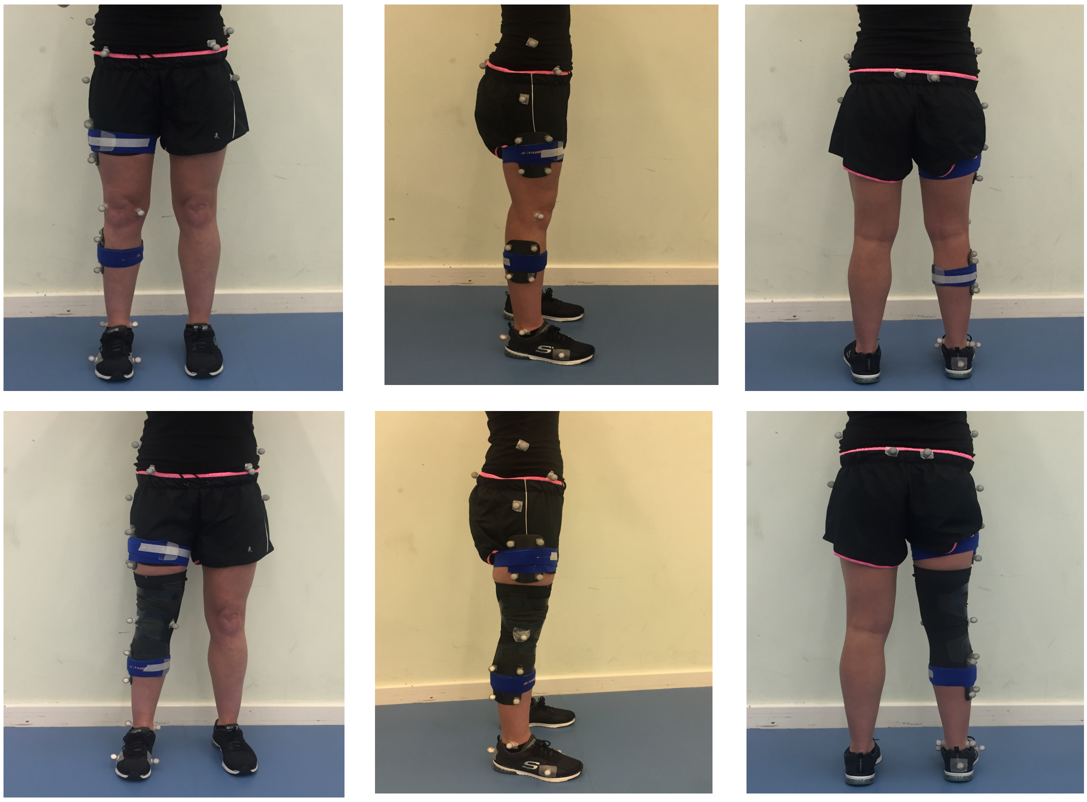

Figure 3.3. CAST Marker placement a) without knee sleeve, b). with knee sleeve.

Technical Tracking frame

To track and establish the technical frame, rigid tracking clusters (Figure 3.4) consisting of four spherical reflective markers fixed onto a thin sheath of lightweight carbon-fibre, were attached to the posterior-lateral distal aspect of the right shank and thigh segments. Marker clusters can be directly attached to the skin or mounted on rigid fixtures, however clusters of four markers mounted to a lightweight shell has been reported to be the most effective method of segmental tracking (Manal et al., 2000). The exact placement of the clusters does not matter as the CAST technique uses the relative positions to the anatomical landmarks used in the static calibration (Richards & Thewlis, 2008). However, to get the most effective tracking the markers are required to be placed at an angle between the sagittal and coronal planes. A minimum of three noncollinear markers is necessary to track the segment in 6 degrees of freedom (Cappozzo et al., 2005).

Figure 3.4. Tracking marker clusters.

3.8.2. The anatomical segment co-ordinate system

To define the anatomical coordinate system axes for each segment the position of a minimum of three anatomical points are necessary (Richards et al., 2008). The method used throughout this study was the segment coordinate system (SCS) found to be more meaningful anatomically than the GCS (Richards & Thewlis, 2008). The SCS uses the proximal and distal end points of each segment to determine the orientation of the *x, y* and *z*-axis of the joint. The unit vector for the Z-axis is positioned from the segments distal to proximal end points. Next, the SCS Y-axis is positioned perpendicular to the Z-axis in the frontal plane from posterior to anterior. The positioning of the Z- and X-axis enforces the right hand rule, which causes the X-axis to be inconsistent anatomically between the left- and right side SCSs of the body. To maintain the right-hand SCS, segments on the right side of the body have the X-axis in the lateral direction, and segments on the left side have the X-axis in the medial direction (Robertson et al., 2004). Joint rotations were calculated based on the notion that X is flexion-extension; Y is ab-adduction and Z is internal-external rotation.

3.8.3. Calculation of 3D angular kinematics

When the position of each segment is established, segmental rotations and translations are utilized to quantify 3D joint angles and velocities. This was calculated using the cardan/euler technique described by Grood and Suntay (1983), The joint coordinate system (JCS) proposed by Grood and Suntay usually relates to the cardan sequence xyz. The sequence order in which xyz rotations are placed may affect the orientation of the segment axes and thus the resultant joint angles. Ultimately, the cardan/euler technique calculates the angles that are represented by vectors from one coordinate system axes relative to another. However, to establish the segment orientation and joint angle the position vector and rotation matrix needs to be known. The position vector defines a pivot point between two segments and the rotation matrices describe the xyz axes of the SCS.

3.8.4. Data collection and analysis

Once all data were collected using Qualisys Track Manager (QTM) as .QTM files, the files were digitized and the anatomical and tracking markers were identified, using the marker configuration system, then exported as .C3D files. The .C3D files were imported into Visual 3D (C-Motion Inc., Gaithersburg, MD, USA) where marker data were smoothed using a low-pass Butterworth fourth-order zero-lag filter at a cut off frequency of 12Hz (Sinclair et al., 2014).

Similarly, Sinclair et al., (2014) ‘calculated angular kinematics of the lower extremity joints using XYZ (sagittal, coronal and transverse) sequence of rotations.’ The particular sequence XYZ is widely used and is a recommended standard for a range of dynamic movements (Lees et al., 2010). The International Society of Biomechanics (ISB) currently recommends lower extremity kinematics being quantified by means of an XYZ cardan sequence of rotations (Wu and Cavanagh, 1995). All the kinematic outcome measurements were normalized to 100% of the stance phase then processed files were averaged. Kinematic measurements extracted from statistical analysis were 1) angle at foot strike, 2) peak angle, and 3) relative range of motion (the angular displacement from foot strike to peak angle).

3.9. Calculation of Kinetic Data

Kinetic data were collected during the stance phase of the running, pivot and cutting movement; taken as the time over which >20 N of vertical force was recorded by the force platform (Sinclair et al., 2011). For the counter-movement vertical jump this movement was taken from foot contact (which was defined as the point at which >20 N of vertical force was applied to the force platform) to the instance of maximum knee flexion (Sinclair et al., 2014).

Results for the kinetic variables for trial were averaged for the run, cut, pivot and jump per individual, before creating a group mean for each movement. To allow normalisation amongst participants, forces were reported in bodyweights (B.W) by dividing the force measurements by bodyweight.

3.10. Calculation of Patellofemoral Loading

The peak extensor moment, patellofemoral contact force (PCF) and patellofemoral pressure (PP) were extracted from the data to quantify the knee loading experienced. In order to calculate the PCF and PP, a previously used algorithm was used (Ward & Powers, 2004), which has previously been used to identify differences between those with and without PFP (Heino & Powers, 2002).

Using the biomechanical model of Ho, Blanchette and Powers (2012), extracting the knee flexion angle (*KFA*) and knee extensor moment (*KXT*) allowed the estimation of the PCF (N/kg). The quadriceps effective moment arm (QMF) was calculated as function of KFA by applying a nonlinear equation (Van et al., 1986).

$$\mathrm{QMF} = 0.00008KFA^3 - 0.013KFA^2 + 0.28KFA + 0.046$$

Secondly, the quadriceps force (QF) was computed by dividing the knee flexion moment (*KXT*) by the effective lever arm (QMF).

$$\mathrm{FQ} = KXT \,/\, QMF$$

Third, PCF was estimated by multiplying the quadriceps force (QF) with a constant (KN).

$$PCF = FQ\ KN$$

The constant (KN) was estimated for *KFA* using the following nonlinear equation on the basis of the curve fitting to the data of Van Eijden et al., (1986).

$$KN = \frac{(0.462 + 0.00147KFA^2 - 0.0000384KFA^2)}{(1 - 0.0162KFA + 0.000155KFA^2 - 0.0000698KFA^3)}$$

Fourth, *PP* (MPa) was calculated using the PCF divided by the patellofemoral contact area.

$$PP = PCF\ /\ \text{contact area}$$

The patellofemoral contact area was estimated based on cadaveric data reported by Powers et al., (1998). A second-order polynomial curve was fitted to discrete data, displaying differences in patellofemoral contact areas at varied KFAs (0 °, 15 °, 30 °, 45 °, 60 °, 70 °).

3.11. <u>Statistical Analysis</u>

3.11.1. Descriptive statistics

Descriptive statistics of means and standard deviations were used to describe the anthropometric measurements of the participants (i.e. height, mass) as well as for each of the outcome variables.

3.11.2. Inferential statistics

Differences between parameters were examined using repeated measures analysis of variance (ANOVA) (5x2 design) with statistical significance accepted at the $p<0.05$ levels to control type 1 error, rather than using a bonferroni adjustment with the recommendation of Sinclair et al., (2013). In this review, it was advocated to follow a strategy of not making adjustments for multiple analyses as it will lead to less errors of interpretation and allows more exploration among data. Effect sizes were calculated using partial eta squared ($p\eta 2$).

3.11.3. Subjective participant feedback

Using the data collected from the subjective feedback based on participants' opinion on the stability and comfort of the knee sleeve, preferences were examined using a Chi-Square test. This assessed whether significantly more participants would prefer to wear the prophylactic knee sleeve during a netball environment, specifically based on perceived stability and comfort levels. Statistical tests were conducted using SPSS v21 and Microsoft Excel.

CHAPTER 4

RESULTS

4.1. Introduction

Twenty female netball players (age = 20.95 ± 1.76 years, height = 1.67 ± 0.04 m, mass = 61.45 ± 7.04 kg) with no previous knee injuries undertook all five movements, with three trials for each different movement. These five movements were performed with and without the Trizone knee brace, where kinetic and kinematic parameters were extracted during data processing.

4.2. 3D Kinematics

4.2.1. Sagittal Joint Angles

Table 1.0: Knee joint kinematics (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD
RUN				
X (+=flexion/-=extension)				
Angle at Footstrike (°)	20.12	4.57	17.66	4.18
Peak Range of Motion (°)	24.61	4.60	25.21	3.00
Peak Flexion (°)	44.73	4.11	42.86	4.79
CUT				
X (+=flexion/-=extension)				
Angle at Footstrike (°)	18.19	4.51	17.53	3.88
Peak Range of Motion (°)	34.12	7.24	34.63	5.11
Peak Flexion (°)	52.31	6.86	52.16	6.44
JUMP				
X (+=flexion/-=extension)				
Angle at Footstrike (°)	21.10	4.22	21.07	6.48
Peak Range of Motion (°)	64.12	15.81	62.93	10.81
Peak Flexion (°)	85.22	17.11	85.00	11.39
PIVOT LAND				
X (+=flexion/-=extension)				
Angle at Footstrike (°)	14.87	5.16	4.49	4.16
Peak Range of Motion (°)	39.78	5.78	40.63	2.92
Peak Flexion (°)	54.65	6.87	55.17	5.18
PIVOT TURN				
X (+=flexion/-=extension)				
Peak Range of Motion (°)	38.84	8.60	39.97	6.98
Peak Flexion (°)	15.08	6.19	14.58	5.09

Angle at Heel strike

The results show no significant difference in the knee angle at heel strike when wearing the knee brace in all movements, $F(1,16) = 1.01$, $p = 0.33$, $\eta p2 = .060$. The main effect of the different movements on the knee angle at heel strike were significant, $F(4,64)$, 307.36, $p < .001$, $\eta p2 = .951$. Specifically, post hoc tests revealed a significant difference in knee angle between the run and pivot landing ($p = .001$), the cut and jump landing ($p = 0.03$), the cut and pivot landing ($p = .004$). There was no significant and between the bracing x movement, $F(4,64) = 1.12$, $p = .37$, $\eta p2 = .065$.

Peak Range of Motion

The results show no significant difference in the peak range of motion when wearing the knee brace in all movements, $F(1,16) = 0.70$, $p = 0.42$, $\eta p2 = 0.42$. The main effect of the different movements on the peak range of motion were significant, $F(4,64)$, 62.74, $p < .001$, $\eta p2 = .797$. Specifically, post hoc tests revealed a significant difference in peak knee flexion between all movements ($p < .05$) apart from the pivot land and pivot turn, which displayed no significant difference ($p = .67$). There was no significant interaction between the bracing and movement, $F(4,64) = .10$, $p = .98$, $\eta p2 = .006$.

Peak Flexion

The results show no significant difference in peak knee flexion when wearing the knee brace in all movements, $F(1,16) = 0.26$, $p = 0.62$, $\eta p2 = .016$. The main effect of the different movements on the peak knee flexion were significant, $F(4,64)$, 209.70, $p < .001$, $\eta p2 = .929$. Specifically, post hoc tests revealed a significant difference in peak knee flexion between the run and cut ($p < .05$), the run and jump ($p < .05$), and the pivot turn with the other four movements ($p < .001$). There was no significant interaction between the bracing and movement, $F(4,64) = 0.39$, $p = .85$, $\eta p2 = .021$.

4.2.2. Coronal Joint Angles

Table 2.0: Knee joint kinematics (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD
RUN				
Y (+=adduction - =abduction)				
Peak Range of Motion (°)	8.23	4.11	6.70	2.81
Maximum Angle (°)	-0.86	3.70	-2.24	2.95
Minimum Angle (°)	-9.09	4.67	-9.24	4.52
CUT				
Y (+=adduction - =abduction				
Peak Range of Motion (°)	8.84	3.25	9.50	3.04
Maximum Angle (°)	-2.68	3.39	-3.32	3.12
Minimum Angle (°)	-11.51	5.82	-12.82	4.79
JUMP				
Y (+=adduction - =abduction)				
Peak Range of Motion (°)	9.88	3.53	10.62	3.13
Maximum Angle (°)	-2.19	3.72	-3.83	4.63
Minimum Angle (°)	-12.08	5.17	-14.46	5.59
PIVOT LAND				
Y (+=adduction - =abduction)				
Peak Range of Motion (°)	7.06	2.75	6.70	3.21
Maximum Angle (°)	-1.01	2.93	-2.40	5.11
Minimum Angle (°)	-8.07	4.02	-9.39	5.64
PIVOT TURN				
Y (+=adduction - =abduction)				
Peak Range of Motion (°)	8.86	2.61	8.11	3.93
Maximum Angle (°)	2.03	3.57	0.22	5.25
Minimum Angle (°)	-6.83	4.89	-7.89	4.38

Peak Range of Motion

The results show no significant difference in the peak range of motion when wearing the knee brace in all movements, $F(1,16) = 0.05$, $p = .83$, $\eta p2 = .003$. The main effect of the different movements on the peak range of motion were significant, $F(4,64)$, 6.22, $p < .001$, $\eta p2 = .280$. Specifically, post hoc tests revealed a significant difference in peak range of motion between the run and cut ($p < .05$), run and jump ($p < .05$), cut and pivot land ($p = .001$), jump and pivot land ($p < .001$), jump and pivot turn ($p < .05$), and pivot land and pivot turn ($p < .05$). There was no significant interaction between the bracing and movement, $F(4,64) = 1.22$, $p = .31$, $\eta p2 = .071$.

Maximum Angle

The results show no significant difference in the maximum knee angle when wearing the knee brace in all movements, $F(1,16) = 1.60$, $p = 0.22$, $\eta p2 = .091$. The main effect of the different movements on the maximum angle were significant, $F(4,64)$, 13.54, $p < .001$, $\eta p2 = .458$. Specifically, post hoc tests revealed a significant difference in the maximum knee angle between the run and cut ($p = .05$), run and jump ($p < .05$), and pivot turn with all other movements ($p < .001$). There was no significant interaction between the bracing and movement, $F(4,64) = 0.60$, $p = .69$, $\eta p2 = 0.34$.

Minimum Angle

The results show no significant difference in the minimum knee angle when wearing the knee brace in all movements, $F(1,16) = 0.65$, $p = 0.43$, $\eta p2 = .039$. The main effect of the different movements on the minimum angle were significant, $F(4,64)$, 19.85, $p < .$

001, $\eta p2 = .554$. Specifically, post hoc tests revealed a significant difference in the minimum knee angle between the run and cut ($p = .001$), run and jump ($p < .001$), cut and pivot land ($p < .00$), jump and pivot land ($p < .00$), and pivot turn with all other movements ($p < .05$). There was no significant interaction between the bracing and movement, $F(4,64) = 1.17$, $p = .16$, $\eta p2 = .097$.

4.2.3. Transverse Joint Angles

Table 3.0: Knee joint kinematics (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD	
RUN					
Z (+=internal/- =external)					
Peak Range of Motion (°)	19.76	5.67	15.91	3.86	*
Maximum Angle (°)	9.09	4.39	8.79	3.86	
Minimum Angle (°)	-10.67	4.98	-7.11	3.39	*
CUT					
Z (+=internal/- =external)					
Peak Range of Motion (°)	18.04	4.66	14.43	3.36	*
Maximum Angle (°)	8.46	4.59	8.70	3.63	
Minimum Angle (°)	-9.58	5.48	-5.73	4.37	*
JUMP					
Z (+=internal/- =external)					
Peak Range of Motion (°)	8.85	2.78	9.17	2.63	*
Maximum Angle (°)	2.18	5.22	1.24	4.09	
Minimum Angle (°)	-6.67	5.11	-7.92	5.22	*
PIVOT LAND					
Z (+=internal/- =external)					
Peak Range of Motion (°)	9.20	3.37	8.22	2.71	*
Maximum Angle (°)	6.37	5.92	6.36	4.00	
Minimum Angle (°)	-2.82	4.59	-1.87	3.86	*
PIVOT TURN					
Z (+=internal/- =external)					
Peak Range of Motion (°)	18.96	5.27	16.29	5.93	*
Maximum Angle (°)	3.80	5.53	4.00	4.21	
Minimum Angle (°)	-15.17	5.02	-12.29	5.36	*

Peak Range of Motion

The results show there was a significant difference in the peak range of motion when wearing the knee brace in all movements, $F(1,16) = 14.36$, $p < .05$, $\eta p2 = .473$. The main effect of the different movements on the peak range of motion were significant, $F(4,64)$, 32.98, $p < .001$, $\eta p2 = .673$. Specifically, post hoc tests revealed a significant difference in peak range of motion between the run and jump ($p < .001$), run and pivot land ($p < .001$), cut and jump ($p< .001$), cut and pivot land ($p< .001$), jump and pivot turn ($p< .001$), and pivot land and pivot turn ($p< .001$). There was a significant interaction between the bracing and movement, $F(4,64) = 3.77$, $p = .01$, $\eta p2 = .190$.

Paired samples t-test displayed a significant difference in the peak range of motion in the transverse plane during the run movement, where the peak range of motion was reduced in the bracing condition compared to the no brace condition, $t(18)$, 4.29, $p<.001$. Range of motion in the transverse plane differed between the cutting manoeuvre, where the no brace condition displayed a greater range of motion than the brace condition, $t(18)$, 4.02, $p<.05$. The pivot turn movement displayed a reduction in the range of motion in the transverse plane during the bracing condition compared to the no brace condition, $t(17)$, 2.13, $p<.05$.

Maximum Angle

The results show there no significant difference in the maximum knee angle when wearing the knee brace in all movements, $F(1,16) = 0.42$, $p = 0.84$, $\eta p2 = .003$. The main effect of the different movements on the maximum angle were significant, $F(4,64)$, 24.97, $p < .001$, $\eta p2 = .609$. Specifically, post hoc tests revealed a significant difference all movements ($p<.05$), apart from the run and cut ($p = .48$) and, jump and pivot turn ($p = .06$). There was no significant interaction between the bracing and movement, $F(4,64) = 0.44$, $p = .78$, $\eta p2 = .027$.

Minimum Angle

The results show there was a significant difference in the minimum knee angle when wearing the knee brace in all movements, $F(1,16) = 7.50$, $p < .05$, $\eta p2 = .318$. The main effect of the different movements on the minimum angle were significant, $F(4,64)$, 25.40, $p < .001$, $\eta p2 = .614$. Specifically, post hoc tests revealed a significant difference in the minimum knee angle between the pivot land and the other movements ($p < .001$), and the pivot turn and the other movements ($p < .001$). There was a significant interaction between the bracing and movement, $F(4,64) = 5.55$, $p <.05$, $\eta p2 = .257$.

Paired samples t-test displayed a significant difference in the minimum angle in the transverse plane during the run movement, where the minimum angle was increased in the bracing condition compared to the no brace condition, $t(18)$, 3.51, $p<.05$. Minimum angle in the transverse plane differed between the cutting manoeuvre, where the no brace condition displayed a greater minimum angle than the brace condition, $t(18)$, 3.02, $p<.05$. The pivot turn movement displayed an increase in the minimum angle in the transverse plane during the bracing condition compared to the no brace condition, $t(17)$, 2.74, $p<.05$.

4.3. Kinetic Data

Patellofemoral Load

Table 4.0: Knee joint PCF (N/Kg) and PP (MPa) (Mean and SD) measured for no brace and brace conditions (* = significant interaction between brace and movement p≤0.05).

	No Brace	SD	**Brace**	SD	
RUN					
Patellofemoral Contact Force (N/kg)	38.06	9.53	38.53	12.12	
Patellofemoral Pressure (MPa)	9.65	2.01	9.81	2.64	
CUT					
Patellofemoral Contact Force (N/kg)	45.75	11.84	47.21	12.99	
Patellofemoral Pressure (MPa)	11.58	2.74	11.93	3.05	
JUMP					
Patellofemoral Contact Force (N/Kg)	36.70	15.09	42.84	12.20	*
Patellofemoral Pressure (MPa)	16.14	10.80	16.97	7.32	
PIVOT LAND					
Patellofemoral Contact Force (N/Kg)	37.98	13.81	40.57	11.65	
Patellofemoral Pressure (MPa)	9.77	3.71	10.33	2.97	
PIVOT TURN					
Patellofemoral Contact Force (N/Kg)	32.69	11.84	32.88	8.33	
Patellofemoral Pressure (MPa)	8.40	3.20	8.39	2.34	

Patellofemoral Contact Force

The results show there was no significant difference in the PCF when wearing the knee brace in all movements, $F(1,18) = 3.95$, $p = .06$, $\eta p2 = .180$. The main effect of the different movements on the PCF were significant, $F(4,72)$, 35.64, $p < .05$, $\eta p2 = .271$. Specifically, post hoc tests revealed a significant difference in the PCF between all movements ($p < .05$), apart from the run and jump ($p = .63$), the run and pivot land (p =

.77), the run and pivot turn ($p = .10$), and the jump and pivot land ($p =.87$), which all displayed no significant differences. There was a significant interaction between the bracing and movement, $F(4,72) = 2.66$, $p = < .05$, $\eta p2 = .129$.

Paired samples t-test displayed a significant difference in the PCF in the jump movement, where the PCF was greater in the bracing condition compared to the no brace condition, $t(18) = -.280$, $p <0.05$.

Patellofemoral Pressure

The results show there was no significant difference in the PP when wearing the knee brace in all movements, $F(1,18) = 1.25$, $p = .28$, $\eta p2 = .065$. The main effect of the different movements on the PP were not significant, $F(4,72)$, 0.22, $p = .926$, $\eta p2= .012$. Specifically, post hoc tests revealed a significant difference in the PP between the run and cut ($p < .05$), cut and pivot land ($p < .05$), cut and pivot turn ($p < .001$), and the pivot land and pivot turn ($p < .001$). There was no significant interaction between the bracing and movement, $F(4,72) = 1.01$, $p =.410$, $\eta p2 = .053$.

4.3.1. Sagittal Joint Moments

Table 5.0: Sagittal knee joint moments (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD
RUN				
Sagittal Plane (X)				
Maximum Moment (Nm/kg)	2.96	0.68	2.99	0.78
CUT				
Sagittal Plane (X)				
Maximum Moment (Nm/kg)	3.23	0.66	3.34	0.71
JUMP				
Sagittal Plane (X)				
Maximum Moment (Nm/kg)	2.00	0.56	1.81	0.48
PIVOT LAND				
Sagittal Plane (X)				
Maximum Moment (Nm/kg)	0.17	0.28	0.15	0.24
PIVOT TURN				
Sagittal Plane (X)				
Maximum Moment (Nm/kg)	2.29	0.52	2.25	0.48

Maximum Moment

The results shows no significant difference in the maximum moment when wearing the knee brace in all movements, $F(1,16) = 5.46$, $p = .051$, $\eta p2 = .218$. The main effect of the different movements on the maximum moment were significant, $F(4,64)$, 36.77, $p < .001$, $\eta p2 = .697$. Specifically, post hoc tests revealed a significant difference in the maximum moment between all movements ($p < .05$), apart from the run and pivot land, which displayed no significant difference ($p = .17$). There was no significant interaction between the bracing and movement, $F(4,64) = 1.61$, $p = .18$, $\eta p2 = .091$.

4.3.2. Coronal Joint Moments

Table 6.0: Coronal knee joint moments (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD	
RUN					
Coronal plane (Y)					
Maximum moment (Nm/kg)	0.11	0.10	0.13	0.18	*
Minimum moment (Nm/kg)	-1.04	0.46	-0.86	0.39	
Range of motion (Nm/kg)	1.15	0.46	0.99	0.44	
CUT					
Coronal plane (Y)					
Maximum moment (Nm/kg)	0.49	0.38	0.75	0.65	*
Minimum moment (Nm/kg)	-1.07	0.52	-0.96	0.49	
Range of motion (Nm/kg)	1.56	0.57	1.71	0.71	
JUMP					
Coronal plane (Y)					
Maximum moment (Nm/kg)	0.38	0.20	0.45	0.18	*
Minimum moment (Nm/kg)	-0.06	0.07	-0.14	0.19	
Range of motion (Nm/kg)	0.43	0.16	0.58	0.27	
PIVOT LAND					
Coronal plane (Y)					
Maximum moment (Nm/kg)	0.17	0.28	0.15	0.24	*
Minimum moment (Nm/kg)	-0.83	0.40	-0.86	0.47	
Range of motion (Nm/kg)	1.00	0.30	1.01	0.40	
PIVOT TURN					
Coronal plane (Y)					
Maximum moment (Nm/kg)	0.20	0.12	0.28	0.19	*
Minimum moment (Nm/kg)	-0.57	0.29	-0.62	0.38	
Range of motion (Nm/kg)	0.77	0.27	0.91	0.41	

Maximum Moment

The results shows a significant difference in the maximum moment when wearing the knee brace in all movements, $F(1,16) = 10.83$, $p < .05$, $\eta p2 = .404$. The main effect of the different movements on the maximum moment were significant, $F(4,64)$, 12.56, $p < .001$, $\eta p2 = .440$. Specifically, post hoc tests revealed a significant difference in the maximum moment between all movements ($p < .05$), apart from the run and pivot land ($p = .53$), the cut and jump ($p = .09$), and the cut and pivot land ($p =.12$), which all displayed no significant differences. There was a significant interaction between the bracing and movement, $F(4,64) = 3.26$, $p <.05$, $\eta p2 = .169$.

Paired samples t-test displayed a significant difference in the maximum moment in the coronal plane during the cutting manoeuvre, where the maximum moment was greater in the bracing condition compared to the no brace condition, $t(18) = 2.70$, $p <0.05$. Maximum moment in the coronal plane differed in the pivot turn differed between the brace and no brace conditions, where the bracing condition displayed a greater maximum moment compared to the no bracing condition, $t(17)$, 2.49, $p<0.05$).

Minimum Moment

The results shows no significant difference in the minimum moment when wearing the knee brace in all movements, $F(1,16) = .45$, $p = .51$, $\eta p2 = .027$.The main effect of the different movements on the minimum moment were significant, $F(4,64)$, 35.64, $p < .001$, $\eta p2= .690$. Specifically, post hoc tests revealed a significant difference in the minimum moment between all movements ($p < .001$), apart from the run and cut ($p = .54$), the run and pivot land ($p = .09$) and the pivot land and pivot turn ($p =.16$), which all displayed no significant differences. There was no significant interaction between the bracing and movement, $F(4,64) = 2.33$, $p = .06$, $\eta p2 = .127$.

Range of Motion

The results show there was no significant difference in the range of motion when wearing the knee brace in all movements, $F(1,16) = 1.86$, $p = .19$, $\eta p2 = .104$. The main effect of the different movements on the range of motion were significant, $F(4,64)$, 30.40, $p < .001$, $\eta p2 = .655$. Specifically, post hoc tests revealed a significant difference in the range of motion between all the movements ($p < .05$), apart from the run and pivot land ($p = .47$) which displayed no significant difference. There was no significant interaction between the bracing and movement, $F(4,64) = 2.33$, $p = .07$, $\eta p2 = .127$.

4.3.3. Transverse Joint Moments

Table 7.0: Transverse knee joint moments (Mean and SD) measured for no brace and brace conditions (* = significant difference between no brace and brace p≤0.05).

	No Brace	SD	**Brace**	SD
RUN				
Transverse plane (Z)				
Maximum moment (Nm/kg)	0.09	0.08	0.09	0.07
Minimum moment (Nm/kg)	-0.13	0.13	-0.13	0.13
Range of motion (Nm/kg)	0.22	0.14	0.22	0.14
CUT				
Transverse plane (Z)				
Maximum moment (Nm/kg)	0.25	0.22	0.20	0.13
Minimum moment (Nm/kg)	-0.17	0.19	-0.19	0.15
Range of motion (Nm/kg)	0.42	0.31	0.38	0.22
JUMP				
Transverse plane (Z)				
Maximum moment (Nm/kg)	0.17	0.06	0.18	0.07
Minimum moment (Nm/kg)	0.00	0.03	-0.01	0.03
Range of motion (Nm/kg)	0.17	0.06	0.19	0.07
PIVOT LAND				
Transverse plane (Z)				
Maximum moment (Nm/kg)	0.08	0.08	0.07	0.06
Minimum moment (Nm/kg)	-0.33	0.17	-0.35	0.18
Range of motion (Nm/kg)	0.41	0.16	0.41	0.16
PIVOT TURN				
Transverse plane (Z)				
Maximum moment (Nm/kg)	0.30	0.09	0.31	0.09
Minimum moment (Nm/kg)	-0.29	0.17	-0.88	2.32
Range of motion (Nm/kg)	0.59	0.21	0.63	0.20

Maximum Moment

The results show no significant difference in the maximum knee moment when wearing the knee brace in all movements, $F(1,16) = 0.32$, $p = 0.58$, $\eta p2 = .020$. The main effect of the different movements on the maximum angle were significant, $F(4,64)$, 24.91, $p < .001$, $\eta p2 = .609$. Specifically, post hoc tests revealed a significant difference in the maximum knee moment between all the movements ($p<.05$), apart from the run and pivot land ($p =.45$) and the cut and jump ($p = .15$), which displayed no significant differences. There was no significant interaction between the bracing and movement, $F(4,64) = .87$, $p = .49$, $\eta p2 = .052$.

Minimum Moment

The results shows no significant difference in the minimum moment when wearing the knee brace in all movements, $F(1,16) = 1.16$, $p = .30$, $\eta p2 = .298$. The main effect of the different movements on the minimum moment were significant, $F(4,64)$, 2.99, $p < .05$, $\eta p2 = .158$. Specifically, post hoc tests revealed a significant difference in the minimum moment between the run and jump ($p <.001$), run and pivot land ($p< .001$), cut and jump ($p<.001$), cut and pivot land ($p<.001$), and the jump and pivot land ($p< .001$). There was no significant interaction between the bracing and movement, $F(4,64) = 1.12$, $p = .36$, $\eta p2 = .065$.

Range of Motion

The results show there was no significant difference in the range of motion when wearing the knee brace in all movements, $F(1,16) = .08$, $p = .78$, $\eta p2 =.005$. The main effect of the different movements on the range of motion were significant, $F(4,64)$, 37.40, $p < .001$, $\eta p2 = .700$. Specifically, post hoc tests revealed a significant difference in the range of motion between all the movements ($p < .001$), apart from the run and jump ($p = .24$) and cut and pivot land ($p = .86$), which displayed no significant differences. There was no significant interaction between the bracing and movement, $F(4,64) = 0.67$, $p = .62$, $\eta p2 = .040$.

4.4. Subjective feedback on the knee brace

The subjective feedback questionnaire provided information on the comfort and stability of the knee sleeve for each different movement.

Run movement

The Chi-Square test displayed no significant difference in the scale of comfort when wearing the knee sleeve during the run movement, $X^2 = 3.34$, $p = 0.09$. The test was significant in the scale of stability, $X^2 = 3.84$, p = $p<0.05$, and showed that significantly more participants found the sleeve to provide greater stability during the run movement compared to feeling 'very unstable.'

Cutting manoeuvre

The Chi-Square test displayed no significant difference in the scale of comfort when wearing the knee sleeve during the cut movement, $X^2 = 3.84$, $p = 0.11$. The test was significant in the scale of stability, $X^2 = 3.84$, p = $p<0.05$, and showed that significantly more participants found the sleeve to provide greater stability during the cut movement compared to feeling 'very unstable.'

Countermovement jump

The Chi-Square test displayed a significant difference in the scale of comfort when wearing the knee sleeve during the jump movement, X^2 = 3.84, p<0.05, with more participants finding the brace ‘ok’ compared to being ‘very comfortable’ or ‘very uncomfortable’. The test was significant in the scale of stability, X^2 = 3.84, p = p<0.05, and showed that significantly more participants found the sleeve to provide ‘no change’ during the cut movement compared to being ‘very stable’ or ‘very unstable’.

Pivot movement

The Chi-Square test displayed no significant difference in the scale of comfort when wearing the knee sleeve during the pivot movement, X^2 = 3.34, p = 0.43. The test was significant in the scale of stability, X^2 = 3.84, p = p<0.01, and showed that significantly more participants found the sleeve to provide greater stability during the pivot movement compared to feeling ‘very unstable.’

CHAPTER 5

DISCUSSION

The purpose of this study was to investigate the effects of wearing a prophylactic knee sleeve on knee angle at foot strike, peak knee flexion, and relative range of motion, joint moments, the PCF and PP. These variables were analysed in four different functional movements (run, cut, jump, and pivot) in healthy netball players. In addition to the bracing intervention, changes in knee mechanics between the four movements were discovered. Previous work investigating the biomechanical effects of knee bracing has focussed predominantly on the sagittal plane. The current study aimed to investigate the relevant 3D biomechanical changes at the knee joint in order to identify potential PFP risk factors, and gain subjective feedback on the netballers' perception of the knee sleeve that could possibly influence proprioceptive awareness.

5.1. Biomechanical effects

There has been limited research that has looked at the effect of knee bracing in the transverse and coronal planes. However, on-going discussions continue around two possible explanations of the improved control of the knee joint: mechanical and neuromotor (Selfe et al., 2008). It remains questionable whether a prophylactic knee sleeve has a direct mechanical influence on the tracking of the patella on the trochlear groove. It has been hypothesised that the use of external supports causes a change in the contact area between the patella and trochlea, by settling the patella deeper into the trochlea groove (Powers, 1998). In contrast, Bockrath et al., (1993) showed no significant modification of the patella between the femoral condyles after taping. The few existing studies on the influence of patellofemoral bracing on the position of the patella show contradictory results (Muhle et al., 1999; Shellock et al., 1995). Alternatively, it has been suggested the directional force component applied by the knee brace may account for the greater control seen in the transverse plane (Selfe et al., 2008).

Patellofemoral bracing aims to influence patella control and affect coronal and transverse plane kinematics of the knee (Nadler and Nadler, 2001). Any reduction in the transverse plane range of motion would confirm that the bracing had a significant effect on the mechanics of the knee. The reduced internal rotation is described by the motion of the tibia rotating about the longitudinal axis using the greater trochanter markers and femoral epicondyles at the distal femur as the fixed reference segment (Richards & Thewlis, 2008; Graci & Salsich, 2012). Theoret and Lamontagne (2006) showed that bracing reduced the overall range of motion of the knee joint in the transverse planes during running. Similarly during controlled eccentric step down tasks, knee taping/bracing was found to reduce transverse plane motions in healthy subjects (Selfe et al., 2008) and PFP sufferers (Selfe et al., 2011), which could possibly infer an improvement in joint control. However, little work has looked at whether a possible improvement in joint control could occur during dynamic functional movement tasks using interventions designed to control and give stability of these joints. A unique observation from this study is that the trizone knee sleeve significantly reduced internal rotation of the tibia relative to the femur during the run movement by 3.85°, the cutting manoeuvre by 3.61° and the pivot turn by 2.67°, compared to the non-braced condition.

This work found a significant increase in the coronal moment with the knee sleeve, specifically during the cut and pivot turn movements. This is in contrast to Selfe (2008; 2011) during the step down tasks that found reduced knee rotation in the coronal plane when wearing a knee brace, in both healthy participants and PFP patients. This could possibly be explained by the perceived increase in joint stability reported in the subjective feedback or could be due to the more dynamic nature of the tasks used in the study. Although, it is not known whether the additional load is being supported by active or passive structures i.e. VM and VL. If this is not the case this could mean vulnerable supporting structures, such as the ACL and collateral ligament, could be potentially taking the load therefore producing a greater varus moment. Knee moments in the coronal plane have previously been identified as an important consideration in the development of acute (Myer et al., 2010) and chronic (Hewett et al., 2005) knee injuries in females. The enhanced knee abduction moment with the trizone knee sleeve could potentially enhance loading of the PFJ complex and thus may further contribute to the aetiology of PFP (Myer et al., 2015; Sigward et al., 2012).

Overall, the evident biomechanical changes could possibly be linked to clinical factors associated with PFP. The brace seems to reduce the transverse plane of motion at the knee therefore reducing the extremity of knee malalignment and patella maltracking, which is linked to the development of PFP. Establishing proper patellar tracking within the patellofemoral groove significantly increases the load tolerance of the PFJ, and thereby reduces the risk of patellofemoral overuse during functional movements. By altering joint loading and relieving pressure could potentially reduce knee pain and improve functional efficiency. Clinically, as a vulnerable target group, netball players who are susceptible to PFP or suffers from PFP could experience positive biomechanical changes by wearing the trizone knee sleeve as a preventive or rehabilitation measure in order to improve knee control and stability. This could possibly reduce the incidence rate of PFP among netball players and improve sporting performance.

5.2. Proprioception

Increased proprioception may play an important role in reducing the range of motion in the transverse plane during the run; cut and pivot turn movements when wearing the trizone knee sleeve. Immediately, application of the knee sleeve provides cutaneous stimulation as it covers a large surface area of the skin and applies a compressive force to the area of skin on and around the knee joint, which enhance the neuromotor control. Sensation through stimulation in the sensory receptors in the skin, muscles and joint tissue (Grigg, 1994), may have increased sensory feedback to alter proprioception and muscular control (Baker et al., 2002). Prymka et al., (1998) proposed an elastic knee bandage improved proprioceptive status as it stimulated rapidly superficial receptors in the skin during joint motion and increased pressure on the underlying muscles and joint capsule (Perlau et al., 1995). The improved movement control in the transverse plane could potentially relate to the explanation by Edin (2001), who stated that the stabilising effects seen in taping techniques may be due to altered somatosensory inflow from the knee joint. It was reported that Type III slowly adapting afferents found in the skin about the knee and thigh display omnidirectional strain sensitivity. All types of joint movement are associated with a predictable pattern of changing strain in the surrounding skin, so by applying a knee brace this could significantly alter the pattern of strain in the skin. Therefore the effect of knee sleeve application will allow areas of skin to be subjected to a larger strain than usual, which will cause a different set of cutaneous receptors to be stimulated. Overall, this could contribute to the improved movement control in the transverse plane meaning skin mechanoreceptors thus seem suitable for providing proprioceptive information.

Limited research has looked at the effect of knee bracing on proprioception during functional activities, however Selfe et al., (2008; 2011) highlighted the potential link between knee control and clinically important proprioceptive deficits (Callaghan et al., 2008). Previous findings have revealed potential non-biomechanical effects of patellar bracing during active knee movement. During functional movements, it has been shown good proprioception leads to a decrease in injury rate. (Hewett et al., 1999; Van Tiggelen et al., 2004). This could be due to information obtained through senses that initiates protective muscular reflexes. Such protective reflexes may help prevent an injury to an articular joint or perhaps minimise the extent of an injury. In this current study subjective feedback from the participants found the knee sleeve provided greater knee stability in all four movements. This feedback is similar to those found in Selfe et al., (2011) where PFP patients self-reported their preference resulting in patients most likely to use a brace compared to a neutral patellar taping and no intervention. In addition, Hart et al., (2013) reported improved pain (3%), task difficulty (41%), stability (46%) and confidence (49%) when performing a step-down task with a varus unloader brace. However, it needs to be considered this patient group did have lateral tibiofemoral joint osteoarthritis and valgus malalignment after ACL reconstruction. With participants reporting greater knee stability, this could possibly relate to improved confidence in performance of the movement tasks or a reduction in kinesiophobia if individuals had suffered an injury such as an ACL injury (Tengman et al., 2014). Although, in this study the inclusion criteria required healthy participants meaning the feedback of increased knee stability might have resulted in greater confidence and physical exertion in the performance of the movement tasks, therefore could possibly explain the increased moment in the coronal plane.

Previous studies on proprioception have either measured variables along the efferent and afferent pathways or have assessed the final result of skeletal muscle activation and joint movement (Riemann et al., 2002). Recent advances include the use of fMRI, particularly BOLD contrast, which reflects the loss of oxygen from the haemoglobin during movement tasks causing its iron to become more magnetic (paramagnetic). Previously, fMRI used by Thijis et al., (2010) study found significantly high levels of neuromotor and proprioceptive function with the application of a knee brace. However, this study was limited in the amount of proprioceptive input with the task involving only flexion-extension movements in the sagittal plane. Similarly, Callaghan et al., (2012) investigated sensory input using fMRI when taping was applied during a proprioception task. It was concluded there was an immediate altered brain response when simple taping was used in healthy individuals during a proprioception compared to a simple nonproprioception task. It could be possible that participants in this study may have experienced 'an increased level of brain activation with the application of a brace and sleeve, compared to the condition when no brace was present' (Thjis et al., 2010), which could potentially explain the perceived improvement in stability during the different movements in this study. Although, the longer-term effects of a knee brace intervention remain unknown.

5.3. Patellar malalignment

Patellar malalignment has been commonly reported to have the potential to cause an increase and unusual dispersion of PFJ reaction forces, which can predispose to knee pain and/or structural damage (Grelsamer & Weinstein, 2001). Evidence has shown the influence of patellofemoral bracing (Draper et al., 2009) can lead to improvement in patellofemoral alignment to improve joint contact area and consequently joint pressure/stress (Powers et al., 2004). From a mechanical perspective, patellar stabilisation braces are designed to apply a medially directed force to the patella. In addition to joint compression, proprioceptive effects have been proposed as one mechanism for pain reduction. Powers et al., (1999) proposed changes in PFP symptoms with bracing could be due to changes in patellofemoral contact area, and not necessarily changes in patellar malalignment.

Clinically it may be important to increase the contact area at the PFJ in order to distribute forces over a greater surface area and/or direct forces to less irritated areas, resulting in an immediate reduction in pain. This has previously been shown; braces increased the contact area of the PFJ resulting in reduced joint pressure (Powers et al., 2004). However, Wilson et al., (2010) using a brace which featured a lateral buttress demonstrated similar increases in PFJ contact area but observed increases in patellofemoral pressure. The trizone sleeve used in this study didn't have a lateral buttress, but did improve stability in the coronal and transverse planes. This could be explained by the fact other patella sleeve braces have previously been shown to cause the patella to engage earlier during flexion in the trochlea groove, through their compressive mechanism on the quadriceps tendon (Wilson et al., 2010). This could have potentially contributed to the improved stability in the knee in the transverse and coronal moments; however this suggestion was based on a different designed knee sleeve. This is an interesting area of further investigation using the trizone knee sleeve to identify the effect of the compressive force applied to the PFJ and possible changes in the patella contact area, in absence of changes in patellar malalignment (Powers et al., 2004).

5.4. Landing strategies in different tasks

The significantly greater PCF in the landing of the counter-movement jump with the knee sleeve could potentially be due to a ‘stiffer landing’ strategy, which could result in greater ground reaction forces (Devita and Skelly, 1992), increasing the risk of ACL injury (Williams et al., 2004). Previous studies have reported a ‘stiffer’ landing strategy used by skilled athletes to reduce patella tendon loading when fatigued, to accommodate the inability of the fatigued muscles to efficiently absorb the landing forces (Edwards et al., 2007). However, there were no significant changes when wearing the trizone knee sleeve in knee flexion angle when landing in the counter-movement jump. Additionally, this could insinuate performance in the counter-movement jump was not significantly affected by the possible restrictive mechanisms with the trizone knee sleeve. Therefore an increase in the PCF with the bracing could be due to any potential joint laxity and mediolateral instability that requires increased muscular co-contractions activity to help stabilise the knee (Childs et al., 2004), but increases in PP could lead to potential joint destruction (Lewek et al., 2004). Again, this is unknown in the absence of measuring EMG activity to identify a correlation between an increase in PCF with an increase in muscle co-contraction. It has been reported PFP patients experience pain from increase PCF due to co-contraction of quadriceps and hamstring muscles and experience greater PP compared to pain-free subjects (Besier et al., 2009). The pain relieving effects of bracing still remains controversial, however the purpose remains to increase stabilisation of the joint, which reduces compression of the patella, as well as to prevent excessive laterals shifting and reduce muscle force generation (Nadler & Nadler, 2001).

There were significant differences amongst the different functional movement tasks, where it is clear the control mechanism and demands between these tasks are different. During the sagittal plane, the cut movement exposed the knee joint to the highest range of motion moment in comparison to the other movements, placing great demands on the knee extensors. It is commonly reported females exhibit higher knee extensor moments relative to hip extensor moments (Pollard et al., 2010), which could possibly be the result of weakness in strength of the hip extensors. Females have been reported to have a lack of neuromuscular control at the knee joint during dynamic activities (Mizuno et al., 2001; Stefanik et al., 2011). Due to slower neuromuscular signaling to the hamstrings (Hewett and Johnson, 2010), this could result in women athletes developing an overreliance on their quadriceps and passive restraints in the front plane to absorb impact forces. Additionally, disproportionate activation of the quadriceps and hamstrings allows more frontal plane motion and predominantly using the quadriceps may increase anterior tibial translation, likely to increase the risk of ACL injury (Bell et al., 2012).

In the coronal plane the greatest demands placed on the knee joint structures also occur in the cut movement. By increasing the joint loading in the frontal plane may lead to increased stresses within or around the PFJ and thus leading to pain. Previously external knee abduction moment has been linked to non-contact ACL injury during cutting tasks (Sigward and Powers, 2006). Whereas in the transverse plane, the PFJ is exposed to the greatest external-internal rotation moments during the pivot turn movement. The combination of compressive and rotational joint forces commonly occurring during athletic movements such as rapid cutting and pivoting (Brindle et al., 2001), may contribute to the development of patellofemoral dysfunction resulting in PFP (Myer et al., 2010). In the sagittal and coronal plane of movement, it is evident the cutting manourve displays higher moment loading, whereas in the transverse plane the pivot turn movement is vulnerable to excessive moment loading. It can be proposed the cut and pivot turn movements may increase the risk of developing PFP, however further investigation into the comparison of functional movement tasks is needed (Witrouw et al., 2014).

5.5. Limitations and considerations

During the testing process it was identified variability in movement control could be a potential limitation, specifically during the cutting and pivot movements. There are many ways to successfully perform the dynamic cutting movement. In the game of netball, cutting manourves can be unanticipated in response to a stimulus, and/or anticipated movement involving whole-body change of direction with a change of velocity or direction (Sheppard & Young, 2006). Due to the lab-based environment, it was difficult to replicate unanticipated cutting movements that would commonly occur in the game of netball in response to a stimulus, meaning this study specifically focused on anticipated cutting movement only. This could serve as a limitation as evidence has shown unanticipated cutting movements link to a greater risk of injury because of significant changes in hip and knee kinematics and kinetics (Houck et al., 2006), and relate to the very little time athletes have to adjust their body posture (Besier et al., 2001). In addition to the type of cutting manourve, variability in the anticipated movement occurred. Despite controlling the approaching velocity towards the force platform, it is known the cutting manourve involves a deceleration-acceleration phase upon the initial landing phase (McClean et al., 2004), which was not controlled. However, variability in knee joint angles did decrease in the cut movement when wearing the knee sleeve compared to wearing no knee sleeve in the sagittal, coronal and transverse planes. Using a laboratory as opposed to a field based approach however was deemed most appropriate as this allows more accurate measurements to be obtained in a more standardised manner allowing conclusions regarding the biomechanical effects of the brace to be more readily.

Similarly the pivot movement examined as part of this work may not replicate those typically observed during netball competition. It is likely given the nature of the task used in the current study that the movement velocity of the pivot was lower than those exhibited during competition. However, the reason that the task instructions were given in the manner that they were was to promote a more controlled and replicable movement pattern, as there can be great variability in the performance of pivot movements. This therefore meant that the biomechanical effects of the brace during the pivot movement could be investigated effectively and the confounding influence of movement variability during this motion was attenuated. In addition, though the speed of the movement may not be replicable to the game of netball, the pivot movement still consisted of the required phases of deceleration, 180° change of direction followed by increased acceleration (Greig, 2009). Interestingly, the knee sleeve reduced variability in knee joint angles during the pivot land in the transverse plane, and the pivot land and turn in the sagittal plane. However, variability was seen to increase when wearing the knee sleeve in the coronal plane in both the pivot land and turn.

A potential drawback of the current study is the use of a patellofemoral algorithm to calculate patellofemoral loading. It was necessary to use a mathematical model due to the invasive nature of obtaining direct measures of patellofemoral forces. Previous studies have used the model in runners (Kulmala et al., 2013; Sinclair, 2014) and differences between sexes (Sinclair and Bottoms, 2015). However in order to specify knee loads exclusively in females, the efficacy of the algorithm has yet to be resolved. Also, the model is limited to using sagittal plane information, as there is currently no algorithm that uses coronal and transverse information. This is particularly noteworthy with respect to the findings of the effect of the brace on the coronal and transverse plane of movements of the tibial-femoral joint in this study and their potential importance of the medial/lateral tracking of the patella, therefore future models need to be developed which incorporate more degrees of freedom.

5.6. Future work

Further work could consider looking at additional joint kinematics and kinetics, along with the PFJ. Recent evidence has emphasised the importance of focusing on the lower body kinetic chain and the influence of the hip and ankle joints on PFP (Duffey et al., 2000; Powers, 2003). Particularly abnormal motion of the tibia and femur in transverse and frontal planes may have an effect on PFJ mechanics, which has initiated interest in the development of interventions aimed at controlling proximal stability at the hip and distal stability at the ankle and foot (Powers, 2003). In this investigation, the reduced internal rotation experienced at the PFJ when wearing the knee sleeve could potentially decrease the size of the Q-angle and the magnitude of the lateral vector acting on the patella. Also, previous work has reported a close biomechanical relationship between the tibia and rearfoot where the internal rotation of the tibia in relation to the femur, evident in this study, is coupled with subtalar joint pronation (Barton et al., 2012). It has previously been hypothesised the relationship between the tibia and rear foot could impact PFJ dysfunction (Powers et al., 2002). Therefore, further research is needed to look at the interaction of the hip, ankle and foot on the PFJ in functional movement tasks.

Additionally, quadriceps muscle activity could be explored using electromyography (EMG) biofeedback, as knee flexion is primarily controlled producing a knee-extension moment during closed kinetic chain tasks. Measuring muscular activity of the VM and VL could potentially identify an imbalance of the extensor mechanism and medial/lateral control, which could result in patellofemoral malalignment (Fulkerson & Shea, 1990). It is unknown in this investigation whether the knee sleeve enhanced neuromuscular control of the knee during the different tasks. Previous studies have suggested that bracing alters the recruitment patterns of the surrounding muscles

(Osternig & Robertson, 1993) and unequal recruitment of vasti musculature has been hypothesisd as a possible mechanism for abnormal patellar tracking and pain (Cowan et al., 2002; 2003). However, no research has previously looked at EMG activity with the use of the trizone knee sleeve, and further research is needed to look at muscular activity during different functional movement tasks.

In order to investigate whether the trizone knee sleeve could potentially alter patellofemoral kinematics to reduce the risk of developing PFP, it is important to continue further work on PFP patients. This relates to looking at immediate and long-term effects of wearing the trizone knee sleeve and mapping if the brace continues to cause significant changes in movement. The immediate and long-term pain relief could be considered by test-retest of PFP patients using the Knee injury and Osteoarthritis Outcome Score (KOOS). The KOOS allows the measurement of outcome measures to evaluate the course of knee injury and treatment outcome (Ewa et al., 1998).

5.7. Conclusion

In conclusion this study investigated the effect of a patellofemoral knee sleeve to assess knee mechanics relevant to a potential PFP risk. The literature review displayed no previous studies that have looked the effect of a patellofemoral knee sleeves during the functional movement tasks used in this study, therefore this study has created a new area of interest. Interestingly, significant improvements on the coronal and transverse mechanics of the knee were identified when wearing a prophylactic knee sleeve. This change in knee mechanics further reinforces the importance of coronal and transverse plane mechanics, with clinical studies reporting movements in these planes should not be overlooked when studying PFP (Selfe et al., 2008: 2011). The current investigation provides insight into the aetiology of potential injury patterns and patellofemoral loading between different netball movement tasks that could increase the risk of PFP development in female netball players. The review of participant subjective feedback on the feasibility of the knee sleeve provided further questions into the possible influences from proprioceptive and mechanoreceptors, that could explain the greater knee control and stability. Further work is needed to provide additional 3D examinations of different functional movement tasks and expand on outcome measures using fMRI and EMG activity to develop our understanding on the effects of prophylactic knee bracing.

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Appendices

Appendix A – Ethics form

UNIVERSITY OF CENTRAL LANCASHIRE
Ethics Committee Application Form

PLEASE NOTE THAT ONLY ELECTRONIC SUBMISSION IS ACCEPTED

This application form is to be used to seek approval from one of the four University Ethics Committees (BAHSS; BuSH; PSYSOC & STEM). Where this document refers to 'Ethics Committee' this denotes BAHSS (ADP; ESS; IsLands; JOMEC; Languages; Law; LBS; Archaeology[Forensic]); BuSH (Built[BNE]; STTO & Health) PSYSOC (Psychology & Social Work) & STEM (CEPS; Dentistry & Medicine; Environment[BNE]; Forensic[except Archaeology]; Pharmacy).

If you are unsure whether your activity requires ethical approval please complete an UCLan Ethics Checklist. If the proposed activity involves animals, you should not use this form. Please contact the Graduate Research Office – roffice@uclan.ac.uk – for further details.

Please read the Guidance Notes before completing the form. Please provide all information requested and justify where appropriate. Use as much space as you need – the sections expand as you type. Click on box or circle to select relevant option (e.g. type or Yes/No) and click on 'grey oblong shape' to start typing for the free text entry questions. Each question on this form has instructions on how to answer that particular question. In addition links to relevant documents (e.g. templates, examples, etc.) and further guidelines are available in the Guidance Notes which can also be access from the question by clicking on appropriate question number.

Your application needs to be filled in electronically and emailed to roffice@uclan.ac.uk. Please insert in the subject line of your email the acronym of the committee that needs to deal with your application. Committee acronyms are BAHSS, BuSH, PSYSOC or STEM – see Appendix 1, at the back of this form, for list of Schools associated with each ethics committee.

If this application relates to an activity which has previously been approved by one of the UCLan Ethics Committees, please supply the corresponding reference number(s) from your decision letter(s).

Section 1
DETAILS OF PROJECT

All applicants <u>must</u> complete Section 1

1.1 **Project Type:**

- ☐ Staff Research
- ☑ Master by Research
- ☐ Taught MSc/MA Research
- ☐ Commercial Project
- ☐ MPhil Research
- ☐ PhD Research
- ☐ Undergrad Research
- ☐ Professional Doctorate

1.2 **Principal Investigator:**

Name	**School**	**Email**
Hayley Vincent	School of School, Tourism and the Outdoors	hvincent@uclan.ac.uk

1.3. **Other Researchers:**

Name	**School**	**Email**
Professor Jim Richards	SSTO	JRichards@uclan.ac.uk
Dr Jonathon Sinclair	SSTO	JKSinclair@uclan.ac.uk

1.4 **Project Title:**

Kinetic and 3D Kinematic analysis of netball movements: with and without prophylactic knee bracing

1.5 **Anticipated Start Date:**

October 2014

1.6 **Anticipated End Date:**

September 2015

1.7 **Is this project in receipt of any external funding** (including donations of samples, equipment etc.)?
Yes
£2000 provided from the School of Sport, Outdoor and Tourism to cover 50% of course fees.
1.8 **Brief Project Description** (in lay's terms) including the aim(s) and justification of the project.
Patellafemoral disorders are recognized as the most common chronic pathology in recreationally active individuals, which can diminish functional performance, with females at a much greater risk of developing patellafemoral pain. As such it is hypothesized the reduction in patellfemoral load would be significant in reducing the symptoms of patellafemoral disorders. Improvements in the symptoms of patellafemoral pain have been identified when wearing a patella brace or neoprene knee sleeve in previous studies. The aim of this project is to investigate the effect of a knee proprioceptive sleeve on different netball specific movements and the load experienced by the knee joint, in relation to reducing the risk of netball injuries. Key aspects to be examined are the kinetic and 3D kinematics during specific netball movements involving a jog, a jog and cut, a single leg vertical jump and a step-pivot. Data will be collected in the biomechanics laboratory using the force platform and 3D motion capture system. The second aim of the project is to explore important clinical changes with wearing a proprioceptive sleeve at the knee joint regarding the efficacy and effectiveness during netball movements.
1.9 **Methodology** Please be specific
A minimum of 20 participants will be recruited for this study from the University of Central Lancashire, all of who will be between the ages 18-30. Lower limb and torso kinematics will be analysed by attaching retro-reflective markers to the appropriate anatomical landmarks and tracking the different netball movements using an eight camera Qualysis Track Manager system motion capture system. Participants will be required to perform a jog, a jog and cut, a single leg vertical jump, and a step-pivot movement landing on the embedded force platform to collect

kinetic data. The data will be processed using visual 3D motion analysis software and then exported into SPSS for statistical analysis.
1.10 **Has the quality of the activity been assessed**? (select all that apply)
☐ Independent external review ☑ Internal review (e.g. involving colleagues, academic supervisor, School Board ☐ Through Research Degrees Sub-Committee (BAHSS, STEM or SWESH ☐ None ☐ Other
If other please give details
1.11 **Please provide details as to the storage and protection for your data for the next 5 years** – as per UCLan requirements
The data will be collected on a non-networked university specialist computer that specifically has the required computer software for data collection and processing, which is not available on UCLan networked computers. Using a non-networked computer provides additional security by eliminating the risk of data access from other computers connected to an external network.The data will be anonymized and identifieable via a number only. The data will be stored on a password protected computer. The folder on the laptop which the data is stored will be encrypted. The data will be backed up on a password protected external harddrive which will be stored in a securely locked cabinet at the researchers home. The computer equipment that the data will be stored on will be kept either at home on a password protected computer or in the coded locked biomechanics suite. Paper data i.e. Par-Q and consent forms will be kept in a locked filing cabinet in the PI's office for the duration of the 5 year period.
1.12 **How is it intended the results of the study will be reported and disseminated**? (select all that apply)
☑ Peer reviewed journal ☐ Internal report ☐ Conference presentation ☐ Other publication ☐ Written feedback to research participants ☐ Presentation to participants or releveant community groups ☑ Dissertation/Thesis

☐ Other

If other, please give details

1.13 **Will the activity involve any external organisation for which separate and specific ethics clearance is required** (e.g. NHS; school; any criminal justice agencies including the Police, Crown Prosecution Service, Prison Service, Probation Service or successor organisation)?

○ Yes ◉ No

1.14 **The nature of this project is most appropriately described as research involving:-** (more than one may apply)

☐ Behavioural observation

☐ Self-report questionnaire(s)

☐ Interview(s)

☐ Qualitative methodologies (e.g. focus groups)

☐ Psychological experiments

☐ Epidemiological studies

Section 2
HUMAN PARTICIPANTS, DATA OR MATERIAL
2.1 **Are you using human participants (including use of their data), tissues or remains**?

☐ Data linkage studies

☐ Psychiatric or clinical psychology studies

☐ Human physiological investigation(s)

☑ Biomechanical devices(s)

☐ Human tissue

☐ Human genetic analysis

☐ A clinical trial of drug(s) or device(s)

☑ Lab-based experiment

☐ Archaeological excavation/fieldwork

☐ Re-analysis of archaeological finds/ancient artefacts

- [x] Participants [proceed to question 2.2]
- [ ] Data [proceed to question 2.20]
- [ ] Tissues / Fluids / DNA Samples [proceed to question 2.20]
- [ ] Remains [proceed to question 2.24]
- [ ] No [proceed to Section 3]

2.2 **Will the participants be from any of the following groups:**

- [x] Students or staff of this University
- [ ] Children/legal minors (anyone under the age of 18 years)
- [ ] Patients or clients of professionals
- [ ] Those with learning disability
- [ ] Those who are unconscious, severely ill, or have a terminal illness
- [ ] Those in emergency situations
- [ ] Those with mental illness (particularly if detained under Mental Health Legislation)
- [ ] People with dementia
- [ ] Prisoners
- [ ] Young Offenders
- [ ] Adults who are unable to consent for themselves
- [ ] Any other person whose capacity to consent may be comrpomised
- [ ] A member of an organisation where another individual may also need to give consent
- [ ] Those who could be considered to have a particularly dependent relationship with the investigator, e.g. those in care homes, medical students
- [ ] Other vulnerable groups (please list)

Justify their inclusion

Having student and staff based at the University will offer a fitting sample of healthy individuals. The experience of seeing research conducted and the equipment used will be provided to all participants.

2.3 **Please indicate exactly how participants in the study will be (i) identified, (ii) approached and (iii) recruited**?

With the project specifically focusing on skilled netball players, participants will be required to have experience performing all movements technically correct. Prior to data collection, technical ability will be confirmed with a 'screening process' whereby participants must demonstrate the required movements. If not deemed technically correct, the participant will not be accepted to be involved in the study. This will be verbally explained and stated in the information sheet during the recruitment process. This will maximise the safety of all participants. Those who show interest to become potential participants, but do not meet the criteria, will be told at the earliest opportunity using the same method of communication in which they use to express their interest. The participants who do not fit the requirements of the study will be allowed to discuss the reasons with the experimenters if they wish. The first method of recruitment will be through advertisement (Appendix 5) of the project around the campus on AU lookout via email and physically posted around the campus in unrestricted advertising areas; the advertisement poster is attached with this submission. Secondly opportunity sampling of students and staff from around the university will be carried out, specifically targeting the University Netball Club. The chair of the University Netball Club will be contacted via email (Appendix 7). Participants who express an interest and are experienced in all the netball movements will be aloud to read the participant information sheet and provided that the study meets with their approval then allowed to arrange a time to attend the lab for testing.

2.4 **How exactly will consent be given**?

All participants will be provided with an information sheet (appendix 3) which explains the study and what will be required to them. See attached file. They will then sign a consent form.

2.5 **What information will be provided at recruitment and briefing to ensure that consent is informed**?

See attached participant information sheet.

2.6 **How long will the participants have to decide whether to take part in the research**?

Participants will be recruited a minimum or one week prior to the commencement of the testing itself. Withdrawal can be accepted up until the participants leave the laboratory; following this the data will be anonymized.

2.7 **What arrangements have been made for participants who might not adequately understand verbal explanations or written information given in English, or who have special communication needs**?

No participants whom there may be issues providing consent will be recruited for this study. This is because of safety concerns. Participants will need to follow and understand instructions given by the experimenters clearly when performing all four movements, given that none of the researchers are fluent in languages other than English or in sign language.

2.8 **Payment or incentives: Do you propose to pay or reward participants**?

○ Yes ◉ No

If Yes, please provided details

2.9 **Does the activity involve conducting a survey, interviews, questionnaire, observational study, experiment, focus group or other research protocol**?

X Yes No

Additional subjective feedback will be provided by each participant in the form of a questionnaire (appendix 4) following the completion of testing before exiting the lab. This will focus around the perceived knee stability when wearing the proprioceptive sleeve during the four different movements.

2.10 **Will deception of the participant be necessary during the activity**?

No

2.11 **Does the activity (e.g. Art) aim to shock or offend**?

○ Yes ◉ No

2.12 **Does your activity involve the potential imbalance of power/authority/status, particularly those which might compromise a participant giving informed consent**?

○ Yes ◉ No

2.13 **Does the procedure involve <u>any</u> possible distress, discomfort or harm (or offense) to participants or researchers** (including physical, social, emotional, psychological)?

Participants will perform common netball movements, which like any physical activity do carry a sligh risk of injury. All participants will have previous experience in performing all movements and wi additionally be given a demonstration of the required movements prior to data collection so the risk i minimized. The proprioceptive sleeve will vary in sizes and suited to fit each individual participant t avoid any possible discomfort around the knee joint. Participants will fill in a par-Q form (appendix 8 prior to the commencement of data collection to ensure that none are injured prior to th commencement of data collection.

2.14 **Does the activity involve any information pertaining to illegal activities or materials or the disclosure thereof**?

No

2.15 **What mechanism is there for participants to withdraw from the investigation and how is this communicated to the participants**?

All participation will be completely voluntary. Participants will be free to withdraw at any time during testing without reason, or fear of being penalized in any way. However, following the completion of the data collection, data will be anonymous and thus can no long be withdrawn. This will be clearly communicated verbally during the recruitment process and stated in the consent form.

2.16 **What is the potential for benefit for participants**?

Participants can be provided with a 3D analysis at the end of their testing session of all four movements. This may provide them with insight into their movement technique, in relation to netball, which may help them to improve or to reduce injury with and without the proprioceptive sleeve.

2.17 **What arrangements are in place to ensure participants receive any information that becomes available during the course of the activity that may be relevant to their continued**

participation?

Participants will be made aware of the cumulative results of the investigation upon request when they are available.

2.18 **Debriefing, Support and/or Feedback to participants**

Participants will be given the hypothesis upon debriefing. They will also be allowed to see the data collected from their trials, and the results of the study (once the analysis is complete) upon request. A biomechanical interpretation/explanation will be provided at the participants' request.

2.19 **Adverse / Unexpected Outcomes**

No adverse effects should occur as a result of taking part in this investigation – the risks of taking part are minimal as per the risk assessment. If by chance participants do experience any slight pain or discomfort when wearing the proprioceptive sleeve, the proprioceptive sleeve will be immediately removed with care. It will be verbally expressed to participants they can withdraw from the study and do not have to continue. However, if participants are voluntarily willing to continue and provide further consent, testing will resume with re-sizing of the knee sleeve to avoid any discomfort. (Stated in participant information sheet). It should be expressed the bracing condition is designed to alleviate pain through enhanced proprioception, and although these would not normally be worn by subjects without pain, they should not produce any adverse effects.

2.20 **Will the activity involve access to confidential information about people without their permission**?

No

2.21 **Does the activity involve medical research, human tissue samples or body fluids**?

No

2.22 **Confidentiality/Anonymity** - Will the activity involve:

	Yes	No
a. complete anonymity of participants is <u>not</u> possible (i.e. researchers may or will know the identity of participants and be able to return responses)?		X
b. anonymised samples or data (i.e. an irreversible process whereby identifiers are removed from samples/data and replaced by a code, with no record retained of how the code relates to the identifiers. It is then impossible to identify the individual to whom the sample or information relates)?		X
c. de-identified samples or data (i.e. a reversible process in which the identifiers are removed and replaced by a code. Those handling the data subsequently do so using the code. If necessary, it is possible to link the code to the original identifiers and identify the individual to whom the sample or information relates)?		X
d. participants having the option of being identified in any publication arising from the research?		X
e. participants being referred to by pseudonym in any publication arising from the research?		X
f. the use of personal data?		X

2.23 **Which of the following methods of assuring confidentiality of data will be implemented**? (Please select all relevant options)

2.24 **Does the activity involve excavation and study of human remains**?
No
☐ Human remains analysis ☐ Other (please specific in the box below)

Section 3
BIOLOGICAL ORGANISMS/ENVIRONMENT

3.1 **Does the activity involve micro-organisms, genetic modification or collection of rare plants**?

No

Section 4
HAZARDOUS SUBSTANCES

4.1 **Does the activity involve any hazardous substances**?

No

Section 5
OTHER HAZARDS

5.1 **Does the activity relate to military equipment, weapons or the defence industry**?

No

5.2 **Does the activity relate to the excavation of modern battlefields, military installations etc**?

No

Section 6

FIELDWORK/TRAVEL

6.1 **Does the activity involve field work, lone working or travel to unfamiliar places**?

Section 7

ETHICAL AND POLITICAL CONCERNS

7.1 **Are you aware of any potential ethical and/or Political concerns that may arise from either the conduct or dissemination of this activity** (e.g. results of research being used for political gain by others; potential for liability to the University from your research)?

○ Yes ◉ No

If yes please provide details below

If no please continue

7.2 **Are you aware of any ethical concerns about collaborator company / organisation** (e.g. its product has a harmful effect on humans, animals or the environment; it has a record of supporting repressive regimes; does it have ethical practices for its workers and for the safe disposal of products)?

○ Yes ◉ No

If yes please provide details below

If no please continue

7.3 **Are there any other ethical issues which may arise with the proposed study and what steps will be taken to address these**?

○ Yes ◉ No

If yes please provide details below

If no please continue

Section 8
DECLARATION

This section needs to be signed by the Principal Investigator (PI), and the student where the study relates to a student project (for research student projects PI is Director of Studies and for Taught or Undergrad project the PI is the Supervisor). Electronic submission of the form is required to roffice@uclan.ac.uk. Where available insert electronic signature, if not a signed version of the submitted application form should be retained by the Principal Investigator.
Declaration of the:

(•) Principal Investigator

OR

( ) Director of Studies/Supervisor and Student Investigators

(please check as appropriate)

- The information in this form is accurate to the best of my knowledge and belief, and I take full responsibility for it.

- I have read and understand the University Ethical Principles for Teaching, Research, Knowledge Transfer, Consultancy and Related Activities.

- I undertake to abide by the ethical principles underlying the Declaration of Helsinki and the University Code of Conduct for Research, together with the codes of practice laid down by any relevant professional or learned society.

- If the activity is approved, I undertake to adhere to the study plan, the terms of the full application of which the Ethics Committee蜉* has given a favourable opinion and any conditions of the Ethics Committee in giving its favourable opinion.

- I undertake to seek an ethical opinion from the Ethics Committee before implementing substantial amendments to the study plan or to the terms of the full application of which the Ethics Committee has given a favourable opinion.

- I understand that I am responsible for monitoring the research at all times.

- If there are any serious adverse events, I understand that I am responsible for immediately stopping the research and alerting the Ethics Committee within 24 hours of the occurrence, via roffice@uclan.ac.uk.

- I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.

- I understand that research records/data may be subject to inspection for audit purposes if required in future.

- I understand that personal data about me as a researcher in this application will be held by the University and that this will be managed according to the principles established in the Data Protection Act.

- I understand that the information contained in this application, any supporting documentation and all correspondence with the Research Ethics Committee relating to the application, will be subject to the provisions of the Freedom of Information Acts. The information may be disclosed in response to requests made under the Acts except where statutory exemptions apply.

- I understand that all conditions apply to any co-applicants and researchers involved in the study, and that it is my responsibility to ensure that they abide by them.

- **For Supervisors/Director of Studies:** I understand my responsibilities as Supervisor/Director of Studies, and will ensure, to the best of my abilities, that the student investigator abides by the University's Policy on Research Ethics at all times.

- **For the Student Investigator**: I understand my responsibilities to work within a set of safety, ethical and other guidelines as agreed in advance with my Supervisor/Director of Studies and understand that I must comply with the University's regulations and any other applicable code of ethics at all times.

☉ **Signature of Principal Investigator:**

or

○ **Supervisor or Director of Studies:**

Print Name: **J. Richards**

Date: 01/10/2014

Signature of Student Investigator:

Print Name: H.Vincent

Date: 01/10/2014

Section 9

ACCOMPANYING DOCUMENTATION

Please indicate here what documentation you have included with your application:

X Proposal/Protocol (Appendix 1)

☐ RDSC2 form ñ Application to Register for a Research Degree / Application for Research Programme Approval

☐ External ethics approval letter

☐ Letter of permission

X Participant Consent form (s) (Appendix 2)

X Participation Information Sheet (Appendix 3)

☐ Interview or observation schedule

X Questionnaire (s) (Appendix 4)

X Advert (Appendix 5)

X DP Compliance Checklist (Appendix 10)

☐ DP Security Questionnaire

X Risk Assessment (Appendix 6)

☐ COSHH

X Other

Other

- Copy of email to send to the Chair of University Netball Club during the recruitment process (Appendix 7)
- Health Screening Questionnaire/Participation Activity Readiness Questionnaire (Appendix 8)
- Data protection (Appendix 9)

Appendix B – Risk Assessment

School of Sport, Tourism and the Outdoors RISK ASSESSMENT FORM (Low risk, Student Version)

Use this form to risk-assess:

- ***Off-campus student activities (research, fieldwork, educational visits etc) in medium/high risk environments such as factories, farms, prisons, or remote areas.***
- ***All student activities involving medium/high risk procedures or use of specialist equipment.***

This form should be completed by the staff member responsible for the activity (e.g. the project supervisor), in consultation with the student and a qualified or otherwise competent person (normally a technician or Faculty HSE officer). Completed forms must be countersigned by the Head of Department or the Chair of the Department Health & Safety Committee.

Student:	**Assessment Undertaken By: (Staff member)**	**Assessment Verified By: (Technician or other competent person)**
Name: Hayley Vincent	Name: Professor Jim Richards	Name: Dr. Jonathon Sinclair
Signed:	Signed:	Signed:
Date: 01/10/2014	Date: 01/10/2014	Date*: 01/10/2014
Note: Risk Assessment is valid for* **one year *from the date given above. Risk Assessments for activities lasting longer than one year should be reviewed annually.*		
Countersigned by Head of Dept or Chair of H&S Committee:		
Date:		

Risk Assessment For:
Activity: Kinetic and 3D Kinematic analysis of netball movements: with and without prophylactic knee bracing. (Movements include: Jog, Jog & Cut, vertical jump, Step & Pivot).
Location of Activity: Biomechanics Laboratory (Darwin building 18).

List significant hazards here:	**List groups of people who are at risk:**	**List existing controls, or refer to safety procedures etc:**	**For risks which are not adequately controlled, list the action needed:**	**Remaining level of risk (high, medium or low):**
Dangerous of faulty facilities.	Researchers and participants.	Area should be well maintained and checked prior to the arrival of participants.		LOW
Medical conditions requiring medication.	Participants	Participants not medically able to compete will be recognised on completion of a par-Q form. Fit, participants should bring any necessary medication with them e.g. Inhalers. Participants who answer yes to any of the questions will be excluded		LOW
Inappropriate attire.	Participants	Participants will be instructed to wear appropriate clothing. The correct size knee brace will be used for each individual participant.		LOW

Fire	Researchers and participants.	Researchers and participants should be aware of where the nearest available fire exit is located. The exits should be kept clear. Researchers will be familiar with fire protocol.		LOW
Personal effects of the floor of the laboratory.	Researchers and participants	Ensure all belongings are placed by the wall, on the table or upstairs prior to the commencement of the testing.		LOW
Muscular Injury	Participants	Participants will have previous experience in performing all movements. Following completion of a suitable warm up.		LOW
Slipping, tripping or falling during trials.	Participants	The laboratory floor will be kept clear in the area in which the participants will perform their		LOW

		movements.		
Damaged equipment	Researchers and participants	All necessary equipment should have recently passed an appropriate safety inspection. PAT tested electrical equipment only, will be used. Any trailing cables etc will be taped down.		LOW
Medical Emergency	Researchers and participants	A first aid kit should be readily available, as should a phone.		LOW
Tripping/stumbling on wires	Researchers and participants	All cables are under tables or kept as far away from the activity as possible. Before hand all staff and participants will be made aware of areas they must stay clear of to avoid any risks wires from any extra mobile equipment could produce.		LOW

Appendix C – Participant Information sheet

Participant Information Sheet

Masters of Research Student: Hayley Vincent

School of Sport, Tourism and the Outdoors

Study title

Kinetic and 3D Kinematic analysis of netball movements: with and without prophylactic knee bracing.

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

Contact between the femur and the patella lead to patellofemoral pain, which is an extremely common injury in athletic populations. During specific netball movements patellofemoral contact forces can be high; this study aims to examine the effects of knee bracing on different netball specific movements and determine the effects of knee bracing on the load experienced by the patellafemoral joint. The study is being conducted as part of postgraduate Masters of Research (MSc Research) project.

Why have I been invited to participate?

You have been invited to take part in this piece of work because you train or/and play netball a minimum of twice a week. You have had no previous knee injuries or injuries causing complete inactivity in the past 6 months.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Participation in this study is completely voluntary. You may withdraw at any time without being penalized or disadvantaged in anyway. However as the data is anonymous and not tied in to your consent form, following completion of the data collection it will no longer be possible for your data to be withdrawn.

What will happen to me if I take part?

You will be contacted via email to schedule a designated time slot. On the data collection day you will arrive at the Biomechanics laboratory (Darwin building 018). You are advised to wear shorts, a t-shirt and the footwear worn when playing netball. Before data collection takes place, the researcher will verbally explain what is involved during the testing. To ensure you fully understand and can correctly perform the movements, the researcher will initially demonstrate the required movements (jog, jog-and-cut, single-leg vertical jump, step-pivot) and you will duplicate what is shown. If the movements aren't deemed 'technically correct' for the testing, this will be attended to at the time, as participation may be inhibited. Once accepted, you will be instructed through a thorough 5 minute warm up consisting of low intense heart raising exercises (jogs, star jumps, high-knees, heel-flicks) and dynamic stretching (lunges, squats). Testing will involve the placement of retro-reflective markers to the lower body; ankle, knee and pelvis, as well as cluster markers attached to the calf and thigh using a wrap-around. It may be required to tuck the top into the shorts or be slightly lifted and secured using tape when applying the markers at the pelvis, but permission will be given from you to ensure you are comfortable. In the laboratory there will be a force platform embedded in the floor surrounded by 3D cameras that will visually capture the markers. You will be instructed to perform three successful repetitions of the jog, jog-and-cut, single-leg vertical jump and step-pivot movements which will involve landing on the force platform, with and without the prophylactic knee bracing. After testing is complete, you will be asked to fill out an anonymous subjective feedback questionnaire based on the knee stability with and without the prophylactic knee bracing. Testing will take approximately 45 minutes-1 hour.

What are the possible benefits of taking part?

Feedback regarding the biomechanics of your technique across all four movements and how they may differ with and without the prophylactic knee brace can be provided on request at the end of data collection. Knee supports have previously been shown to improve stability, however we currently do not know if this will be the case with the tasks and brace being tested here. Though this study may not have direct benefit for yourself, if positive changes are seen then this could of benefit to people with knee instability which may improve aspects of netball performance.

What are the possible risks of taking part?

As with any physical activity there are small risks that are involved. These have been deemed to be minimal as you are performing movements regularly performed as a trained netball player. The screening process prior to data collection minimises risks by accepting those who demonstrate technically correct movements. A health screening form will be administered to you before data collection begins to ensure that you are healthy and haven't had any knee injuries in the past 6 months before data collection commences. If by chance the incorrect size knee brace is provided leading to any slight pain or discomfort, the proprioceptive sleeve will be immediately removed with care. It will be verbally expressed to you that you do not have to continue. However, if you are voluntarily willing to continue and provide further consent, testing will resume with re-sizing of the knee sleeve to avoid any slight discomfort. It should be expressed the bracing condition is designed to alleviate pain through enhanced proprioception, and although these would not normally be worn by subjects without pain, they should not produce any adverse effects.

Will the data that is collected be kept confidential?

All information collected will be kept strictly confidential with all data anonymised in accordance with the Data Protection Act (1998). Only the named researchers will have access to the data. Electronic data will be stored on a password protected encrypted laptop located at the researchers home and on a non-networked UCLan computer as these specific computers have the data processing software required. Health screening forms and informed consent forms (paper documents) will be stored separately in locked drawers. The data will be kept for 5 years and will then be securely destroyed.

What should I do if I want to take part?

Contact the researcher at hvincent@uclan.ac.uk where a time slot for data collection will be arranged. You will be required to fill an informed consent form before the study is further explained and any questions are answered. A screening process will be conducted and, if accepted, data collection will commence.

What will happen to the results of the research study?

The results from this study will be used for the write-up of a Masters of Research (MSc Research) project and scientific publication. If you would like a copy of the research then please contact hvincent@uclan.ac.uk and I will be happy to provide you with the findings.

Who is organising and funding the research?

We are conducting this research as part of postgraduate Masters of Research (MSc Research). A student postgraduate is conducting data collection here at UCLan with two members of staff from the School of Sport, Tourism and Outdoors as first and secondary supervisors.

Who has reviewed the study?

The research has been reviewed and approved by the University Research Ethics Committee.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any possible harm you might suffer will be addressed. If you have any complaints about the study or how you have been treated in the study, please in the first instance contact the researchers (Primary/Secondary contact) using the details provided below, they will do their best to answer your questions. If you do not receive a satisfactory response, concerns should be addressed to the University Officer for Ethics at OfficerForEthics@uclan.ac.uk. Information provided should include the study name or description (so that it can be identified), the principal investigator or student investigator or researcher, and the substance of the complaint.

Who do I contact to volunteer?

Primary Contact

Hayley Vincent

University of Central Lancashire, Preston, PR1 2HE. hvincent@uclan.ac.uk. Tel: 07507567384

Secondary Contact

Professor Jim Richards

Brook Building (Room 118)

University of Central Lancashire, Preston, PR1 2HE. JRichards@uclan.ac.uk. Tel: 01772 894575

Thank you for taking the time to read about the study, if you have any questions please do not hesitate to ask.20/10/2014

Appendix D – Informed Consent form

CONSENT FORM

Masters of Research Student: Hayley Vincent

School of Sport, Tourism and Outdoors

Title of study: Kinetic and 3D Kinematic analysis of netball movements: with and without prophylactic knee bracing

Please read the following statements and initial the boxes to indicate your agreement

Please tick below

1. I confirm that I have read and understand the information sheet, dated 01/10/2014, for the above study and 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 before leaving the laboratory after the completion of testing. ☐

3. I agree to wear shorts and understand why this is required. ☐

4. I agree that my data gathered in this study may be stored (after it has been anonymised) in a specialist data centre and may be used for future research. ☐

5. I understand that it will not be possible to withdraw my data from the study after data collection is complete and I have left the laboratory as data will be anonymised. ☐

Appendix E – Participation Activity Readiness Questionnaire

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

Appendix F

SIGNATURE ______________________________ DATE ______________________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Participant subjective feedback questionnaire

Participant Subjective Feedback Questionnaire

Subject Number: …………… Date: ………………..

Please answer the following questions.

Run

1. How comfortable was wearing the brace when running? (Using the Scale 1-3, 1= very comfortable, 2= Ok/Bearable, 3= very uncomfortable). ……………..

2. What do you think is/are the reason(s) for your rating above? (For example: bracing material, the sizing, restriction, no restriction etc.)
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

3. How stable did you feel when wearing the bracing when running? (Using the Scale 1-3, 1= very stable, 2= no change, 3= very unstable). ……………...

4. What do you think is/are the reason(s) for your rating above? (For example: bracing design, feel protected, unprotected etc.)
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

Cut

1. How comfortable was wearing the brace when performing the cutting manourve? (Using the Scale 1-3, 1= very comfortable, 2= Ok/Bearable, 3= very uncomfortable). ……………..

2. What do you think is/are the reason(s) for your rating above? (For example: bracing material, the sizing, restriction, no restriction etc.)
   ……………………………………………………………………………………………
   ……………………………………………………………………………………………

3. How stable did you feel when wearing the bracing during the cutting manourve? (Using the Scale 1-3, 1= very stable, 2= no change, 3= very unstable). ……………...

4. What do you think is/are the reason(s) for your rating above? (For example: bracing design, feel protected, unprotected etc.)
…………………………………………………………………………………………
…………………………………………………………………………………………

Jump

1. How comfortable was wearing the brace during the jump? (Using the Scale 1-3, 1= very comfortable, 2= Ok/Bearable, 3= very uncomfortable). ……………..

2. What do you think is/are the reason(s) for your rating above? (For example: bracing material, the sizing, restriction, no restriction etc.)
…………………………………………………………………………………………
…………………………………………………………………………………………

3. How stable did you feel when wearing the bracing during the jump? (Using the Scale 1-3, 1= very stable, 2= no change, 3= very unstable). ……………...

4. What do you think is/are the reason(s) for your rating above? (For example: bracing design, feel protected, unprotected etc.)
…………………………………………………………………………………………
…………………………………………………………………………………………

Pivot

1. How comfortable was wearing the brace during the pivot? (Using the Scale 1-3, 1= very comfortable, 2= Ok/Bearable, 3= very uncomfortable). ……………..

2. What do you think is/are the reason(s) for your rating above? (For example: bracing material, the sizing, restriction, no restriction etc.)
…………………………………………………………………………………………
…………………………………………………………………………………………

3. How stable did you feel when wearing the bracing during the pivot? (Using the Scale 1-3, 1= very stable, 2= no change, 3= very unstable). ……………...

4. What do you think is/are the reason(s) for your rating above? (For example: bracing design, feel protected, unprotected etc.)
   …………………………………………………………………………………………
   …………………………………………………………………………………………

Additional Comments

Would you wear this bracing when playing netball regardless of having any previous injuries? Why?

…………………………………………………………………………………………
…………………………………………………………………………………………

Did you find your technique changed when wearing the bracing? How? Positive or Negative?

…………………………………………………………………………………………
…………………………………………………………………………………………

…………………………………………………………………………………………
…………………………………………………………………………………………

Any additional comments related to stability and comfort of the bracing?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

Thank you for participating in this study and completing the Feedback Questionnaire