An investigation of the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists.

by

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A thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy at the University of Central Lancashire

September, 2015

Declaration

Student Declaration

Concurrent registration for two or more academic awards

I declare that while registered as a candidate for the research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic or professional institution

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I declare that no material contained in the thesis has been used in any other submission for an academic award and is solely my own work

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Type of Award: **Doctor of Philosophy (PhD)**

School: **School of Sport, Tourism and The Outdoors**

ABSTRACT

Considering that Patello-Femoral Pain (PFP) is responsible for over 25% of all road cycling related injury and over 65% of injuries in the lower limb, alongside trauma related pain it remains the main injury affecting experienced and elite cyclists and is commonly treated using taping. Taping can broadly be categorised into ‘McConnell’ and ‘Kinesiology type tape’ (KTT) as these are seen as recognised clinical approaches in dealing with patella tracking and pain issues.

The aim was to collect specific data to inform and develop a study into current taping techniques used in cycling related knee pain. An online questionnaire determined the techniques used by clinicians treating elite and experienced cyclists. Recruitment was through professional networking and the social network Twitter™. The questionnaire indicated a clear preference for the use of KTT. A specific taping technique was identified for use in a laboratory-based study. Respondents indicated their rationale for using tape, which included pain reduction, neuro-muscular adaptation, placebo and altered biomechanics. A subsequent study then investigated the interventions, KTT, neutral tape and no taping, alongside comparing asymptomatic (n=12) and symptomatic (n=8) cyclists. Each cyclist conducted three separate and randomised intervention tests at three powers (100W,200W,300W) on a static trainer. Kinematic data were collected using a 10-camera Oqus 3 motion analysis system. Reflective markers were placed on the foot, shank, thigh and pelvis using the CAST technique.

This study showed significant differences in the knee, ankle and hip kinematics between cyclists with and without knee pain. The knee had increased ROM (coronal) in those with knee pain (p=0.005 or 18% change) whereas in the hip, those with knee pain had less movement (p=0.001 or 26% change). The ankle however had an increase in movement (transverse) in those with knee pain (p=0.034 or 14% change). Significant differences in hip, knee and ankle kinematics on the application of KTT were found, however these had no identifiable pattern that suggested any clinical indication. Interestingly, similar levels of differences were also found with the neutral taping application, which indicated that a specific technique might not be critical. It was also noted that

200 watts of power produced the most pain response during testing (33% change) which may have a practical application to future taping related clinical testing.

If we are looking to establish a biomechanical change using KTT, ROM may indeed be reduced, however individuals had different patterns of movement, which did not appear to indicate a consistent or predictable effect. This may mean that pain reduction is more likely through a mechanism of neuromuscular adaptation or proprioception. It appears unclear whether a specific technique of application is fundamental to outcome. The hip, knee and ankle variants may aid clinical application when treating cycling related knee pain through screening and testing. This variation in movement may be linked to increased patello-femoral (PF)/tibio-femoral contact areas and PF stress when significant power is applied during cycling. The findings indicated a proximal to distal relationship, which is in line with current evidence and has implications to rehabilitation. Taping reduced pain, however it is likely that this effect is not what the anecdotal rhetoric presumes. If the intent is to use the tape to elicit specific biomechanical changes then this is difficult to substantiate and measure. If the expectations are purely around pain then it is likely that pain will be decreased using KTT, albeit short term. Further work is clearly required in the area of PFP and cycling.

DEDICATION / ACKNOWLEDGEMENT

I would like to thank my Director of Studies, Professor James Selfe, for his constant support throughout the entire process. He has facilitated my development by both challenging and supporting me at the appropriate moments. I would also like to thank Professor Jim Richards for his continuous drive, motivation and passion for my academic development. His enthusiasm for statistics confounds me but also draws me in. Thankfully my DOS regularly kept me on the straight and narrow and reminded me that statistics aren't everything and that I am a passionate clinician. Finally, from an academic perspective, I would like to thank Dr Hazel Roddam, who has always provided the calmness and clarity that meant she was a vital part of the process.

Lastly, and I suspect for most candidates this is somewhat of an echo, I would like to thank my long-suffering wife, Diane. Not only for 24 years of marriage but predominantly for the last six of which I have been particularly grumpy and difficult to live with. She will forthwith be allowed to live a somewhat normal life and I will now ride my bike………….

“It is the unknown around the corner that turns my wheels.”

~Heinz Stucke, long-distance touring cyclist.

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ABBREVIATIONS AND DEFINITIONS

ADd	Adduction
ABd	Abduction
AROM	Active Range of Motion
AKP	Anterior Knee Pain
ASIS	Anterior Superior Iliac Spine
AKP	Anterior Knee Pain
Biomechanics	The study of the structure and function of biological systems such as humans, animals, plants, organs, and cells by means of the methods of mechanics.
CAST	Calibrated anatomical systems technique. Measurement technique allowing six-degrees of freedom to be measured at a joint, whilst reducing the relative movement of bone and soft tissue.
CMP	Chondromalacia Patellae
Effectiveness	(Clinical) Capability of producing a clinical outcome
Efficacy	(Biomechanical) A capacity to produce a biomechanical change.
EMG	Electromyography
ER	External Rotation
FPS	Frames per Second
IR	Internal Rotation
JPS	Joint Position Sense
Kinematics	The study of mechanics, which describes the motion points, bodies (objects) and systems of bodies (groups of objects) without consideration of the causes of motion.
KTT	Kinesiology type taping – Generic terminology rather than trade names such as Kinesio™, Rocktape™, KTTape™ etc
MRI	Magnetic Resonance Imaging
MVIF	Maximal Voluntary Isometric Force
NPRS	Numeric Pain Rating Scale
PFP	Patello-femoral Pain
PFPS	Patello-femoral Pain Syndrome
PFJ	Patello-femoral Joint
Power	The rate at which energy is generated or consumed and hence is measured in units (e.g. watts) that represent 'energy per unit time'.
PROM	Passive Range of Motion
PSIS	Posterior Superior Iliac Spine
RCT	Radomised Controlled Study
ROM	Range of Motion
TFJ	Tibio-femoral Joint
UCI	Union Cycliste Internationale
UClan	University of Central Lancashire
VAS	Visual Analogue Scale

VL	Vastus Lateralis
VM	Vastus Medalis
VMO	Vastus Medialis Oblique
Watts	The unit, defined as one joule per second, measures the rate of energy conversion or transfer.
XYZ	Refers to an order of rotations in determining the angle at a joint, whereby a segment is rotated first about the X axis in order to project onto another set of axes.
3D	Three-dimensions. Analysis of movement in three dimensions, allowing movement in each cardinal plane to be measured.

CHAPTER ONE – INTRODUCTION

1.1 Introduction

From high profile events such as the Tour de France and the Olympics it is noticeable that taping is used widely within elite and experienced cyclists suffering with cycling related patello-femoral pain. However, taping's capacity to produce a biomechanical change (biomechanical efficacy), and capability of producing a clinical outcome (clinical effectiveness) have not yet been investigated and its specific usage amongst specialist clinicians is at present unknown. Claims from modern tape manufacturers regarding how and why some taping applications work on cyclists are anecdotal at best, and clinicians requiring evidence-based research will find a clear gap in the knowledge alongside a large amount of marketing led statements from taping manufacturers.

Cycling is becoming an increasingly more popular and effective mode of transport for the population, and over the past 10 years high-level competition has become more accessible to the masses. In 2012 the London Olympics elevated cycling to its highest levels in history. In addition, 2012 and 2013 respectively produced the first and second ever British Tour de France winners, which further focused the nation and the world on the popularity of cycling. Recently, 2014 focused the world's eyes onto Yorkshire (UK) for the 'Grand Départ' and initial stages of the Tour de France. The most northerly stage in the history of the Tour was a triumphant success as approximately two million people turned out to cheer on the world's best cyclists. In a 'post 2012' report by Dr Alexander Grous (2012), over 50% of non-cyclists intended to cycle on a regular basis following the successes of cycling in the London Olympic year alone. Of these over 30% intended to either compete or ride sportives (long distance organised rides). Considering that knee pain has been reported as the most common overuse injury in cycling (Bailey et al., 2003, Barrios, 1997, Callaghan, 2005a, Clarsen et al., 2010), and is often referred to as cyclist's knee (Callaghan and Jarvis, 1996, Lucia et al., 2001a), further research into its treatment has become increasingly important to the many clinicians now treating cyclists on a regular basis. Consequently, an elevated understanding of the biomechanical and treatment considerations involved in patello-femoral pain and its associated movement, could greatly improve the active prevention and treatment of overuse knee problems during cycling.

Previous research has demonstrated that patella-taping initiates changes in both healthy and symptomatic subjects (Selfe et al., 2008, Aminaka and Gribble, 2005, McConnell, 1996), however, very little research seems to have been undertaken in the specific area of taping and cycling. It is possible that through taping there is both a biomechanical and proprioceptive reaction that facilitates altered muscular activation, and therefore changes in knee movement and joint stability (Bennell et al., 2006, Dettori and Norvell, 2006). These changes may alter at different power outputs and cadences as cyclists often choose to pedal at high cadence/high power or low cadence/high power to maximise forward movement depending on the situation encountered. Current literature suggests that different power and cadence affects cycling efficiency but this tells us little of the effects on the knee joint, the most common point of cycling problems (Faria et al., 2005a, Pierre et al., 2006, Korff et al., 2007, Hansen and Sjøgaard, 2007).

Historically, taping approaches to knee pain have been limited to McConnell type applications using zinc oxide style non-stretch tape (McConnell, 1996, McConnell, 1986, Wilson et al., 2003), however in the past ten years additional types of taping known as kinesiology type tape (KTT) have been introduced into elite sport. This tape is more malleable to the body's contours and also more sweat resistant when compared to traditional type (Briem et al., 2011). This predisposes it to use with cyclists, as they are often required to exercise in hot conditions across durations in excess of five hours. Its attractiveness is also highlighted by the tapes often colourful presentation and packaging. Manufacturers claims can however often appear anecdotal and marketing led. Consequently, evidence as to its clinical application, and biomechanical effectiveness are somewhat scarce (Mostafavifar et al., 2012). Considering its degree of use and high profile, the proposed work in this study could be seen as timely and much required from a clinical perspective. Bearing in mind the current research, kinesiology type taping (KTT) evidence is limited compared to the richness of the McConnell type taping literature available.

KTT is proposed to have benefits such as stabilisation, pain reduction, alteration of patello-femoral movement and lifting the skin to allow enhanced lymphatic action (Kase et al., 1998b, Williams et al., 2012, An, 2012). Its clinical practice application and reasoning for use has not been fully assessed to date in scientific publication, and therefore the initial requirements prior to any testing in the biomechanical laboratory were to look at its use by specialist cycling clinicians compared to that of McConnell type taping.

The overall study, although complex in its design, execution and outcomes has a simple format underpinning its raison d'être. This format can be seen from figure 1.1.

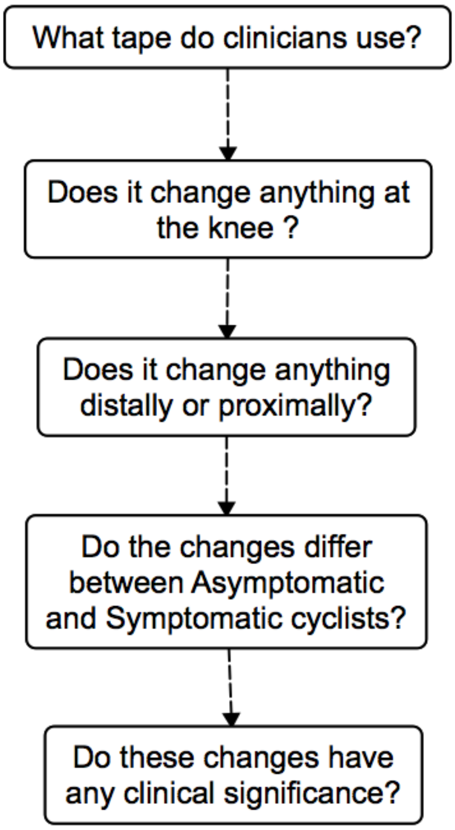

Figure 1.1 Overall project flow format

1.2 Summary of chapters

Chapter One - Introduction: Both a historical and a modern perspective of cycling are provided to give context to the outline of the research associated with cycling related knee pain and taping to date. The challenges related to investigating cycling related knee pain are described and the thesis project is placed within the context of current scientific knowledge.

Chapter Two – Review of Literature: An in-depth review of the limitations of existing research related to Patello-Femoral Pain (PFP), cycling related knee pain, taping for pain, and the measurement of kinematics in cycling. This encompasses a review of relevant findings in relation to these areas with gaps in the knowledge base highlighted. Consideration of the overall project from a research literature perspective leads to the aim and objectives of the project.

Chapter Three – Online Questionnaire: An overview of the initial study investigating the clinical usage of taping to treat cycling related knee pain in experienced and elite cyclists is given. This includes a synopsis of the developmental work undertaken with respect to the rationale for the online questionnaire and methodology used. The methodology utilised experimental procedures such as social media and online questionnaire tools, which are described and discussed. This initial study was the MPhil project and links with the main biomechanical study are discussed and presented, providing a natural progression perspective. The study questions are presented, the results displayed and discussed, and a projected view towards the biomechanical laboratory based study of the thesis is provided.

Chapter Four – Biomechanical Laboratory-Based investigation: Following considerations from the previous study, the pilot and developmental work for the main study are outlined and any learning defined. Using recognised techniques and procedures, the methodology is described in detail. Experimental work using Kinesiology Type Tape (KTT) is detailed, alongside procedures and methods of analysis. Significant results are accompanied by short dialog where appropriate, highlighting notable and definitive findings. Results are described in the three planes across the hip, knee and ankle joints. A clinical application is maintained for the reader to enable interpretation towards practical use in the field for both the clinician and cyclist. Pain results are also reported pre, during and post testing to allow discussion in relation to the movement analysis results.

Chapter Five – Discussion and Interpretation: In order to bring the entire project together, this chapter discusses the results from the knee, hip and ankle across all three-dimensional planes of reference. The pain measurement results are also considered alongside the clinical considerations of the findings. These findings are related to the biomechanical efficacy and clinical effectiveness of taping as well as other findings from the entire project such as proximal and distal rehabilitation considerations. Practical clinical application is maintained as a theme as to the learning outcomes of the entire study.

Chapter Six – Conclusions and Further Work: Considerations aimed at cyclists, clinicians and health professionals and future developments in this research area are identified. This section enables the reader to succinctly understand the overall findings and learning from the project, thus allowing clinical and practical considerations to be determined. Further projected work is outlined.

CHAPTER TWO – REVIEW OF LITERATURE

2.1 Search strategy

Initial database searches from English language peer reviewed literature, without limitation on year of publication, produced no cycling specific knee pain taping studies (EBSCHost, Sciencedirect, PubMed, UClan e-databases, February 2012) using the combined key words patello-femoral pain, knee pain, taping, and cycling. Filtering these search terms by reducing to single and combinations (i.e. knee pain and taping or PFP and cycling) produced relevant studies (n=60), which have been reviewed in the following sections. Further and developmental evaluation of referencing in these studies produced the remainder of the literature. Subsequent searches were carried out at approximately six monthly intervals and any related research is included in this section and throughout the entire document. It is noted that the evidence base of this subject is growing rapidly, and whilst every effort has been made to include the very latest literature, it is inevitable that the most recent publications may have been omitted from the final thesis. Figure 2.1 summarises the search results and timeline representing progression with literature searching.

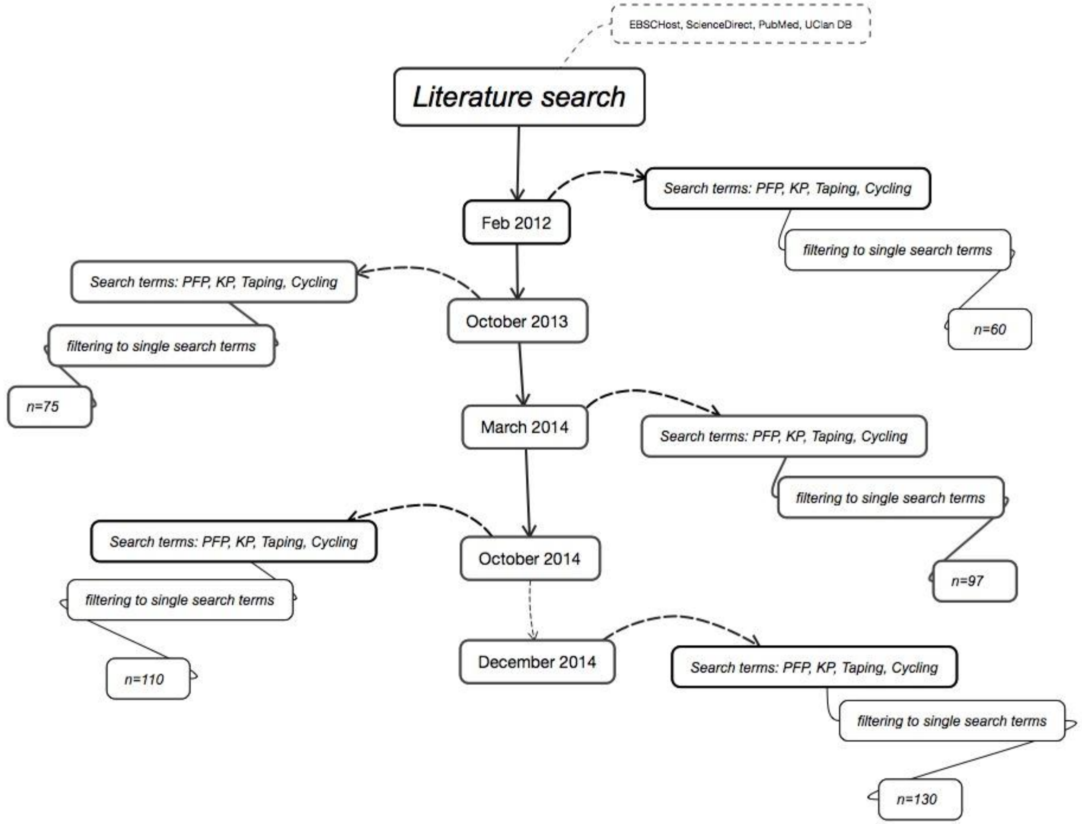

Figure 2.1 Literature search summary

2.2 Patello-Femoral Pain (PFP) – An Overview

PFP can be a challenging pathology due to its multifactorial nature and is one of the most common lower limb conditions encountered in clinical practice (Wood et al., 2011). Not only do the etiology, diagnosis, and treatment remain thought-provoking, but the terminology used to describe PFP can be used inconsistently and is often confusing for the clinician (Powers et al., 2012, Grelsamer, 2005, Crossley et al., 2001, Lopis and Padron, 2007). Patello-femoral pain is also described as Anterior Knee Pain (AKP) and has been defined by Green, (2005), as patella focused pain resulting from physical and biochemical changes in the patello-femoral joint. Although there have been varying descriptions of PFP over the past two decades, this description is in line with the pathophysiology described by Dye (2005). Those with patello-femoral pain typically have a degree of specific anterior knee pain that characteristically occurs with activity and often worsens when encountering step descent or ascent as well as prolonged periods of sitting (Witvrouw et al., 2005, McConnell, 1996). Knees can be affected either uni or bi-laterally, however consensus is generally lacking regarding the cause and treatment of the PFP (Fulkerson, 1994, Crossley et al., 2001, Draper et al., 2011).

Importantly, PFP has, however been distinguished from chondromalacia (CMP), which has been described as pathological or degenerative changes in the articular cartilage of the patella (Dehaven et al., 1980, Ficat et al., 1979). This often involves actual fraying and damage to the underlying patellar cartilage (Ogilvie-Harris and Jackson, 1984). Early work into CMP (Abernethy et al., 1978, Bentley, 1970, Hvid et al., 1981) described similarities to the modern definition of PFP. However the consensus in the field today indicates that CMP is specific to the area of degeneration rather than the recognised classifications of PFP. Although patello-femoral cartilage contact is implicated in PFP, there are many other factors than require consideration such as maltracking, muscle imbalance and proprioception (Amis, 2007, Boling et al., 2010, Callaghan and Oldham, 2004). CMP is a specific pathological entity outside of the PFP definition for this study. The following sections will address various factors related to PFP, cycling and other relevant areas (Anatomy and movement, nomenclature, etiology, cycling related knee pain, biomechanics and muscular activity, cadence, power and taping).

2.2.1 Anatomy and movement

The knee complex is commonly considered as consisting of the tibio-femoral joint. The joint has three main articulations; two tibio-femoral articulations between the lateral and medial femoral condyles and the tibial plateau, and one intermediate patello-femoral articulation between the patella and the femur. In addition, the superior tibia/fibula joint is often clinically considered in the function of the knee complex. The knee joint is principally a hinge type of synovial joint (Amis, 2007, Grelsamer and Klein, 1998), although rotary movement is an important feature of a normally functioning knee. The articular surfaces have incongruent shapes and are notable in size and weight-bearing ability (Sanchis-Alfonso, 2010, Gill and O'Connor, 1996). The patella is a sesamoid bone, in fact the largest in the human body, within the patella tendon. It is multi-faceted or ridged; superior, inferior, medial and lateral. Its primary function is to facilitate extension and flexion of the knee. (Arendt, 2005, Staubli et al., 1999, Steinbruck et al., 2011, Tecklenburg et al., 2006). Considering cycling is a non-weight bearing activity that involves the primary movements of flexion and extension of the knee (Callaghan, 2005a), the mechanisms and understanding of the patello-femoral joint are seen to be vital to this study. The Vastus Medalis (VM) has been the subject of many studies (Bennell et al., 2010, Chen et al., 2012, Cowan et al., 2001). These have indicated its clear influence on, and timing imbalances within patella alignment, but to date agreement as to its exact influence on PFP, and even in some cases its anatomical presence, is not clear. A proposed component to PFP is a difference in onset timing between the Vastus Medalis (VM) and Vastus Lateralis (VL). In a study by Powers et al., (1996), they were unable to reproduce any difference in timing of activation, cessation, or intensity between the VM and VL, while Gilleard et al., (1998) were in contrast able to show differences in activity. Smith et al., (2009) also found differences but postulated that these were most likely due to the effect pain has on EMG activity (this was noted in individuals with PFP). Interestingly, one of the focal points of the study was to see the effect taping had on VM activation. With taping, vastus medialis activation was shown to occur prior to vastus lateralis activation. The authors were unsure if the cause was through mechanical means or pain reduction.

2.2.2 Nomenclature

The term patello-femoral pain is one used to cover many different pathologies and its terminology and nomenclature are constantly changing and require classification (Grelsamer, 2005). Both Witvrouw (2005) and Merchant (1988) proposed specific classifications of patello-femoral disorders alongside Grelsamer’s (1997, 2009), all of which suggest various connotations to the condition including patello-femoral pain syndrome (PFPS), patella mal-tracking, chrondomalacia, dysplasia, instability and subluxation. These classifications can importantly also be compared with a much cited model of tissue homeostasis

(Dye, 2005). This indicates that any symptom or condition that takes the knee joint complex outside its normal envelope of function or pain free operation will result in an inflammatory or pain related response. Dye originally suggested that patients with PFP are symptomatic due to abnormal loading of anatomically normal knee components (Dye, 1996). In reality, patients with anterior knee pain often lack any easily identifiable structural abnormality to account for the symptoms. Although a well adopted model, its clinical use can be interpreted in many ways and its citation across many papers indicates this. Dye’s theory, albeit accepted, could be deemed somewhat generic in its approach and more recent work has endeavoured to explore the multitude of classifications encountered in PFP (Powers et al., 2012).

Overload and overuse are also specific problems cited in classification of cycling related and patello-femoral knee pain (Bailey et al., 2003). These two terms have been used extensively but without a common approach. Aminaka and Gribble (2005) and Finestone (1993) discussed overuse whilst Cutbill (1997) proposed that a terminology of overload may be more appropriate. Because flexion of the knee increases the pressure between the patella and its various points of contact with the femur, patello-femoral pain syndrome is often classified as an overuse injury (Milgrom et al., 1996). Cycling can produce both increased load (resistance) and overuse (frequency and cadence) so perhaps its combination with PFP could be seen to encompass both groups of terminology (Figure 2.2). Although the most recent research has accepted the presence of both overload and overuse we only seem to be at the beginning of understanding the differences between patello-femoral stress and force

(Witvrouw et al., 2014) in normal gait, let alone with the added complexity of cycling.

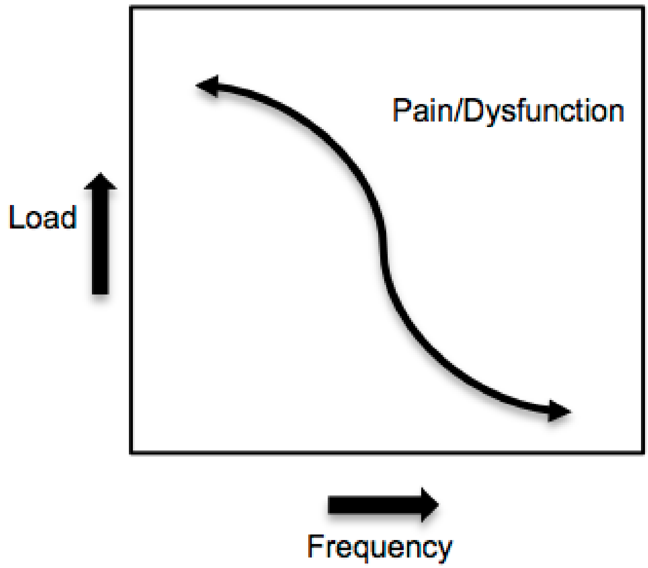

Figure 2.2 Load/Frequency diagram

Since Grelsamer's seminal paper regarding nomenclature of this complex condition (Grelsamer, 1997) there have been collaborative attempts to bring terminology and approaches together (Davis and Powers, 2010, Powers et al., 2012, Witvrouw et al., 2014). Amongst the outcomes of these international meetings, and resultant publications, has been agreement of factors such as the likely sources of pain in PFP. These now seem accepted as primarily patho-mechanics or maltracking, subchondral bone overload, shortened soft tissue structures and nerve changes resulting in pain.

PFP terminology is generic and covers a multi-factorial collection of conditions (Kannus et al., 1999, Lichota, 2003). Consequently, Grelsamer (2005) suggested that the terminology used should be discarded and replaced with that which more accurately explains the pain experienced. He does not however suggest what this would be. Clearly both terms (PFP and PFPS) remain in use from a research and clinical perspective. This study will primarily adopt an approach that is congruent to the PFP definitions agreed in 2014 (Witvrouw et al.) and endeavour to use terminology that has since been accepted as current.

2.2.3 Etiology

To date there have been numerous theories proposed to explain the etiology or cause of patello-femoral pain. These include biomechanical maltracking, sub-chrondral bone overload, shortened soft tissue structures, nerve changes resulting in pain, muscular dysfunction and overuse (Callaghan, 2005a, Crossley et al., 2001, Elliott and Diduch, 2001, Sanchis-Alfonso, 2010). In general, the available literature suggests that the etiology of patello-femoral pain is multi-factorial (Green, 2005, McConnell, 1996, Nijs et al., 2006, Powers, 1998, Grelsamer, 2005, Lankhorst et al., 2012). It has been noted that these multiple factors incorporate soft tissue mechanical implications alongside joint related problems (Garth Jr, 2001).

Whilst an abundance of research exists on influence of the Vastus Medialis Oblique (VMO) in PFP, its very existence has indeed been questioned on occasion (Bennett et al., 1993, Goh et al., 1995, Hubbard et al., 1998, Ono et al., 2005, Lieb and Perry, 1971). Postulation includes it being redefined as not being an independent muscle but merely differing orientation of the VM muscle as well as extensions of adductor magnus (Goldberg, 1991, Messier et al., 1991, Neptune et al., 2000). A comprehensive review by Smith et al., (2009) concluded that the evidence base does not indicate that VMO can be activated separately from VL in order to produce a positive strengthening effect. These findings were underpinned in a study by Bennell et al., (2010), who found no difference between isolation of VMO over general vastus strength work. Another notable discrepancy on muscle (vasti) imbalances was a study by Chester et al., (2008), where 20 papers and 287 participants were reviewed, finding no preferential enhancement of VMO over VL.

Early research by McConnell (1986) speculated on the involvement of Vastus Medialis Oblique (VMO) fibres lacking firing onset in symptomatic individuals, however subsequent research by Gilleard et al., (1998), Cowan et al., (2001) and Christou, (2004) has identified more specific re-training implications of VMO involvement in PFP. Gilleard found that taping of the patello-femoral joint in the manner used in their study altered the timing of VMO and VL activity (VMO earlier than VL with tape) in subjects with PFP during step-up and step-down tasks. Here, it could be that the earlier activation of the VMO may alter the movement of the patella through its function. Cowan also looked at step up and step down tasks, and found that without taping the onset of VMO was before that of VL in both tests. Cowan subsequently used taping in another study that agreed with Gilleard's and Christou's findings that patella taping increased activity of VMO and decreased that of VL, thus consequently decreasing pain in those with PFP (Cowan et al., 2002). Physical therapy for PFP however continues to utilise VMO isolation exercises to treat pain. It has been widely thought that the VMO is responsible for medial patella tracking, due to its oblique fibre orientation (Hubbard et al., 1998, Gunal et al., 1992). When reviewing innervation, some studies in the past have proposed independent innervation, leading to the hypothesis that the VMO was a separate muscle

(Insall, 1982, Huberti and Hayes, 1984). However, subsequently these nerves were found to be superficial separations from the femoral nerve leading to distal motor units, sensory contribution from the saphenous nerve, or penetrating innervation for the knee capsule (Thiranagama, 1990). One could argue that without isolated innervation, the VMO cannot be activated independently (i.e. the patella can not be exclusively pulled medially). The innervation of the femoral nerve appears to stimulate the entire vastus medialis to contract and therefore extend the knee while pulling the patella medially.

Boucher et al., (1992) looked at the vastus-medialis activity in patients with PFP. They found that the vastus medialis and vastus lateralis were not more active in terminal extension. However, they did find that in patients with PFP there was a decreased VM:VL ratio compared to the control group. These differences were found to be attributable to a mechanical disadvantage (greater Q-angle); when the Q-angle was decreased, the ratio returned to normal. This same difference in VM and VL ratio was also found in another study by Souza & Gross (1991) to be related to mechanical factors. Additionally, the authors discovered that isotonic quadriceps contractions elicited larger VM:VL EMG activity compared to isometric contractions. This may be a factor that influences treatment plans for patients with pathologies, such as PFP. Interestingly Ng et al., (2008) and Cowan et al., (2001) also reported this difference in VM and VL ratio with EMG activity. In fact, the authors were able to standardise the EMG activity with use of rehabilitation exercise and biofeedback. Powers (1996) also described a difference between VM and VL activity, though this was attributed to patellar mal-alignment. Figure 2.3 illustrates the variations of influence on the knee complex in the coronal plane. This is purely one dimensional however, and does not illustrate the sagittal and transverse plane which together with the coronal represent the degrees of freedom of the patella-femoral joint (Richards, 2008).

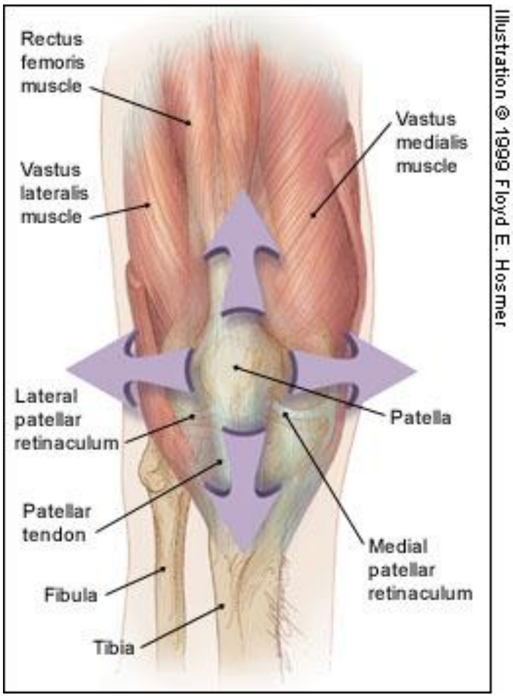

Figure 2.3 Knee complex – Coronal. (Hosmer, F. E., 1999)

The patella articulates with the patello-femoral groove in the femur. Varying forces operate on the patella to provide stability and maintain correct tracking. These forces produce stresses on the articular surfaces within the knee complex and combine to produce a multi-factorial pathology. A joint reaction force is a force within a joint in response to forces acting upon that joint. A combination of body-weight alongside tension from muscles around the joint can produce this measurable force (Koehle and Hull, 2008). These forces can create stresses on the articular surfaces and these stresses can be estimated as the joint force divided by the total joint contact area and has been measured from magnetic resonance (MR) images (Farrokhi et al., 2011). There is general acceptance that patello-femoral joint stress is influenced by a number of variables, these include joint forces and the articulating anatomy of the patella on the femur (Besier et al., 2005, Besier et al., 2008). PFJ stress could cause wear on the cartilage (Fulkerson et al., 1992). However, it has been argued by (Biedert and Sanchis-Alfonso, 2002) that because articular cartilage is aneural it cannot be the cause of pain in PFP and therefore the subchondral endplate, which contains pain receptors, may be the source of this pain. In Farrokhi et al's., 2011 study, PF stress was measured in patients with PFP and supported the principle that PFP is linked to abnormal joint loading. Although findings were of increased PF stress in those with PFP it should be noted that patients were all female and that PFP is influenced by more variables functionally that in a controlled laboratory environment (static squatting).

A general misunderstanding is that the patella only moves in a proximal and distal direction. In fact, it has 6 degrees of freedom of movement and is the most unstable joint in the lower limb (Richards, 2008). It also therefore tilts and rotates, hence there are differing points of contact between the undersurface of the patella and the femur (Koh et al., 1992), (Figure 2.4). Recurring contact at any of these areas, occasionally combined with misaligned tracking of the patella that is often not detectable by the naked eye (Freedman and Sheehan, 2013), can be a likely symptomatic mechanism of patello-femoral pain (Belvedere et al., 2012, Wilson et al., 2009). The result can be a classic presentation of retro-patellar and peri-patellar pain (Willy et al., 2012, Kannus and Niittymaki, 1994, Herrington, 2008). This re-occurring contact is especially significant when considering the repetitive nature of cycling.

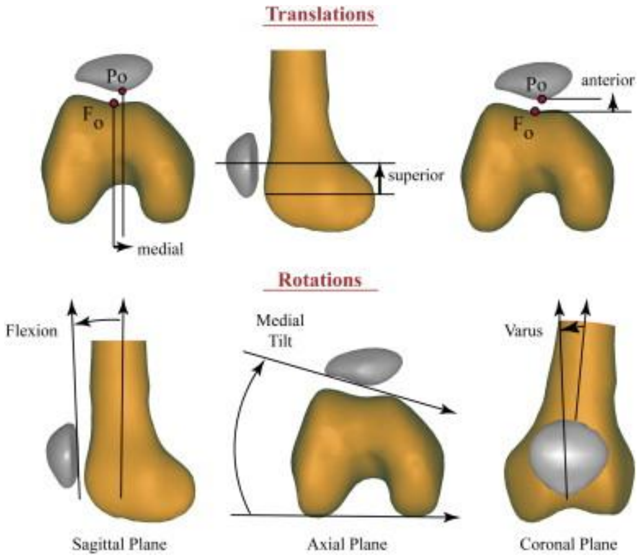

Figure 2.4 Patella movement (Borotikar et al., 2012)

Consequently, one of the most widely accepted theories regarding the etiology of PFP suggests that the symptoms are the result of varying patello-femoral joint stresses due to abnormal patellar tracking, resulting in inflammatory pain (Fulkerson, 2002, Merchant, 1988). Some studies however, have questioned a simply causal connection between mal-tracking and knee pain with PFP patients (Arroll et al., 1997, Cutbill et al., 1997, Dye, 2005, Sanchis-Alfonso et al., 1999). These mal-tracking symptoms are said to be related to abnormal loading of the PF joint (Dye, 2005). Recent work by Chen et al., (2010) investigated how to quantify the volumes and varieties of stresses involved on the PF contact areas through the working ROM. Chen utilised MR imaging, 3-dimentional gait analysis (VICON) and EMG activity across the knee in both static and loaded dynamic variables. A model was then created combining both static and dynamic measurement of PFJ stresses during supine squat and functional movement. This was precursor work to that of Farrokhi et al., (2011) whose methods also used MR imaging during supine knee flexion under load, a 3-dimentional gait analysis system (VICON) and EMG. One significant difference between these studies being Chen's use of supine squat (open chain) and Farrokhi's use of a more functional (closed chain) squat on force platforms. Although broadly in agreement that PFJ stress increases were predominately posterior and lateral, it should also be noted that the former study (Chen) utilised both male and female (healthy) participants whereas Farrokhi used only females (50/50 pain/healthy). The reasoning for this was not explained and therefore it is difficult to draw any meaningful conclusions as to functional outcomes across the entire PFP population. Joint stresses remain a factor however and a mal-tracking patella is seen as very much part of the PFP conundrum.

If we consider effects outside of the knee complex there are both proximal and distal factors that can influence PFP. Proximally, internal rotation (IR) of the femur and consequent hip strength have been studied and are now regarded as important factors in PFP (Barton et al., 2012a, Bini et al., 2011, Bolgla et al., 2008, Dolak et al., 2011, Fukuda et al., 2012, Long-Rossi and Salsich, 2010, Powers, 2003, Powers et al., 2012, Nakagawa et al., 2013). In a study conducted by Niemuth et al., (2005) hip strength in runners with lower limb injuries (including PFP) was investigated. 30 injured patients (17F/13M) had their isometric hip strength measured using hand held dynamometers. Compared to a control group (30 uninjured, 16F/14M), the injured runners had significantly weaker hip flexors and hip abductors on the injured side, while their adductors were stronger on the injured side. The healthy runners displayed no side-to-side differences in muscular strength. Interestingly, despite the influence of muscle strength imbalances, no relationship was found between the injured side and the runners' dominant leg.

A more condition and gender specific study by Ireland et al. (2003) established similar results. Isometric hip strength was measured in runners with PFP again using hand held dynamometers (side-lying abduction) and compared with age-matched control subjects. As with Niemuth's study the injured runners had weaker hip abductors as well as weaker hip external rotators on their injured leg compared to a control group. Unfortunately, this study did not measure hip strength on the healthy side, neither did it assess hip flexor/adductor strength. Despite this it confirmed Niemuth's findings. Following on from this study, Niemuth et al., (Cichanowski et al., 2007) published a follow-up study with athletes with PFP. This used a more rigorous procedure that applied identity blinding of control vs. injured, six musculature movements of the hip (Flx/Ex/Ab/Add/IR/ER), a higher grade dynamometer than previously, utilising digital display and muscle contraction length and also measuring both affected and unaffected sides. Again, as previously reported, they revealed that the injured athletes had increased weakness on their affected side. They also found subjects to be weaker overall in measurements of five of the six major hip muscle groups compared to healthy runners (the missing group was adductors). One could argue that using hand held dynamometers has limitations in that it can often rely on the strength of the tester, and also that static isometric contractions do not effectively represent functional activity. It may also have been an interesting addition to measure EMG muscle activity during a functional step down exercise to correlate increased pain alongside altered muscle activity with the injured group. These studies indicate that PFP is associated with a weakness in hip abduction, however, they are all retrospective and one could argue that injury may itself cause hip weakness; the question being whether people develop PFP because of weaknesses, or whether they simply get weaker because the pain inhibits their activities.

Distally, the foot and tibia have been the focus of many studies in relation to PFP (Fulkerson, 2002, Levinger and Gilleard, 2007, Levinger et al., 2006, Powers, 2003, Salsich and Perman, 2007) although the findings appear to be somewhat variable. For example Reischl et al., (1999) found that peak pronation was not predictive of tibial and femoral rotation whereas Levinger found increased rear-foot movement was associated with those with PFP. Powers suggested that although distally, movement at the foot can be associated with PFP. It is also possible that this is influenced by knee valgus and hip movement and that the entire kinetic chain should be assessed rather than a focus on distal effects. Salsich and Perman expanded on this using MRI and found increased tibio-femoral rotation in those with PFP. In addition to tibia rotation, the effects of foot orthoses have been found to be influential in the mechanics of the knee in those with PFP (Barton et al., 2011, Barton et al., 2010, Collins et al., 2009, Vicenzino et al., 2008, Vicenzino et al., 2010, Collins et al., 2007). Orthoses exact effects and mechanisms remain unclear and even more so when combined with physical therapy treatment (Vicenzino et al., 2008). However, their use in cycling seems to be constantly increasing and consequently this is a potential area for future research in PFP. With regard to their use in cycling, a recent comprehensive review by Yeo and Bonnano (2014) found limited evidence that orthoses had any effect on lower limb kinematics. There have been no specific orthoses based studies and PFP in cyclists to date and so any claims of effectiveness of orthotic influence on PFP could be seen to be anecdotal or marketing led. Together with hip movement outlined earlier, the variability in study findings seem to represent an approach of looking at the entire chain of joint movement and muscular contribution when treating PFP.

Alongside synovial nerve endings and associated synovitis related pain (Dye, 1983), the fat pad is also an structure that has received attention from researchers (Dragoo et al., 2012). Taping of the knee has been seen to affect (offload) the fat pad (McConnell, 2000, Ng and Cheng, 2002) and since it is vascular and highly innervated it is reasonable to assume that it is an exceedingly pain-sensitive structure within the knee (Dye, 1996, Crossley et al., 2001). In addition to mechanical factors, ischemia or a restriction in blood supply caused by high inter-osseous pressure, has been suggested as a possible pain mechanism (Hejgaard and Arnoldi, 1984, Hejgaard and Diemer, 1987). In agreement with the ischemia theory, Dye (Dye and Vaupel, 1994, Dye et al., 1999, Dye, 2005) suggested the much cited tissue homeostasis theory. This encompassing etiology theory takes a pain mechanism into consideration. It proposes that the etiology of patello-femoral pain comes from a lack of homeostasis in patello-femoral tissues (Dye and Vaupel, 1994, Dye, 2005, Dye et al., 1999). Whilst this much cited perspective accepted the multi-factorial nature of PFP, and gave clinicians more understanding of the potential mechanisms of pain, it also proactively provided a catalyst for further research in this area. A later version in 2005 expanded the perspective and developed further terms such as ‘envelope of function’, and provided some clinical guidance for the priority of regaining homeostasis in the knee irrespective of the structures involved or the increased loading/stress on the PFJ. Even though a number of authors have concluded that this restriction in blood supply is the possible trigger for the pain in PFP, they propose different backgrounds. Selfe et al., (2002), looked at the growing collection of evidence for the ischemia theory and concluded that there is a requirement to consider the influence of vascular malfunctions in PFP. To some degree, a history of overuse of the patello-femoral joint or an escalation in activity is reported in almost all people with PFP (Thomee et al., 1995, Fairbank et al., 1984). Alongside overuse, cited causes include historical or recent trauma (Fulkerson and Arendt, 2000). That said, Dye (2005) reported that most patients with PFP had very little history of trauma. In cycling, trauma is often reported as an initial cause of knee pain (Barrios, 1997, Callaghan, 2005a), yet its effect on PFP has not been investigated fully. Clearly the research outlined in this section underpins the multi-factorial nature of PFP. The following section will look at specific cycling related knee pain in more detail.

2.3 Cycling Related Knee Pain

It is likely that the increase in popularity of cycling and long distance timed non-competitive cycling events (cycling sportives) have impacted upon the cycling scene in the past 5-10 years, potentially creating an increased prospect of knee pain incidence. It has been identified that AKP and PFP are the most likely injuries affecting elite cyclists, along with lower back pain (Clarsen et al., 2010). According to Bailey et al., (2003) and Milligan (1996) some cyclists are naturally pre-disposed to medial and lateral movement of the knee during the coronal plane pedal stroke and in addition Ruby et al., (1992b) and Wolchok (1998) also outlined excessive patello-femoral loading during cycling. Anatomical factors, such as an abnormally large Q angle, have been said to predispose cyclists to anterior knee pain and patellar tendonitis by disrupting the knee extensor mechanism. The Q-angle influence is however largely associated with females. Early work by Hannaford et al., (1986) and Francis (1986) looked at the coronal plane kinematics and suggested that excessive movement distal to the knee was influential in PFP issues. This, however, was prior to the advanced development of modern ‘clipless’ pedal systems that allows for more adjustment of medial lateral movement in this plane. Ruby et al., (1992a, 1992b, 1993) continued this work by looking at knee kinematics in relation to foot movement at the pedal. Albeit not in relation to PFP, it nevertheless was an interesting development in understanding the influence of coronal foot movement and its impact on how the knee moves during seated cycling. Ruby appeared to be instrumental in establishing that by increasing movement of the foot in the coronal plane it is possible to reduce tibio-femoral movement. When combined with cycling at different power levels and cadence, this excessive movement and associated variable forces may be affected by taping of the knee joint (Holmes et al., 1994, Mellion, 1991). These variables (PF forces, increased PF stress etc.), within the movement patterns associated with cycling, can also be linked to the varying classifications outlined earlier (Grelsamer, 2005) and a disruption of homeostasis (Dye, 2005), that of patella-maltracking, dysplasia, resultant inflammation and instability. The repetitive nature of cycling (Abbiss et al., 2009) could be seen to be highly susceptible to many of these classifications.

Research into cycling has also increased alongside its expansion as both a sport and a leisure activity. It is now second to swimming in participation according to a (2013) Sport England study. Cycling is considered to be much less injury prone than running (Burke, 2003), however, it can be subject to a number of overuse injuries due to its repetitive nature. Callaghan (2005b) reviewed the multi-faceted nature of lower limb cycling injuries, but nine years on from this much cited paper, there remains a relatively low number of specific studies investigating the effects of taping on PFP. An interesting and unique study by Millgan (1996) reported a significant difference (p=0.001) in medial/lateral (coronal plane) movement in those cyclists with PFP (n=8). This was compared to 12 asymptomatic cyclists. Although this contributed some initial understanding of what movement planes are affected with symptomatic cyclists with knee pain, its limitations were that it only used two dimensional video analysis (sagittal & coronal) and therefore complete understanding on the rotational movement of the knee was not comprehensive. Dettori's (2006) literature review into non traumatic cycling injuries reported knee pain as being present in 21-65% of cyclists during long rides, however it is unclear as to which classification of cyclists (i.e. elite, experienced or recreational) were indicated in this case. This could be seen as important as bike set up and seat height has been found to have a significant effect on knee forces (Bini, 2012). Recreational cyclists would be seen as less likely to have a recognised and accurate bike set up over elite and experienced cyclists. He also reported two additional studies (Wilber et al., 1995, Weiss, 1985) where knee injuries (non-traumatic) represented >50% of total injuries reported. Once again, these studies had the limitation in that they did not identify any particular classification of cycling population and so the range of cyclists could be seen as too wide to be able to interpret any specific groups of cyclists (such as recreational or elite) with PFP. Until 2011 the literature only comprised two relevant studies providing epidemiological data on the injuries suffered by elite road cycling racers (Barrios, 1997, Clarsen et al., 2010). The former comprises the injuries occuring between 1983 and 1995. In an updated study (Barrios et al., 2011) traumatic injuries had increased two-fold whereas overuse related injuries had remained stable. This could be seen to be indicative of the increase in cycling as a popular sport and pastime but gives little insight into PFP.

Bailey et al., (2003) conducted a kinematic study looking at AKP in two planes (Sagittal and Coronal), investigating 24 active male experienced cyclists using right side only markers and digital video camera recording. The cyclists used their own bike at a set cadence (90rpm) and fixed power (200w). Although a regularly referenced study, the equipment and software used did not seem to allow the resultant data to accurately represent joint centres compared to more recent three dimensional equipment and software available. Hence the shank angles may have been influenced by the proximal and distal contributory joints. This is unknown as these were not reported. It is also notable that the transverse plane was not examined and therefore it could be argued that an influential movement was not included in the results. Interestingly, this was not mentioned as a limitation in the study. Perhaps this is representative of the lack of research into this area rather than a direct denunciation of the work itself. Early work by Wolchok's et al., (1998) into cycling related knee joint mechanics provided valuable initial insights into patello-femoral contact areas in medial and lateral movement during cycling. This work built on from work by Ruby et al., (1992a) into knee joint loading during cycling. Wolchok's study looked at how fixed (relative to five degrees of movement from pedal) 'clipless' pedals can affect the forces at the PFJ and found that internal rotation (IR) and coronal changes increase the PF contact areas and associated forces. This early work was however restrained to cadaver experiments. Consequently, perhaps when adapted to the most recent technology used to measure PFJ compressive forces (Farrokhi et al., 2011), it would be interesting to repeat this work with symptomatic and asymptomatic cyclists.

2.3.1 Cycling biomechanics, three-dimensional kinematic analyses of cycling, power, muscular activity and cadence

The cyclist's riding position is influenced by many variables including: anthropometric measurements, strength and flexibility, muscle recruitment patterns and lower limb muscle length (Wishv-Roth, 2009). Pedalling technique is an important contributing factor to cycling performance and optimal muscle recruitment while cycling (Faria et al., 2005a). However, aside from the equipment and technique utilised, the speed at which a cyclist can propel a bicycle depends on how much power the cyclist applies to the pedals (Burke, 2003). Peak power output appears to be highly correlated with cycling performance and in turn related to patello-femoral forces and stress (Faria et al., 2005a, Faria et al., 2005b).

A noteworthy area of interest in cycling research has been that of muscle recruitment patterns. It is generally accepted that multiple muscle co-activation occurs throughout the pedalling action and that the degree of this co-activation differs in position and ability (Chapman et al., 2006, Chapman et al., 2008, Faria et al., 2005a, So et al., 2005). With regard to incline (slope) and posture (of cyclist), Duc et al., (2008) found that although different positions did not significantly affect the amount of muscular activity, however it did change the timing of (EMG) muscle activation. It should be noted that this was one of few studies that utilised a treadmill based ergometer system rather than a stationary cycle method that has traditionally been the preferred method of testing (Li and

Caldwell, 1998). It is clear from the abundance of work in this area that muscle recruitment patterns vary from individual to individual and are directly related to position, cadence and resistance. In Ashe et al's., (2003) study into the body position of untrained cyclists, they discuss the physiological affects of body position in relation to joint angles, force production and muscle length. However, unfortunately their results did not seem to quantify this in sufficient detail to examine the coronal and transverse planes of movement.

Studies of cycling require accurate measurement of kinematic movement in order to determine differences in movement patterns. To this effect, increasing use of three-dimensional kinematic analyses in laboratory settings allows quantification of the movement characteristics; therefore, enabling justifiable comparison of different movement patterns. These measurements have been further developed from two-dimensional work undertaken by Bailey et al., (2003) to 3D analysis using manufacturers such as Qualisys (Qualisys Medical AB, Sweden) and Vicon (Vicon Motion Systems, Oxford, UK). In order to standardise the reporting of this area of work, The International Society of Biomechanics (ISB) developed a protocol in reporting joint motion built around the Joint Coordinate System (JCS) (Wu et al., 2002). This allowed data to be expressed in a clinically useful way. The JCS originally proposed by Grood and Suntay (1983) allows the description of the relative movement of two adjacent body segments about the joint centre (joint kinematics). Further developments of marker based systems allowed body segments to be defined in six degrees of freedom using the Calibrated Anatomical System Technique (CAST) which used anatomical markers on the palpable bony landmarks are required to be identified relative to the segmental or local coordinate systems (Cappozzo et al., 2005). A typical ‘static’ trial with both anatomical and segmental markers allows the anatomical markers’ position in the segmental coordinate system to be identified. Consequently, the joint centres are determined using the location of the segmental markers/coordinates through the appropriate software (Winter, 2009). Previous work has determined that joint centres correlate with modern markers sets such as Bone-embedded anatomical frame (BAF), Intra-cortical pins and exo-skeleton tibio-femoral harness (Hagemeister et al., 2005, Labbe, 2014, Andriacchi et al., 1998). It is therefore important that the location of the anatomical markers determining the joint centres is consistent across study participants and this consistency can be maximised by a single person applying the markers through all experiments (Leardini et al., 2005).

As cycling is predominantly a lower limb movement its measurement is determined upon accurate modelling of joint centres for the hip, knee and ankle (Momeni et al., 2014, Disley, 2013). As described in the previous paragraph, these joint centres are derived using recognised approaches that utilise reflective markers on the representative anatomical areas of the body (Cappozzo et al., 1997, Sayers et al., 2012). Once identified, these joint movements can be accurately measured using software such as Visual 3D (C-Motion Inc, Germantown, USA). Importantly, the resultant data can contain errors from soft tissue movement, unsuitable digitization of retro-reflective markers and electrical interference (Winter et al., 1974). These errors (or noise) require filtering out of the data in order to leave the true signal unaffected (Winter, 1990). This ‘noise’ is deemed low frequency and so in order to allow the higher frequency (marker movements) to be accurately determined the fourth-order zero-lag is utilised (Yu et al., 1999). These are broadly known as

Butterworth filters (Sinclair et al., 2013a) and are widely used in cycling kinematic studies (Bini and Diefenthaeler, 2010, Dingwell et al., 2008, Sayers et al., 2012, Tamborindeguy and Rico Bini, 2011).

Although the selection of a frequency cut-off is deemed important when filtering kinematic data, the efficacy of the different methods for determining the optimal cut-off frequency is not fully understood. Sinclair et al., (2013a) examined various low frequency cut-off protocols in order to determine the optimum level for lower limb kinematics for running tasks. 10Hz was found to be the highest cut-off with no evidence of noise. These results were substantiated by a spectral analysis of the marker trajectories using a fast-fourier transform (conversion of time to frequency) to examine the cumulative content of the signal in the frequency domain (Giakas and Baltzopoulos, 1997). Typically the choice of cut-off is taken as the frequency at which either 95 or 99% of the signal power is contained below (Sinclair., 2013). It is recognised however, that more distal and proximal joints are more suited difference cut-off frequencies (Sinclair et al., 2013a) and in fact in their (2010) study, Hanaki-Martin et al., used 8Hz (leg) 6Hz (pelvis) and 4Hz (trunk) for seated cycling tasks. This undoubtedly produced substantially more data and considering the small differences in variation, could be questioned as to its practical application. Due to previous work in seated cycling kinematics, it is therefore suggested that either 10 Hz or 15 Hz is the recognised frequency for cycling related kinematics (Bini et al., 2010c, Dingwell et al., 2008, Disley, 2013, Momeni et al., 2014, Sinclair et al., 2013b, Tamborindeguy and Rico Bini, 2011, Theobald et al., 2014, Fonda et al., 2015).

As with cut-off rate there also appears to be consensus on sampling rate of data collection with cycling related three-dimensional studies. This rate is translated into frames per second and the studies mentioned previously all listed sampling rates of between 200 Hz and 250 Hz. The sampling rate selected is recognised as conforming to Nyquist sampling criteria, which indicates that the sampling rate selected should be twice that of the maximum frequency of the signal (Winter, 2005). Although this is not thought to be completely infallible (Lyons, 2004), the criteria appears fully accepted and utilised. While it has been noted that higher rates than 200Hz produce more accurate findings, the data collected are often difficult to manage (Lee, 2012). Sampling of at least 200 Hz is seen as desirable for lower limb movement (Martinez-Solis et al., 2014, McGinnis, 2013, Richards, 2008) although to date no specific studies have investigated cycling specific kinematics with regards to different sampling rates.

Cycling power (watts) are produced by applying force to the pedals (Wishv-Roth, 2009). The complete cycling pedal stroke is often divided into two sections (0° to 180° & 180° to 360°), down-stroke and up-stroke. This represents the pushing down or propulsion of the pedals/bike and the pulling up or recovery part of the stroke. (So et al., 2005, Holmes et al., 1994, Abbiss et al., 2009, Bini et al., 2010b). During the pedal cycle, the knee goes through approximately 75° of motion. The knee begins the power phase flexed about 110° and extends to approximately 35° of flexion. During the initial propulsive phase (power stroke), the pedal is pushed downwards and thus a larger force is produced in comparison with the upstroke (recovery) phase (Bertucci et al., 2005b). The quadriceps and gluteal muscle groups are the prime agonist movers to generate energy to the crank arm (Duc et al., 2008, Faria et al., 2005b). The quadriceps muscle provides most of the force in seated cycling, with input from the hamstring and gluteal muscles. While the knee extends, it also adducts because of the normal valgus angulation of the distal femoral condyles relative to the femoral shaft and foot motion during the power phase. This motion leads to medial movement of the knee during the pedal stroke while the knee extends (Sanner and O'Halloran, 2000, Li and Caldwell, 1998, So et al., 2005).

Power (watts) can affect both movement and associated forces when cycling (Bertucci et al., 2005a). With the development and testing of more accurate power meters, both at the crank arm and the wheel (Hurst and Atkins, 2006, Duc et al., 2007, Ebert et al., 2006), we now have the ability to accurately measure power both inside and outside of the laboratory environment. To measure a specific power output there are many devices available to the cyclist. Power measurement can be achieved by SRM crankset (Schoberer Rad Messtechnik, Jüllick, Germany), Powertap rear wheel hub (Saris Cycling Group, Madison, USA), Stages crank (Stages Cycling, LLC 2012, Colorado, USA) or Garmin pedal system (Schaffhausen, Switzerland). When testing different cyclists it is seen as important to minimise the many variables and represent the individual cyclists set up (Faria et al., 2005a, Ebert et al., 2006, Burke, 2003). By using one of these measuring devices a cyclist can reliably and consistently measure force delivered to the pedals. There is limited data available on joint forces and power, however an ergometer based study by Kutzner et al., (2012) reported higher tibio-femoral forces and shear forces with increased power (up to 100w). Higher cadences produced lower forces. This study was limited by the low power tested and the cyclists were not experienced or elite. Similar results were found in additional studies with experienced and elite cyclists (Strutzenberger, 2012, Bini, 2012). However the majority of studies that examine this area considered additional factors such as chain ring shape and seat height. Considering the available technology there remains no definitive study on joint forces in symptomatic and asymptomatic cyclists with knee pain. There are many muscles contributing to the pedalling cycle. These are predominantly bi-articular and function in different ways from the prime movers. Muscles such as gastrocnemius, soleus, rectus femoris and gluteus medius provide propulsion and also stability to the knee joint. The gluteus medius and associated hip musculature is one muscle group that has been well researched as to its contribution to PFP (Barton et al., 2012a, Green et al., 1999, Dolak et al., 2011, Thijs et al., 2011). Its contributory evidence to cycling however seems scarce and to date very little work has been done to correlate any non-cycling findings to cycling related PFP.

The patello-femoral joint can experience forces surpassing body weight during cycling. At the same time the knee complex has to maintain stability throughout the entire pedal stroke. (Callaghan, 2005a, Ericson and Nisell, 1987). This stability is achieved though coordination of muscle groups and neural firing patterns. The forces generated at the patello-femoral joint surface are increased by the degree of knee flexion attained by the cyclist at the beginning of the propulsion (power) stroke (Callaghan, 2005a). Tracking of the patella through the trochlea groove of the femur is controlled by the muscles immediately proximal and distal to the knee complex (Salsich et al., 2001). The position of the patella and the muscle activity affecting its position is therefore instrumental in either increasing or decreasing these forces on the cartilage surfaces of the femur, tibia and patella (Powers et al., 2012). To date there have been no studies accurately tracking the patella through the cycling motion. We are thus forced to consider weight bearing (WB) studies to consider cycling related knee pain.

In cycling, cadence is the number of revolutions of the crank (pedal arm) per minute (Rossato et al., 2008, Nesi et al., 2005). This is the rate at which a cyclist is pedalling/turning the pedals. Cadence is related to wheel speed, but is a distinct measurement. Factors such as resistance (gearing), weather conditions, fitness levels and duration of activity can affect a cyclist's cadence. There have been several studies that have measured the variability of muscle activity at different cadences (Lepers et al., 2001, Foss and Hallén, 2004, Bertucci et al., 2005b, Bini et al., 2010b). It appears accepted however that cadences in excess of 80 RPM are the norm for elite and experienced cyclists (Abbiss et al., 2009, Lucia et al., 2001b, Foss and Hallén, 2004, Mora-Rodriguez and Aguado-Jimenez, 2006, Nesi et al., 2005). The advantages of higher cadences are the improved blood flow to working muscles, minimisation of local muscle stress and decreased PFJ forces/stress (Bailey et al., 2003, Baum and Li, 2003, Ettema et al., 2009, Faria et al., 2005a, Holmes et al., 1994, Lucia et al., 2001b).

2.4 Taping for Knee Pain

2.4.1 Traditional taping

Patellar taping is frequently used during the treatment of patello-femoral pain (PFP), often as part of multiple modality-based treatment protocols (Callaghan et al., 2008). Taping of the PFJ is indeed a principle factor of evidence-based PFP rehabilitation approaches (Aminaka and Gribble, 2005, Barton et al., 2013). Amongst the many taping techniques and protocols in existence, one of the most commonly used ones is the well-recognised McConnell taping protocol (Crossley et al., 2001, McConnell, 1986, McConnell, 1996). This is where adhesive, rigid taping is applied to the knee to affect lateral glide, tilt and rotation of the patella dependent on the clinical assessment (Figure 2.5 and 2.6). McConnell (1996) produced seminal pieces of work on taping and PFP, and her work remains topical and clinically relevant today. The widely accepted McConnell (1986) taping method has been shown to be helpful in patients with PFP and is supported by Bockrath et al., (1993) and Powers (1998). Although its effectiveness within cycling has been questioned due to its lack of longevity and the repeated action of cycling on the tape (Burke, 2003), it is unclear from the available literature whether this form of taping is utilised in cycling related knee PFP. Additional taping methods used clinically and evaluated in the literature include untailored medially directed (figure 2.5) taping, (Keet et al., 2007) and inferiorly directed taping (Mason et al., 2011). Efficacy and effectiveness of McConnell taping appears relevant to the following areas; immediate pain reduction effects, (Aminaka and Gribble, 2005), chronic pain, (Warden et al., 2008) patella movement (Bockrath et al., 1993, Larsen et al., 1995), muscle activity (Gilleard et al., 1998, Salsich et al., 2002, Callaghan et al., 2001, Christou, 2004), gait & biomechanics (Powers et al., 1997, Selfe et al., 2011, Bennell et al., 2006) and proprioception (Callaghan et al., 2008, Akseki et al., 2008, Callaghan et al., 2012). There have been numerous rigorous reviews of the literature, which provide a comprehensive legitimacy to its use in treatment and rehabilitation (Barton et al., 2013, Warden et al., 2008, Crossley et al., 2001, Powers, 1998, Arroll et al., 1997, Callaghan and Selfe, 2012).

Figure 2.5 McConnell taping (medial)

Figure 2.6 McConnell taping (lateral)

In a well-cited review, (Crossley et al., 2001) concluded that taping may well affect the patella alignment, quadriceps function and joint reaction forces within the patello-femoral joint. Alongside this, it concluded that taping provides a useful treatment technique as part of rehabilitation programmes whilst at the same time recognising the unknown factors such as pain mechanisms, causes and consequences. Notably for the subject and methodology of this study, the review also advised that placebo or neutral taping should be further researched. In a recently published Cochrane review (Callaghan and Selfe, 2012) on patello-femoral taping, it was accepted that the currently available evidence from trials reporting clinically relevant outcomes is low quality, and insufficient to draw conclusions on the effects of taping. This was irrespective of whether used on its own, or as part of a treatment programme. This suggests that further quality studies are required that measure clinically important outcomes and long-term results. Thus, it seems consensus is required on the diagnosis of patello-femoral pain, the standardisation of outcome measurement and an acceptable and effective approach to patellar taping.

2.4.2 Kinesiology type taping

Over the past ten years, new taping products such as Kinesiology type tape (KTT), a generic term utilised rather than trade specific (Kinesio, Rocktape, Theratape, KTtape etc.), have become available for clinical use. KTT has a greater in-situ longevity and malleability than athletic taping (Kase et al., 1998b). Kinesiology type tape is made of tightly woven elasticated cotton fibres, the glue on the back is acrylic, durable and waterproof. Hence, it is claimed, the tape can be worn for up to a week withstanding vigorous movement, sweat and total immersion in water (Williams et al., 2012). Kinesio taping (original trade name), is a specific technique/tape that was first established in the 1970's by Dr. Kenzo Kase (Thelen et al., 2008, Briem et al., 2011). Both the technique and the tape itself claimed several main effects; to affect muscular function, re-alignment of joints to decrease pain, to improve lymphatic drainage and blood flow, to aid in the correction of possible articular mal-alignments and to protect against muscle fatigue and injury (Kase et al., 1998a). Over the last five years, many other manufacturers have begun to produce similar tape, consequently it is now referred to as kinesiology type taping (KTT) rather than using a trade name to avoid trade-mark issues. Some example of KTT techniques from various manufacturers can be seen in figure 2.7.

Figure 2.7 Various Kinesiology type tape techniques

The malleability of KTT appears to be a useful feature when considering cycling. This is in part due to the repetitive nature of cycling and the requirement for flexibility and minimal inhibition of movement. Considering that the main mechanism of PFP has been identified as increased or altered PF forces and stress across the load bearing joint surfaces of the knee complex, it would be logical to consider KTT from this perspective, alongside its resultant and proposed pain reducing mechanisms.

Studies looking at pain effects have reported an immediate reduction in pain (Thelen et al., 2008, Kaya et al., 2011, Paoloni et al., 2011, Tsai et al., 2010, Gonzalez-Iglesias et al., 2009, Freedman et al., 2014). In all but one case (Kaya et al., 2011), the pain relief was temporary at best and no longer-term measures were taken on its effects when worn and possibly more importantly, after removal. In one PFP related study by Akbas et al., (2011), pain was indeed reduced but no more so when compared to a protocol that involved a recognised exercise therapy programme for PFP. A more recent study (Song et al., 2014) using participants with PFP utilised KTT to control femoral rotation during single leg squats and found that it decreased pain, albeit temporarily. This temporary reduction in pain is seen to be important to the management of cycling related knee pain however its longer-term effect clearly requires further research. Although pain was reduced there was no discussion around the proposed mechanism for the pain reduction or indeed measurement of any differences in rotational movement of the femur. Consequently, the short-term pain reduction cannot be reliably attributed to any biomechanical changes or force/stress reduction around the PFJ. The study interestingly also found some pain changes with the sham or neutral taping technique but was in female participants only. This may indicate some limiting factors as the female gender is known to have specific increased links to femoral-PFJ angles and pain, therefore one may have expected a more significant outcome regarding pain due to the KTT placement controlling femoral activity.

Corporate sponsored studies into KTT regularly produce positive results around pain reduction and performance enhancements (Burke, 2005, Chen et al., 2007, van den Dries, 2011), however none of these have to date used biomechanical investigation and these studies have numerous questions as to their methodologies and are often published in non peer-reviewed publications. This again does not underpin any proposed re-alignment of joints or joint force/stress effect. Those studies, openly endorsed by manufacturers, are notable by their lack of inclusion in credible scientific journals. This may or may not be due to bias. Alongside these studies there is an abundance of analysis of

KTT available on the internet. A recent content and quality based analysis study of internet based information (Beutel and Cardone, 2014) looked at websites containing proposed evidence of KTT. It looked at 44 websites that met the inclusion criteria and found, that less than 35% of them were updated on a regular basis and over 70% were predominantly commercially focused. 0% were of an academic nature. It concluded that there was a high degree of poor quality and often misleading information available, most of the sites being commercially focused. This would appear to underpin the call for higher quality studies into this clinically utilised technique.

Additional claims of efficacy and effectiveness that are of direct relevance to cycling, and this study, are that of the effect on muscle function, the mechanical effect on joint range of movement (ROM) and in turn PF force/stress and the effect of joint position sense or proprioception. A recent study by Gómez-Soriano et al., (2014) indicated a short term affect on surface EMG activity in the gastrocnemius muscle, yet no increase in muscle activation was found. This double blind, controlled trial into the effects of KTT on the gastrocnemius also concluded that KTT had no effect on isometric force (MVIF) and EMG activity. This may indicate that any perceived pain reduction was due to mechanisms other than direct effect on the muscle itself. In some degree of contrast to this, Lumbroso and Kalichman (2014) found an increased force and ROM in both the gastrocnemius and hamstring after the application of KTT. Both KTT techniques for the gastrocnemius were the same though its exact application may have differed in tension and position. It should also be noted that the methods of measuring force of the gastrocnemius differed from a dynamometer apparatus perspective and this study was not double blinded. Perhaps more interestingly, this increase was both immediate and also after two days of wearing the tape, which may indicate more longevity of effect than previously reported. Lumbroso and Kalichman (2014) also recommended the use of sham or neutral tape in future studies which, when considering the more recent KTT studies appears to be adopted as an accepted method of testing. This has interesting connections to cycling as treatment options include the control of muscle activity in the vasti group and their effect on PFJ tracking and associated PF forces. Application of this protocol would perhaps indicate an area of future research into PFP with cyclists. A recent 2014 meta analysis of current evidence of KTT muscle strength effects by Csapo and Alegre (2014) looked at 19 studies of moderate to good methodological quality. They concluded that muscle effects have been numerously investigated and KTT’s ability to facilitate muscular contraction is very limited. KTT’s effect on muscle function is an important factor when linked to the proposed mechanism of PFP. If muscle function can be reduced, increased or altered then joint stress and force may be indirectly affected. To date, although claims of altered muscle function (albeit short term) and joint alignment are claimed, KTT’s efficacy in consistently or significantly producing this response is limited (Cho, 2014, Beutel and Cardone, 2014, Csapo and Alegre, 2014, Parreira et al., 2014a).

Chen, et al., (2008) investigated the use of KTT on the biomechanics in subjects with PFJ pain during stair climbing. In their study of 15 participants they found that kinesiology type tape resulted in decreased peak ground reaction forces, when compared with no tape or placebo taping, during ascending and descending stairs. Also there were significant differences between taping and no taping in vertical ground reaction forces. This suggests that the subjects with knee pain were avoiding knee flexion/force whilst they had pain, and that the kinesiology type tape reduced the pain enough for them to allow greater knee flexion and consequently have better force attenuation through the lower limb. They also suggested that the onset of Vastus Medialis Oblique (VMO) activity occurred earlier with kinesiology tape. In an interesting study comparing McConnell and KTT by Campolo et al., (2013), it was found that both forms of taping seemed to reduce pain when descending steps but neither affected pain during full squats. Although neither function is cycling based, the single leg descent could be argued to be unilateral in nature and closer in relationship to the single leg biomechanics of cycling. Considering that McConnell taping has been shown to affect joint alignment and decrease pain (Crossley et al., 2009, Powers et al., 1997) it could be postulated that KTT achieves pain reduction in a similar manner. Its increased malleability, compared to that of McConnell, may however negate this as a direct mechanism on PF stress and associated forces.

An additional dual modality knee based study by Murray (2001), examined the effects of KTT for increasing joint range of motion and increasing muscle strength. The study involved the application of two taping methods to the quadriceps muscle post anterior cruciate ligament repair. Three techniques were used on each participant (n = 2); no tape, athletic tape and KTT. An improvement was only seen on the application of KTT, where a significant increase in the active range of motion during knee extension with a decrease in knee lag was seen, as well as an increase in muscle activity seen on surface electromyography (EMG). Although related to this study in that it was knee based, its numbers were very small and neither forces nor biomechanical changes were measured. Consequently, KTT's affect on PF joint stress and the associated PF forces generated were not examined or presented.

A recent study by Griebert et al., (2014) found that KTT decreased medial loading for those suffering with medial tibial stress syndrome. This would indicate that KTT could indirectly affect forces about a joint and also resultant stress placed on a tendon. The study found that the tape reduced loading on a weight bearing section (medial plantar) of the kinetic chain during walking and so it is possible to postulate that this effect may be repeatable to a greater extent with a predominantly non weight bearing (NWB) activity such as cycling. There may indeed be a connection with the knee mechanism here and although it is recognised that the two areas are separate, they are in fact part of the same kinetic chain during the pedalling action. As with the previously discussed study by Lumbroso et al., (2014), Griebert et al., also used a longer time frame to collect data (immediate and 24hrs). Unfortunately no symptomatic related data were collected during the experiments. A PFP study using KTT was undertaken by Aytar et al., (2011), where 24 participants were tested. Quadricep muscle strength was measured using an isokinetic (Cybex) dynamometer. Joint position sense was measured using the same dynamometer, balance was measured using a Kinesthetic Ability Trainer (KAT 3000) assessing static and dynamic stability. Pain was recorded by VAS. KTT and neutral tape were compared however no significant differences were reported. Although randomised and double blinded, this study did not have a control group and participants were all female. Again, this study focused on the immediate effects rather than longer term.

A small case study by Brandon (2005) reported pain reduction when using KTT with PFP patients. Again there was no control and no alternative comparison tape used.

It has been suggested that in addition to pain relief, KTT may also affect proprioception (Schneider, 2000, Chang et al., 2012). Proprioception has been defined by Rieman and Lephart (2002) as the outcome of the processing by the central nervous system of afferent information from various mechanoreceptors about joint position, joint movement and joint force. Further research has, on the contrary, shown that KTT did not improve proprioceptive response at the ankle with measures of reproduction of joint position sense (RJPS) in plantar flexion and inversion (Halseth et al., 2004). Interestingly, these KTT studies looking at proprioception did not use recognised isokinetic tests based on Passive Angle Reproduction (PAR) or Active Angle Reproduction (AAR) but instead used either specifically built instrumented platforms (Halseth) or dynamic balance trainers (Aytar). A very recent study by Hosp et al., (2014) looked at proprioception of the knee using a similar technique to the main biomechanical study in this project (Chapter four). Measuring active joint position sense reproduction they found an improvement with KTT but only with those predisposed with poor status of proprioception. It was suggested that a tactile input may stimulate the cutaneous mechanoreceptors and hence improve performance, however the study only looked at healthy participants and additionally only females. There were no data produced to indicate any degree of longevity was sustained in performance.

In another study using KTT, it was shown that individuals treated with tape over a 24-hour period exhibited mild improvements in inflammation and pain reduction (Gonzalez-Iglesias et al., 2009). This again, potentially shows that

Kinesiology tape's benefits are limited to short-term use. More recently, systematic reviews have been published (Kalron. A, 2013, Morris et al., 2013, Williams et al., 2012). All of these broadly agreed in the lack of RCT's, variation of applications, potential medical database bias, short-term outcome measurement, and limited clinical effectiveness. Overall they all conclude that there is currently insufficient evidence that supports KTTs use over other modalities.

An interesting claim to how KTT attains its effects is by subcutaneously lifting (de-compressing) the skin to improve lymphatic drainage and produce positive pain reduction results for the top layers of fascia, as well as the much deeper layers (Schneider, 2000, Kase and Stockheimer, 2006). The tape is manufactured to produce a wrinkled (convoluted) effect when applied in a stretched position over the skin and claims around this 'de-compressive' effect on the removal of pain generating chemicals produced during the inflammatory process appear dominant (figure 2.8).

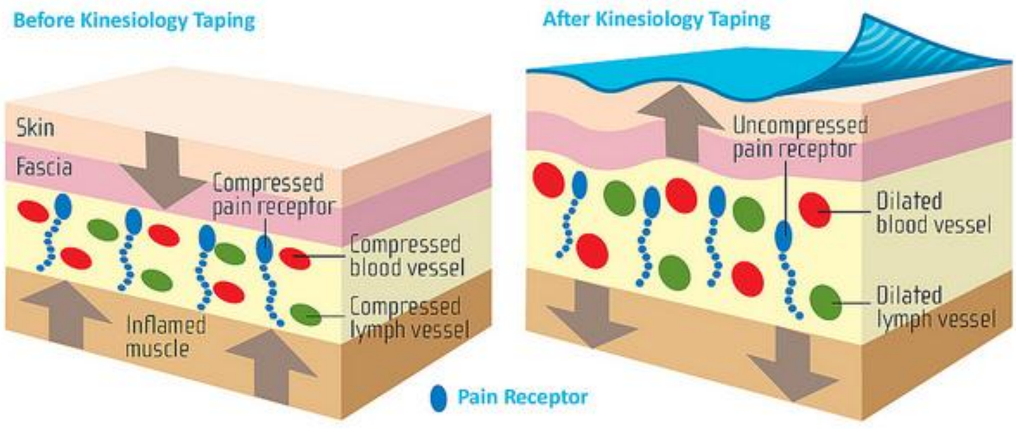

Figure 2.8 Pain reduction proposition (kinesio tape)

It proposes to use the tape's inbuilt construction to achieve this alongside its elastic nature. This claim does not appear to have been substantiated in any way in scientific research and, to date, this improvement of fluid movement is unclear. It is unclear how this mechanism would affect PF joint stress and force production. There have been some small studies looking at lymphatic disorders and KTT, however the results were also inconclusive and numbers small with no statistical results reported (Białoszewski et al., 2009, Tsai et al., 2009). A recent study (Parreira et al., 2014b) investigated this lifting and de-compressive (Figure 2.8) effect on 148 participants with low back pain over a four week period. They found no significant differences between KTT and a neutral tape. It is worth noting though that from a clinical perspective, KTT alone would not be the only treatment applied to a patient with low back pain. This study adds evidence that KTT alone does not provide a significant change in pain. An additional assertion is that through its application directly to the skin, KTT stimulates the mechanoreceptors of the skin and decreases pressure on these receptors, thus reducing pain (Kase and Stockheimer, 2006). This is one area of interest in cycling related knee pain as a potential mechanism of pain reduction however does not appear to infer any relationship with the decrease in PF forces and stress required to have a significant effect on PFP.

The body of evidence on taping for cycling related PFP therefore appears to leave important gaps in the knowledge base. From the increased appearance of different manufacturers of Kinesiology type tape and its use in high profile events, taping use in the management of knee pain in cycling seems to have become widespread. However its application to cycling as a specific sport has not been investigated fully. As cycling is repetitive in nature, therefore with injury and pain, muscular restrictions may occur and cause decreases in ROM as a result (Burke, 2003). The application of KTT may indeed serve to correct this by affecting muscle function and biomechanical movement. These changes may in turn affect the PF forces produced and also alter the PF stress known to be a predominant factor in PFP (Witvrouw et al., 2014). Alternatively its effect on the skin and joint position sense may also be influential. Its short-term effects appear recognised across the available evidence. Specific to this study there is distinct lack of information regarding the application of KTT and its effect on PFJ forces/stress, knee pain, power output and hip, ankle/foot and knee range of motion in cyclists. Considering that PFP has been shown to have direct links to increased or altered joint force and stress, the evidence that KTT affects this mechanism is very limited, especially in cycling related PFP. Studies appear focused simply on pain reduction and not the direct and evidenced mechanisms that may produce the pain reduction (decreased PF force and stress). Thus, future work should consider investigating these known mechanisms further. Recent research has produced more comprehensive reviews of KTT and its proposed effects (Williams et al., 2012, Parreira et al., 2014a, Montalvo et al., 2014, Kalron. A, 2013, Morris et al., 2012), all of which indicate limited to moderate evidence of clinically effective outcomes. Interestingly, De Ru (2014) published a direct criticism of the Parreira review (2014a) as to its inclusion of original techniques rather than modern progressions currently used clinically. De Ru also called for combining research with clinical practice rather than a mutually exclusive approach.

2.5 Aims & Objectives

To investigate the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists both with and without Patello-femoral pain (PFP).

Online clinician questionnaire aim

To design and implement an online questionnaire establishing specific current clinical practice of taping techniques for the treatment of elite and experienced cyclists with patello-femoral pain.

Questionnaire objectives

- To communicate with a number of clinicians (n= >25) currently engaged in the treatment of elite and experienced cyclists with PFP
- To design, pilot and implement an online questionnaire to determine current taping techniques for PFP in elite and experienced cyclists
- To identify a specific taping technique to be used in the lab-based study

Biomechanical investigation aim

To investigate the biomechanical efficacy of patello-femoral taping in elite and experienced cyclists both with and without PFP.

Biomechanical study objectives

- To measure any biomechanical changes around the knee in elite and experienced cyclists using the previously established taping treatment from the online questionnaire at different power outputs
- To measure asymptomatic cyclists and then compare these results with symptomatic cyclists
- To determine any additional changes in the hip and foot that may impact on knee movement during cycling

- To determine the potential clinical impact of PF taping by examining the relationship between the efficacy and effectiveness of the treatments.

Summary of aims and objectives

A study collecting data on the current usage of taping for cycling related knee pain (Online questionnaire) assessed current clinical practice and determined the technique to be investigated. This information was in turn used to investigate the efficacy and effectiveness on asymptomatic and symptomatic cyclists (Biomechanical study). Both of these studies provide an original contribution to knowledge on the current usage and common treatments of cycling related knee pain using taping. They also aim to evidence the points of proposed efficacy and effectiveness of taping when used with elite and experienced road cyclists in both a clinical and laboratory setting. The data from the questionnaire informed the biomechanical laboratory study and enabled evaluation of a specific and clinically relevant taping as a treatment for patello-femoral pain in cycling. By determining evidence of the current approaches and specific treatment techniques regarding cycling related taping, and consequently testing them, it is possible to provide clinically useful information that will enable clinicians to treat cyclists more effectively from an evidence based and reasoned perspective.

CHAPTER THREE – Online Questionnaire

Investigation into the clinical usage of taping with cycling related knee pain in experienced and elite cyclists

3.1 Introduction

To date there are no data available as to clinical use of taping for cycling related knee pain. This information was deemed important in order to identify an appropriate technique to test in any biomechanical study into taping efficacy and effectiveness. Figure 3.1 outlines the thought process that enabled development of the aim and objectives of the online questionnaire. Furthermore it provides an initial understanding as to the clinical rationale behind the progression between the questionnaire and the subsequent biomechanical study.

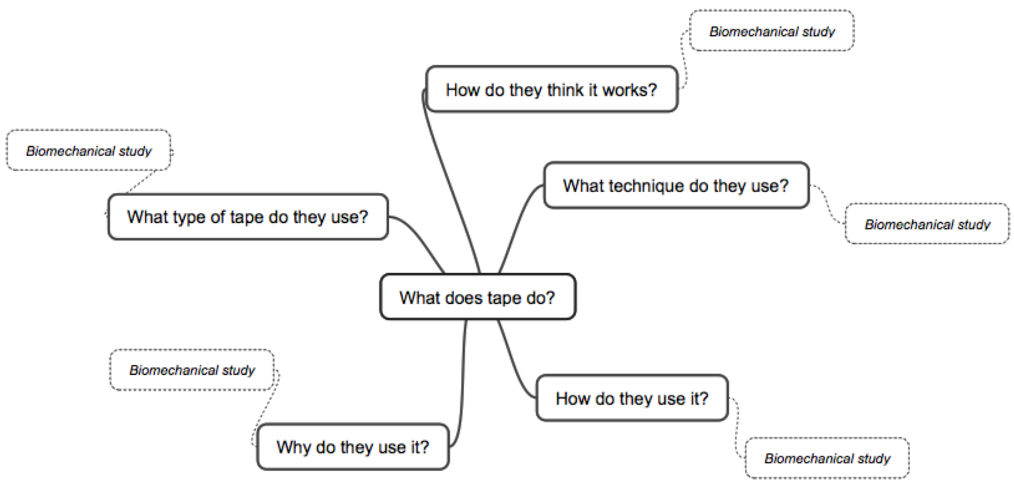

Figure 3.1 Online questionnaire mind map

3.2 Rationale for Methods of Questionnaire for Clinicians Using Taping

Before the proposed biomechanical study, it was recognised that it is predominantly unknown as to the level of use of tape within cycling. Its use is mainly anecdotal and often driven by marketing and media. In order to determine any specific taping technique to be tested, further information was required as to the context of if, when and why tape is used with cycling related knee pain. Considering the perceived scope of use across the globe it was determined that the best format was an online questionnaire. This allowed control of data, security of data and the ability to collect data systematically and with clarity. It also allowed instant access to the target group in the targeted Union Cycliste Internationale (UCI) countries. This was a natural pre-curser to any biomechanical study to collect base-line information on taping in cycling, with cycling specific clinicians using a simple format that had minimal effect on busy clinical workloads.

3.3 Methods

Ethics approval was gained prior to data collection through the University of Central Lancashire Faculty of Health & Social Care Ethics Committee (Reference number: BuSH 107). All data was stored in line with UClan regulations. Electronic data was stored on a password-protected computer. Social media communications were located within a password-protected system.

3.3.1 Online Questionnaire: Content and development

The online questionnaire (see appendix 11 for full version) was developed using proprietary software (www.surveymonkey.com) and was selected in order to reach a group of clinicians from around the world but within the Union Cycliste Internationale (UCI). The online format of the questionnaire tool allowed the researcher to change question order, content and emphasis at will, and thus the development of the questionnaire could be facilitated and managed both cost effectively and quickly.

3.3.2 Research population and demographics

All clinicians were recruited from (UCI) Union Cycliste Internationale affiliated countries (n=30) due to the global nature of cycling and the equally global nature of social media Twitter™. This recognised and representative global organisation (UCI) was felt to be integral to the group of experienced and elite cyclists. Recruiting from the United Kingdom alone would not have reflected the true use of taping in cycling at this time. The UCI countries represented by the respondents were Great Britain, Ireland, Belgium, France, USA, Switzerland, Spain, Italy, Norway, Germany, Canada, Australia and New Zealand. English speaking clinicians were felt to be key in understanding and completion of accurate responses to the questionnaire. This was made clear through Twitter™ and other recruitment by direct reference. Table 3.1 indicates further demographic information on respondents.

Table 3.1 – Biomechanical study participants

		Cyclists treated			Gender split	
Country	No.	Elite	Ex	Pro	Male	Female
GB	7	Y	Y	Y	5	2
Ireland	1	Y	Y	N	1	0
Belgium	4	Y	Y	Y	4	0
France	1	Y	N	Y	1	0
Germany	2	Y	Y	Y	1	1
Italy	2	Y	N	Y	2	0
Norway	1	Y	Y	N	0	1
USA	4	Y	Y	Y	3	1
Canada	1	Y	N	Y	0	1
Australia	5	Y	Y	Y	4	1
NZ	2	Y	Y	N	1	1

3.3.3 Participant distribution

Figure 3.2 overleaf outlines the participant distribution for the online questionnaire.

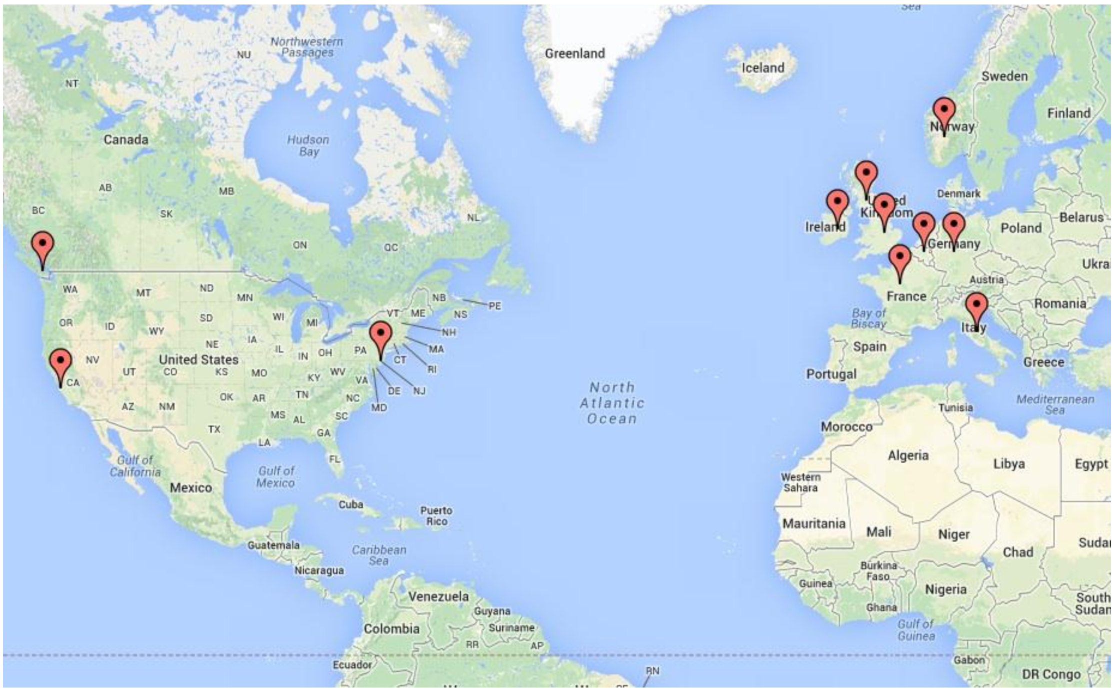

Figure 3.2 Participant distribution

3.3.4 Participant information and communication

Participant information and consent were distributed in person, online and via email. This information was also available in hard copy if required. All participant information and consent forms for the clinician online questionnaire are available in appendix numbers 12 to 16. Communication was facilitated where possible via the platform of preference for the participant. For example, if they were recruited via Twitter™ then a Direct Message (DM) from within that medium was the normal conduit for any communication.

3.3.5 Sample size calculation

Due to the unknown population of clinicians treating elite and experienced cyclists in the target group with taping, a formal sample size was unable to be calculated. To put this into context, the Tour de France normally has 20 teams of nine riders competing. Each team will normally have one or two people who can tape knees. n=30 composed a representation of a cross section from this little researched area. The clinicians worked in private clinics (experienced cyclists), directly with professional teams (elite) and also with amateur teams and individual racers (experienced and elite cyclists).

3.3.6 Data collection and analysis

Data collection was from the online source of Survey Monkey™ and downloaded from a secure and password protected server provided. The information was available in both chart, pie chart, excel and pdf formats. The data is formatted into chart format direct from the online software and formatted from an excel spreadsheet. The data was analysed and presented in simple chart format to facilitate clinical interpretation.

3.4 Pilot Questionnaire Work

The questionnaire method was piloted for feedback by consulting two clinicians from a local cycling network. Decisions on the category of scales to be used were important in order to ascertain that the clinicians remained engaged and were encouraged to reflect clinically rather than simply score middle ground. From pilot study feedback and to avoid middle ground scoring a 4-point Likert scale was selected. Equal point scoring was seen to ensure that the participant cannot simply score the average or central ground and encourages a firm decision either side of a specific point (Nicholls et al., 2006). For taping this was important in order to obtain a clear opinion of topics such as whether a technique was clinically effective or was felt to reduce pain for example. It allowed the participant to understand the clarity of their answers and in turn provide clear data to evaluate. An example of this scale and related question can be found in figure 3.3.

Efficacy and Effectiveness of taping.

How effective do you think the following applications are in treating knee pain with elite and experienced cyclists?

	NOT AT ALL EFFECTIVE	SOME EFFECT	EFFECTIVE	VERY EFFECTIVE
MCCONNELL				
KINESIO				

Figure 3.3 Example of online question format

Follow-up informal conversations from the pilot questionnaires were undertaken for subtle changes in questions to ensure that the data received was in line with the aims and objectives.

3.4.1 Further development and learning

Further development of the questionnaire was undertaken over a period of one month and both format and content were updated during this time. Participants (n=5) were invited to give feedback on the outcome question areas from the pilot and changes were made in question order and content. The questions derived initially from the literature base. For example: Pain is a regular research topic with all taping, hence taping's effects on pain was a question required. Feedback was predominantly around terminology and outcome measurement specific to the field of cycling related knee pain and its treatment. It was key to ensure that clinicians felt that the flow of the questionnaire followed a natural progression. One example of this would be splitting the 'success' of taping into two questions. Initially there was a single question as to whether taping was a success. From feedback an additional question exploring how clinicians measure success was added to provide further clarity. Feedback was implemented into two further drafts until consensus from the clinicians was in line with the objectives and the flow of the questionnaire was felt to be appropriate to elicit the data required. Once achieved, the study information was made available through a single source access link on the author's website. The full online questionnaire (screenshots) can be found in appendix 11.

Recruitment of participants was through Purposeful Sampling via professional, social and personal networking with Chain Referral or Snowballing Sampling as well as direct messaging. Initially, five clinicians were contacted. From this a further four were identified through snowball and networking by email. Developmental recruitment using social networking media Twitter™ is outlined later in this section. The inclusion criteria was as follows:

Do you treat elite and/or experienced cyclists with patello-femoral knee pain?

Do you use, or have you used any form of taping as a treatment technique for cycling related patello-femoral knee pain?

Are you prepared to participate in a small questionnaire aimed at this target group and treatment?

Participant information and all other documentation were also made fully accessible through the same website link. Participant information and consent forms are contained in appendices 13 to 15. Consent was collected in the initial question online for those recruited. The questionnaire was designed to gather basic information including consent and participant clinical usage of taping with knee pain, then to progress through the following outcome related question areas (full questionnaire questions in appendix 11).

3.5 Development of the Twitter™ Methodology

Both personal and professional networking and the consequent snowballing effects from this were recognised as an ideal format to recruit participants. These methods were undertaken both in person and by email and produced some of the initial participants (n =5). However, due to the author’s personal contribution to the online social network of Twitter™ it was identified that this method was a potentially useful additional and effective method of recruitment. Twitter™ is an online social networking and micro-blogging service that enables its users to send and read text-based posts of up to 140 characters, informally known as "tweets". As of June 2010, approximately 65 million tweets were posted each day, equaling about 750 tweets sent each second, according to Twitter (Garrett, 2010). The service has rapidly gained worldwide popularity, with more than 100 million users who, in 2012, posted 340 million tweets per day. Users can group posts together by topic or type by use of hashtags – words or phrases prefixed with a "#" sign. Similarly, the "@" sign followed by a username is used for mentioning or replying to other users. To repost a message from another Twitter user, and share it with one's own followers, the re-tweet function is symbolized by "RT" in the message. Followers and following are discretionary and can be controlled online easily. On September 7, 2011, Twitter announced that it had 100 million active users logging in at least once a month and 50 million active users every day. As of September 2013, the company's data showed that 200 million users send over 400 million tweets daily, with nearly 60% of tweets sent from mobile devices. User numbers of this kind enabled access to a much wider network of clinicians by ‘tweeting’ specific messages and these being relayed accordingly to appropriate users. Messages such as; “Please ‘RT (re-tweet) if you know clinicians who treat cyclists with knee pain please ask them to consider helping my research work - http://tiny.cc/rzsv3’ (link to questionnaire info).” were used.

Initially five clinicians were identified on Twitter™ as suitable for direct messages (DM). Direct messaging to users was also used to ascertain that participants understood the context of the questionnaire and the location of the participant information online. Re-tweets (RT) were checked and followed up via the platform of Tweetdeck™ which can be used to follow live tweets, specific searches and users. Direct messages (DM) were also followed up. A total of four original (identical) tweets were sent, the participants were recruited directly from consequent re-tweets, snowballing and direct messages from followers. No additional communication was required due to the mechanism utilised. The flow diagram (Figure 11) illustrates the process in a simplified format. Combined with the initial professional network group, consequent snowballing sampling from this and the Twitter™ contacts the group (n=30) was felt to be representative of the target participants required for quality data. Most clinicians using Twitter™ publish their professional details and activity online via their profile and this can be accessed to clarify the area of specialism. All the clinicians operated within the field of cycling and also treated patello-femoral related cycling pain using taping. This process in no way compromised their rights as the medium of Twitter™ allows this information to be completely public and the participants personal information remained confidential at all times.

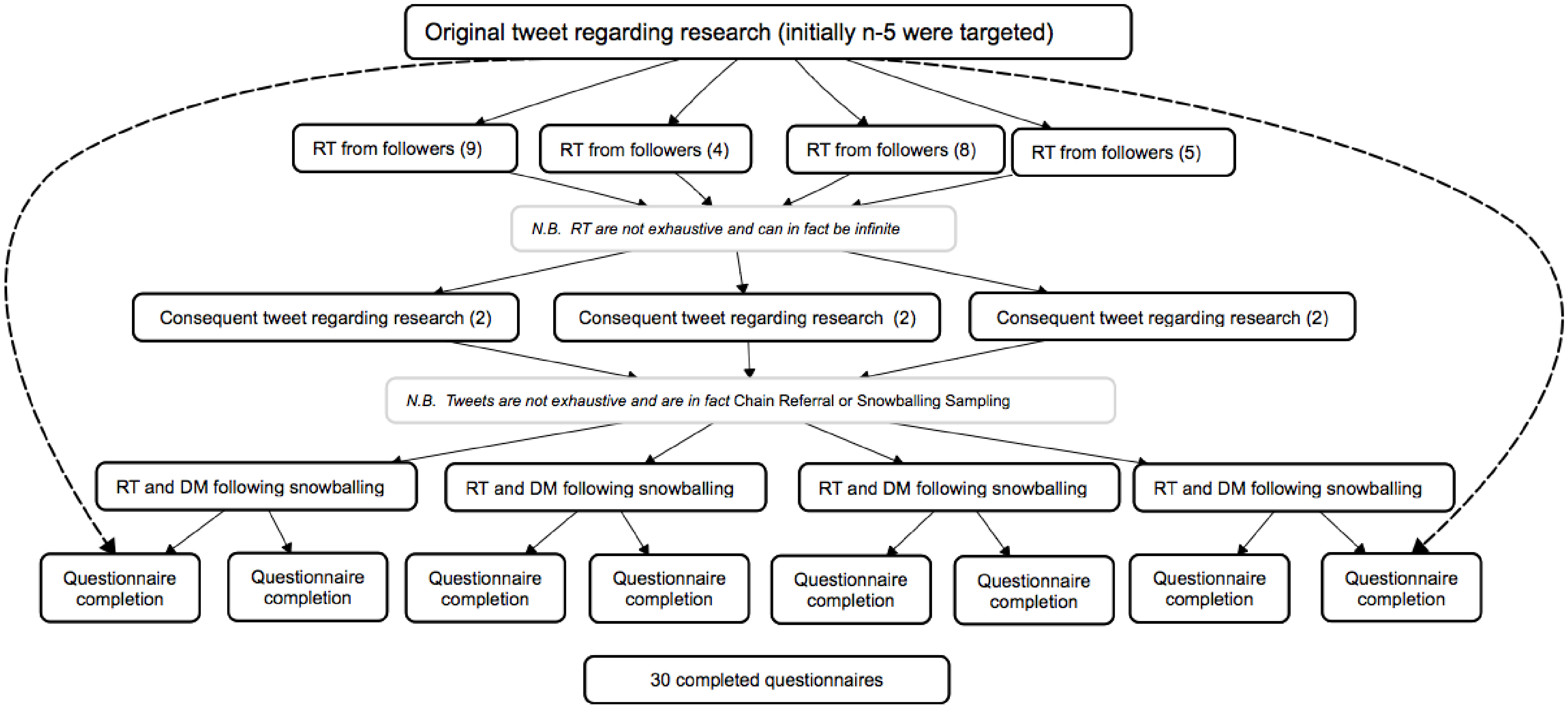

Figure 3.4 Twitter process (snowballing sampling and chain referral)

3.6 Questionnaire content:

1. **Consent and Understanding**
2. **Taping and Cycling knee pain**

    a. Which of the following do you, or have you used to treat knee pain in elite or experienced cyclists………

3. **Taping application and your experiences**

    a. Normally, when you apply taping to elite or experienced cyclists with knee pain, what are your clinical outcome goals?

    b. When applying taping techniques to elite and/or experienced cyclists, do you..............

    c. How often would you use taping in treating cycling related knee pain?

    d. When treating experienced and elite cyclists, which specific pathologies do you use taping for?

4. **Taping training and your experiences**

    a. Have you been formally trained in the following taping techniques?

    b. Do you, or have you ever used taping as a neutral or placebo treatment for cycling related knee pain with experienced and elite cyclists?

    c. Clinically, is your taping treatment a success with regard to cycling related knee pain in elite and experienced cyclists?

    d. How do you measure the success of your taping treatment with elite and experienced cyclists with knee pain?

5. **Efficacy and Effectiveness of taping**

(Taping that produces the desired results on the knee.

Clinical success of taping treatment in regards to cycling related knee pain).

    a. How effective do you think the following applications are in treating knee pain with Elite and Experienced cyclists?

b. Do you think taping affects cycling related knee pain in elite and experienced cyclists by.............

c. With regard to the questions around the efficacy and effectiveness of taping on elite and experienced cyclists, please rate how important the following are to you.

6. **McConnell Taping (please skip if you do not use)**

a. Why do you use McConnell taping with experienced and/or elite cyclists with knee pain (skip if you do not use)?

b. Which McConnell technique do you, or have you used with experienced and/or elite cycling related knee pain?

7. **Kinesio Taping (please skip if you do not use)**

a. Why do you use Kinesio taping with experienced and/or elite cyclists with knee pain (skip if you do not use)?

b. Which Kinesio taping technique do you, or have you used with experienced and/or elite cycling related knee pain?

8. **Final questions**

a. Please provide any other comments, observations or relevant information with regard to your treatment of experienced and/or elite cyclists with knee pain using taping.

9. **Information about you – CONFIDENTIAL**

This section was completed by all of the participants but was stated as NOT compulsory.

3.7 Methodology Development

Initially by utilising the free service package of the Survey Monkey™ software it was realised that questions were limited to a specific number per questionnaire. Therefore two separate sections were designed to make up the completed questionnaire. Although this worked to some degree it was evident early on that even though instructions were very specific as to part two being required after completion of part one, participants appeared to have omitted the second section. Once this was noted (after five participants) it was decided to upgrade to the subscription service to enable one complete questionnaire to be undertaken. Uptake and compliance improved immediately and the five participants were contacted and asked to repeat the questionnaire in full. One participant did not complete the full questionnaire from these five.

3.8 Online clinician questionnaire - Results

The results have been presented in chart format. The demographics and additional information concerning the respondents can be found in table 3.1 in section 3.3.2. Response count is shown in each chart in brackets for clarity and interpretation.

3.8.1 Taping techniques used

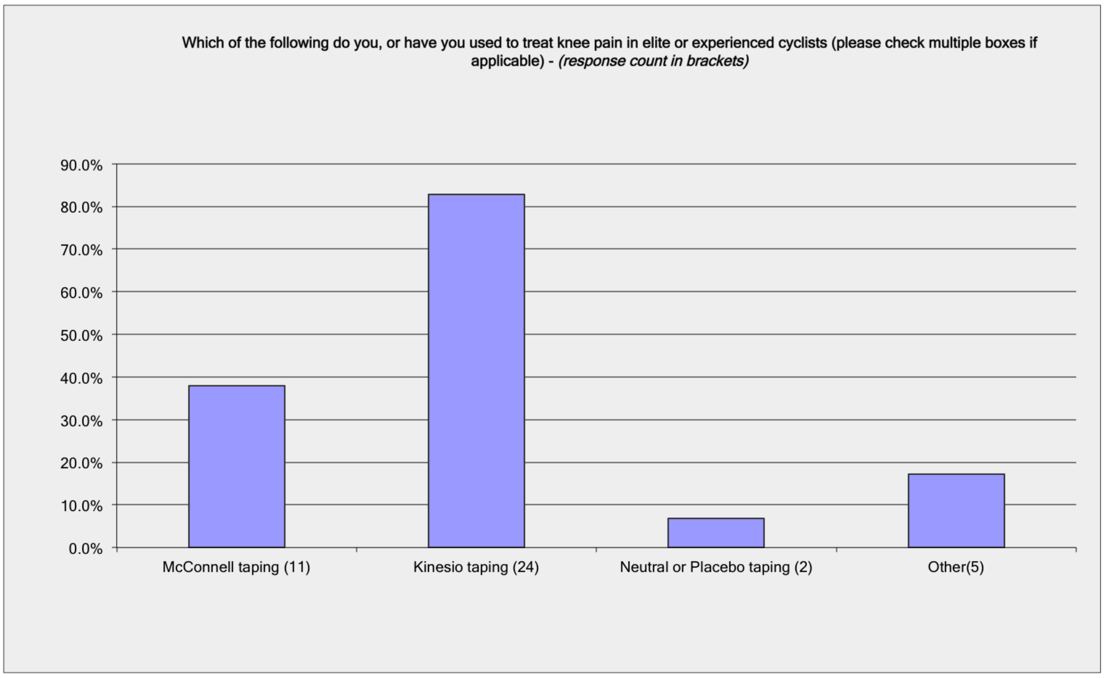

Figure 3.5 Taping techniques used

3.8.2 Clinical outcome goals

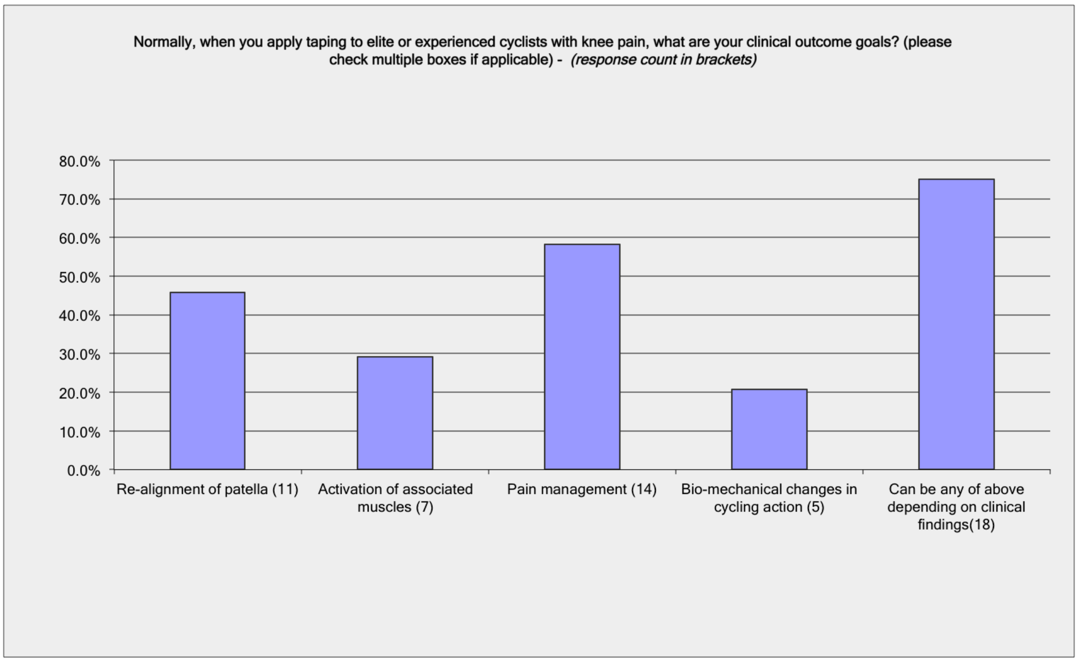

Figure 3.6 Clinical outcome goals

3.8.3 Applying taping techniques

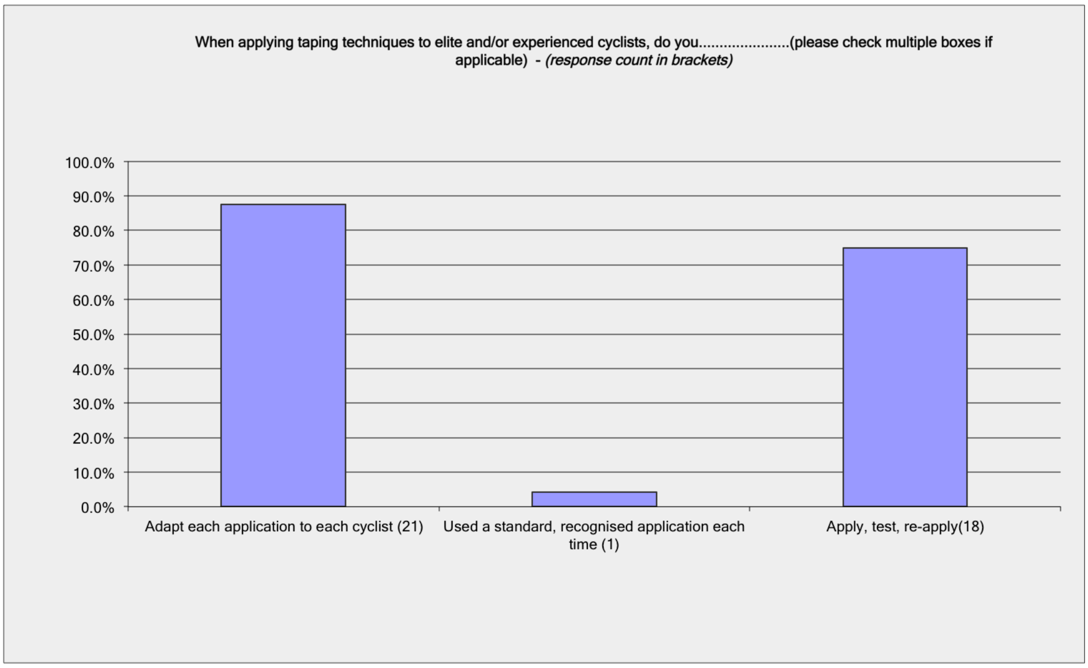

Figure 3.7 Applying taping techniques

3.8.4 Use of tape

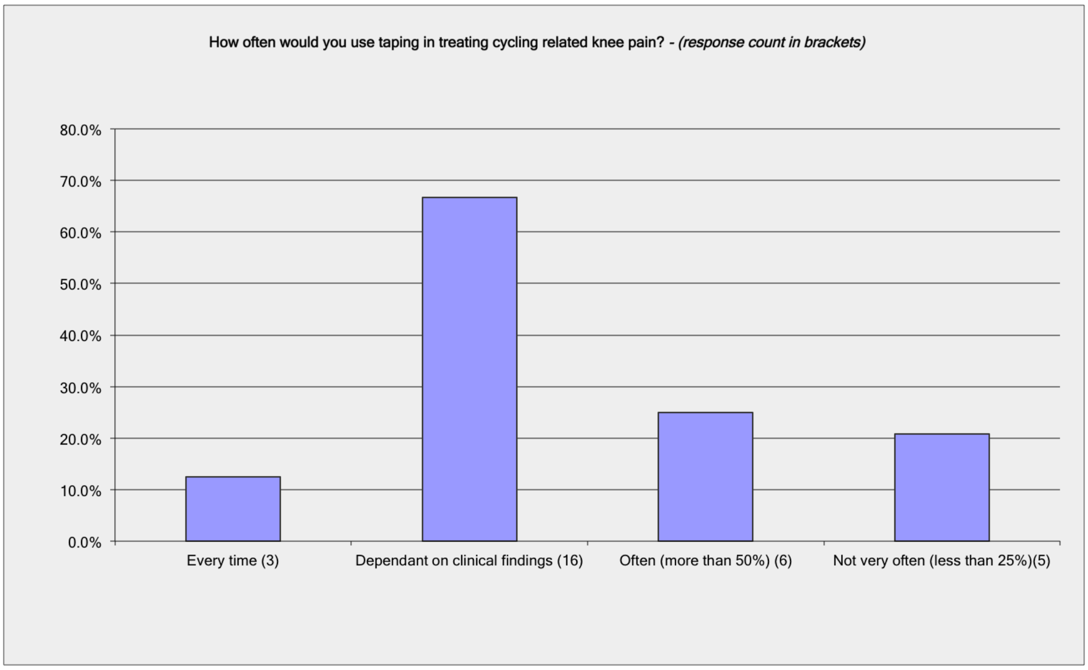

Figure 3.8 Use of tape

3.8.5 Pathologies treated

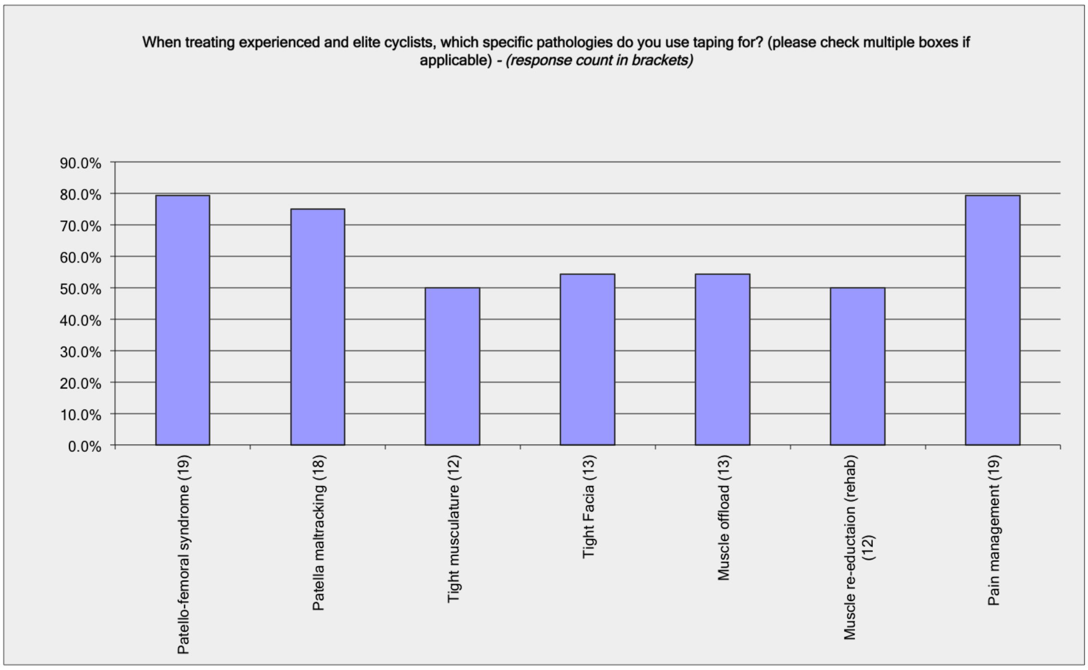

Figure 3.9 Pathologies treated

3.8.6 Formal training

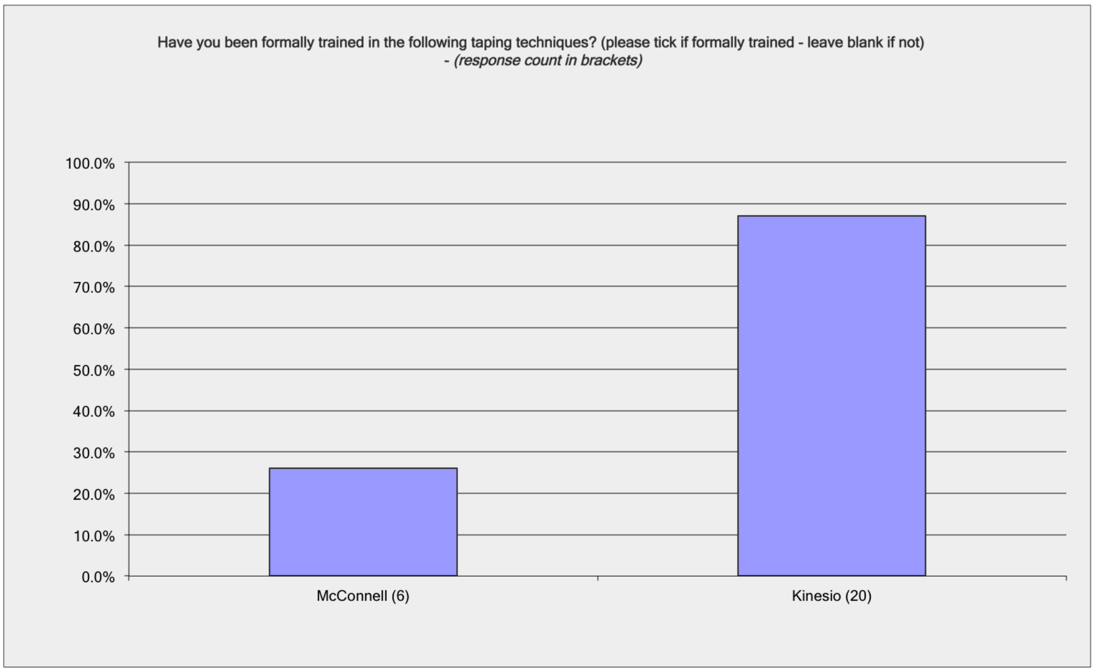

Figure 3.10 Formal training

3.8.7 Neutral/Placebo application

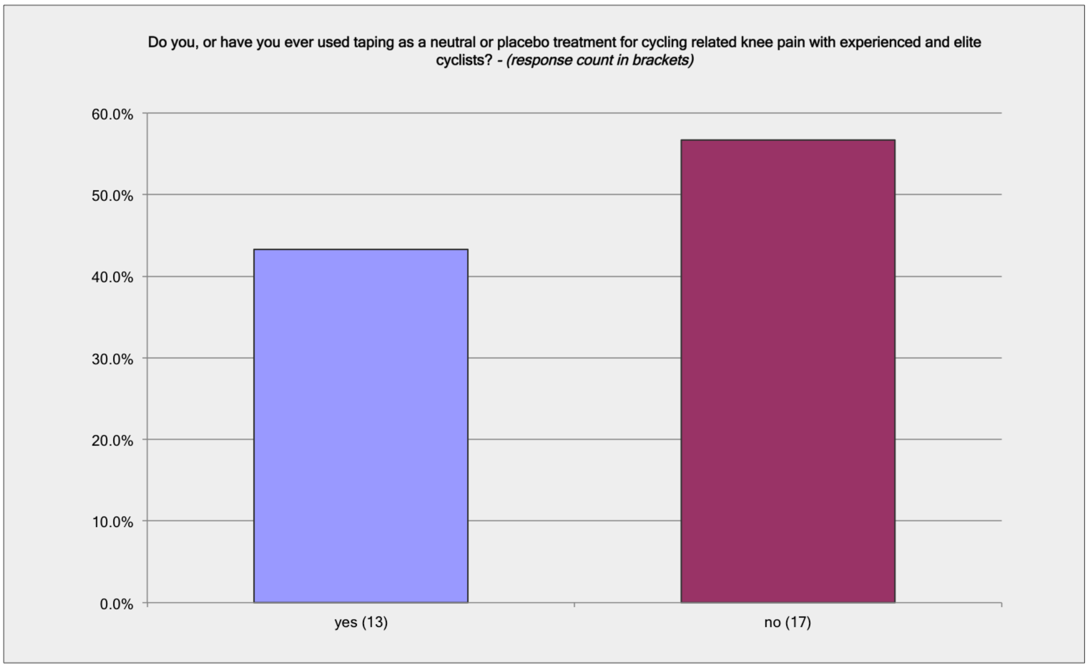

Figure 3.11 Neutral/Placebo taping

3.8.8 Clinical taping success

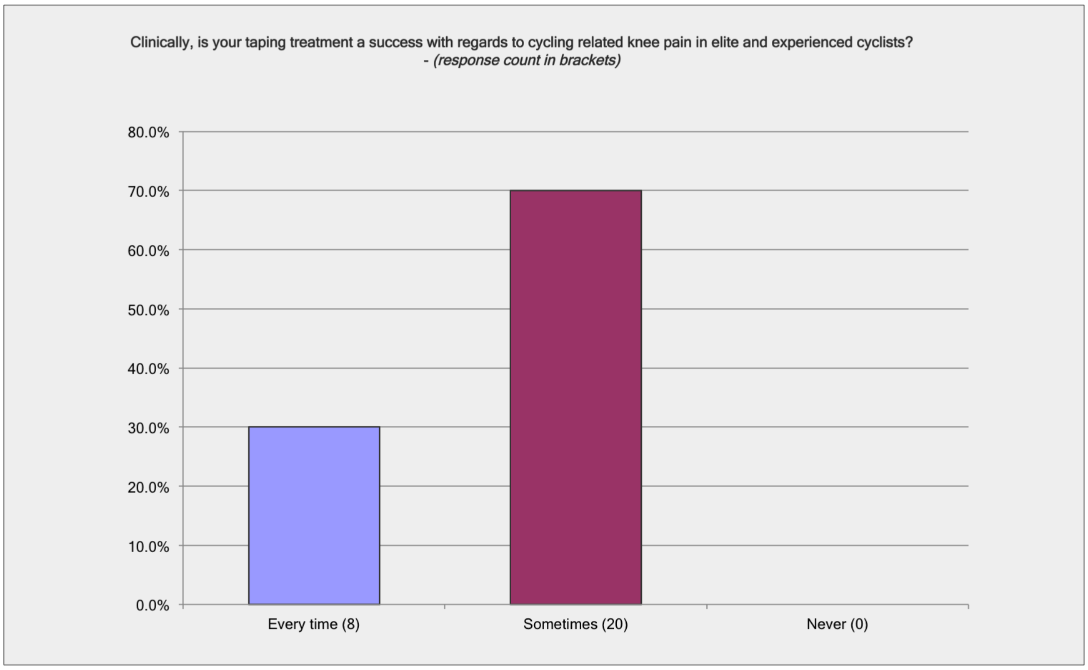

Figure 3.12 Clinical taping success

3.8.9 Measuring success

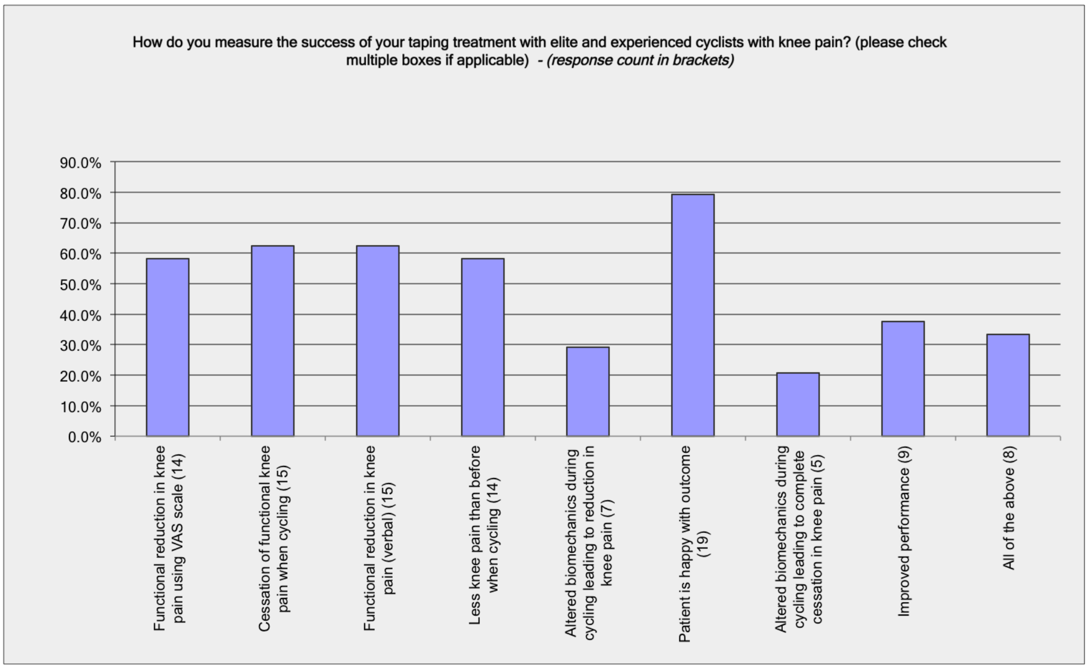

Figure 3.13 Measuring success

3.8.10 Taping effectiveness

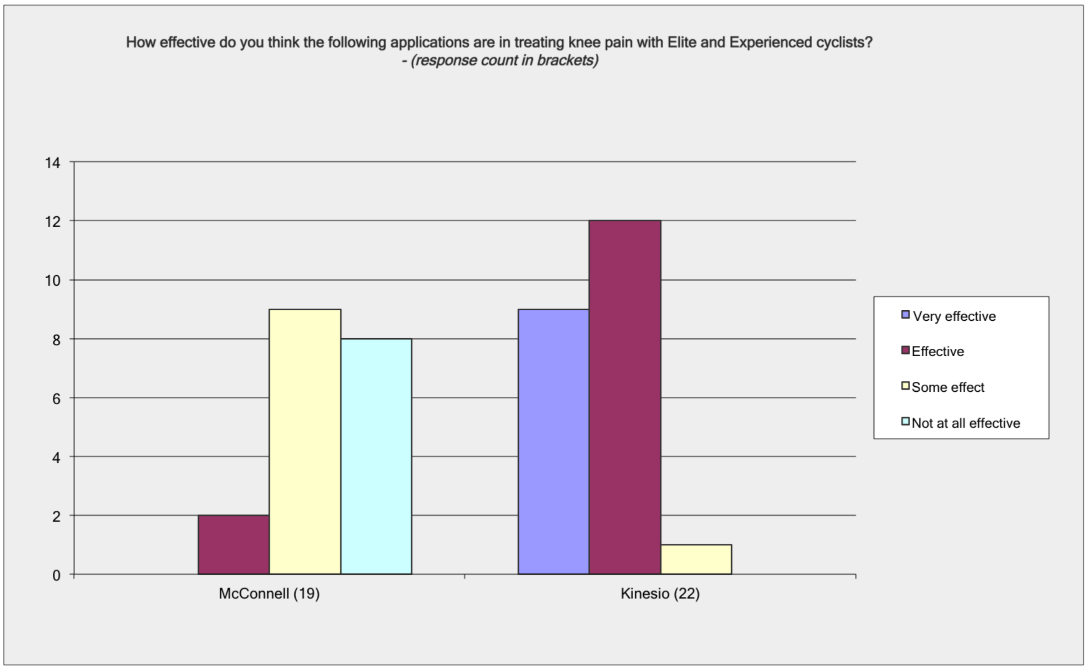

Figure 3.14 Taping effectiveness

3.8.11 Perceived taping effects

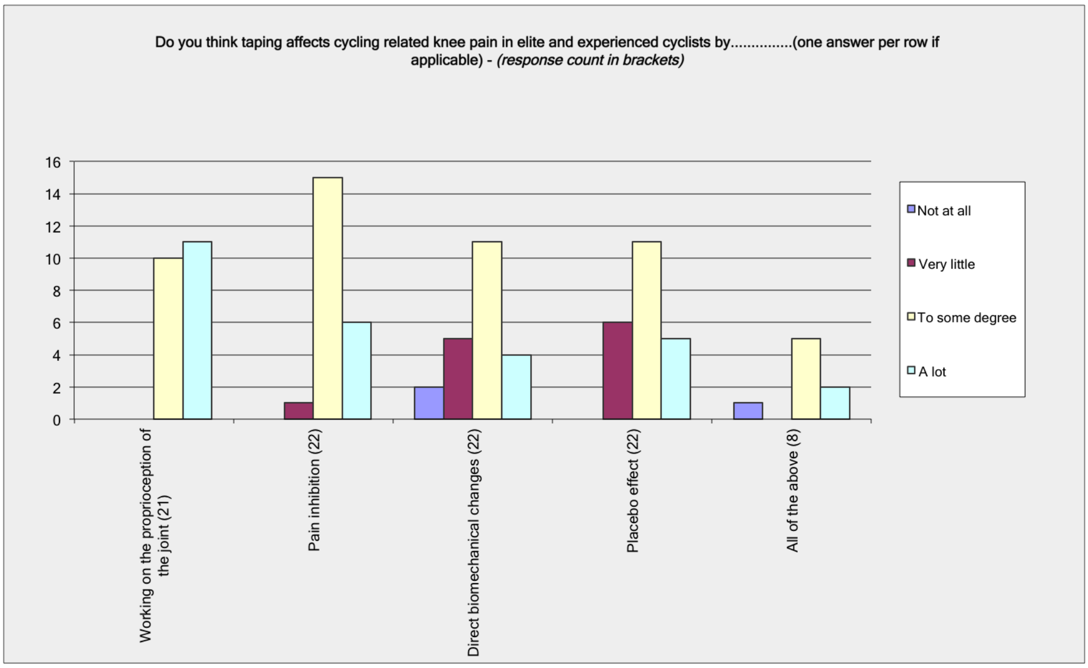

Figure 3.15 Perceived taping effects

3.8.12 Importance of taping effects

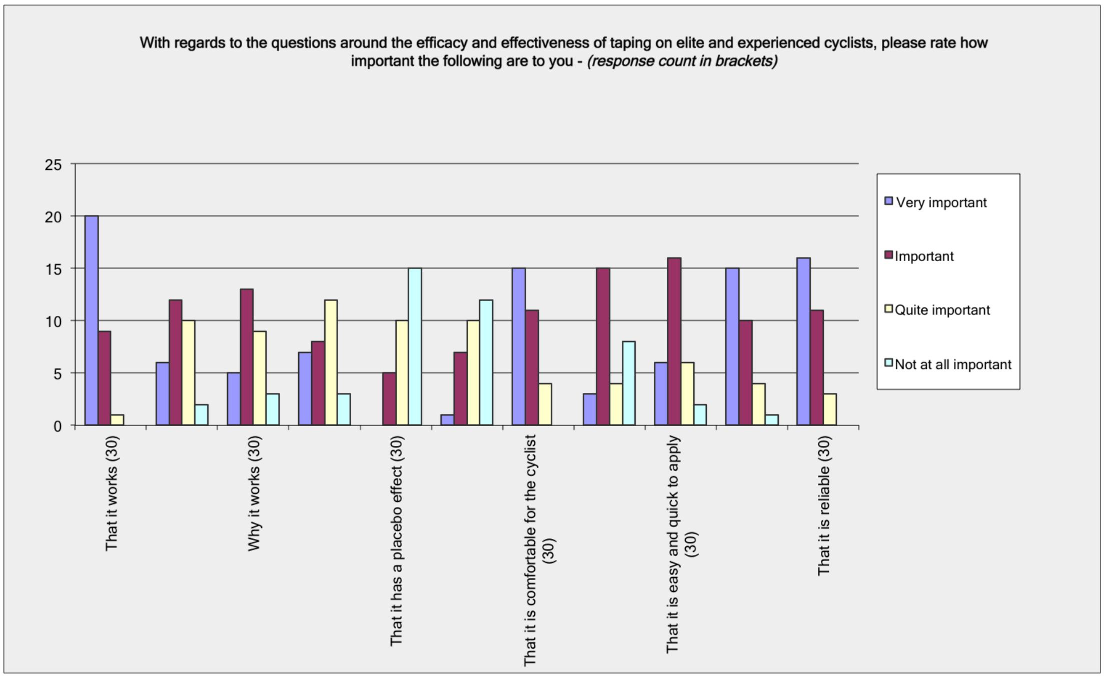

Figure 3.16 Importance of taping effects

3.8.13 McConnell taping use

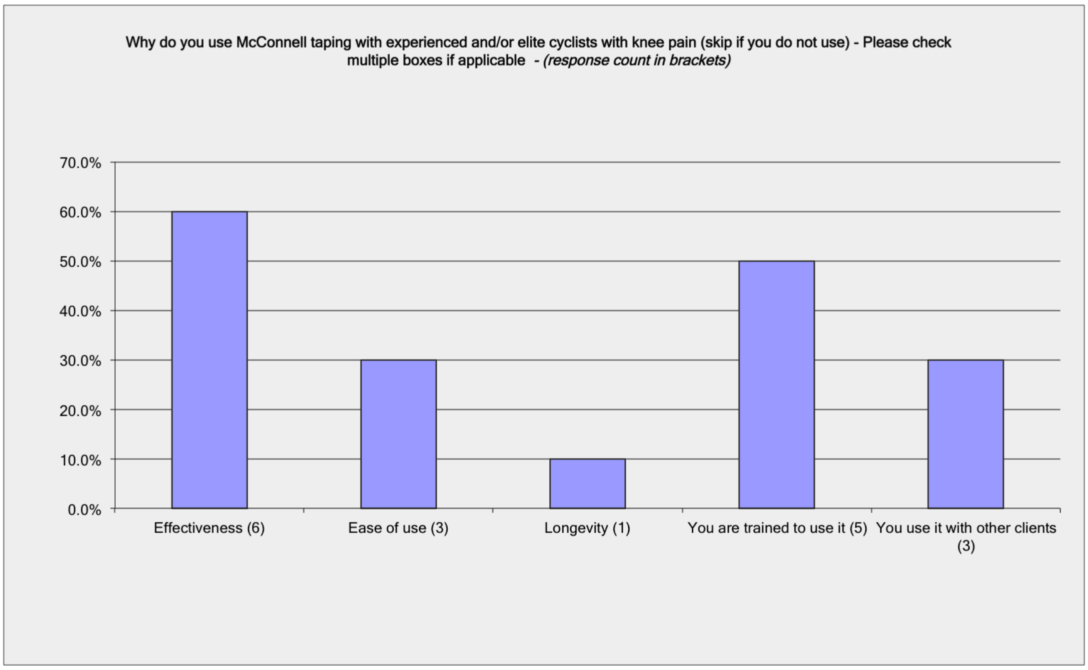

Figure 3.17 McConnell taping use

3.8.14 McConnell technique used

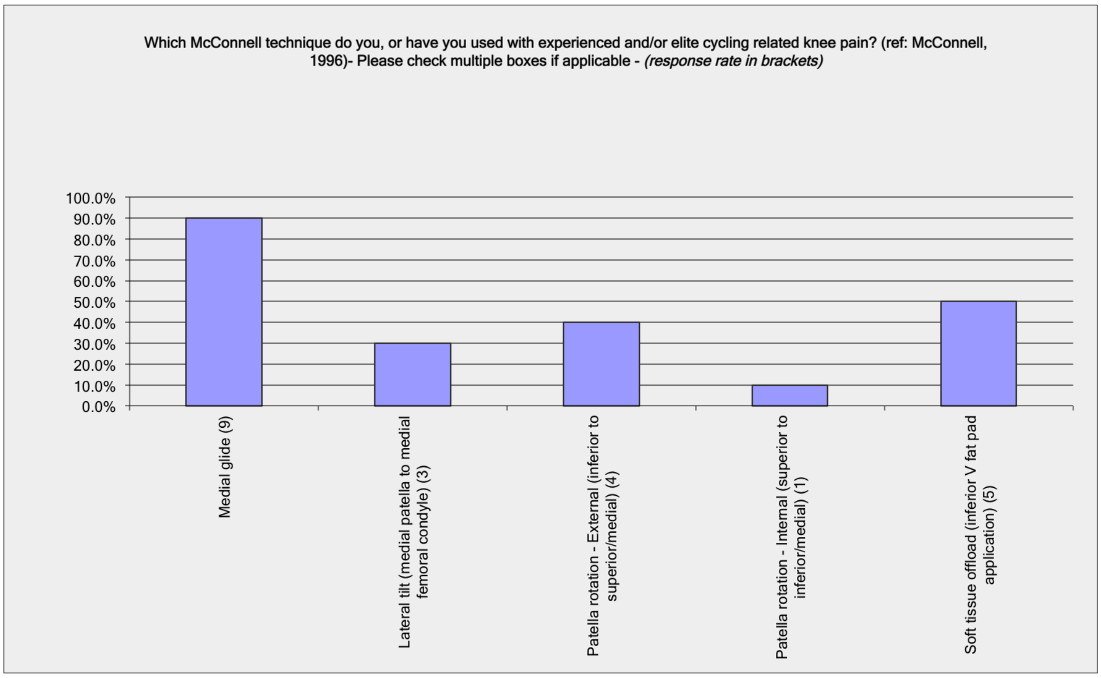

Figure 3.18 McConnell technique

3.8.15 Kinesio taping use

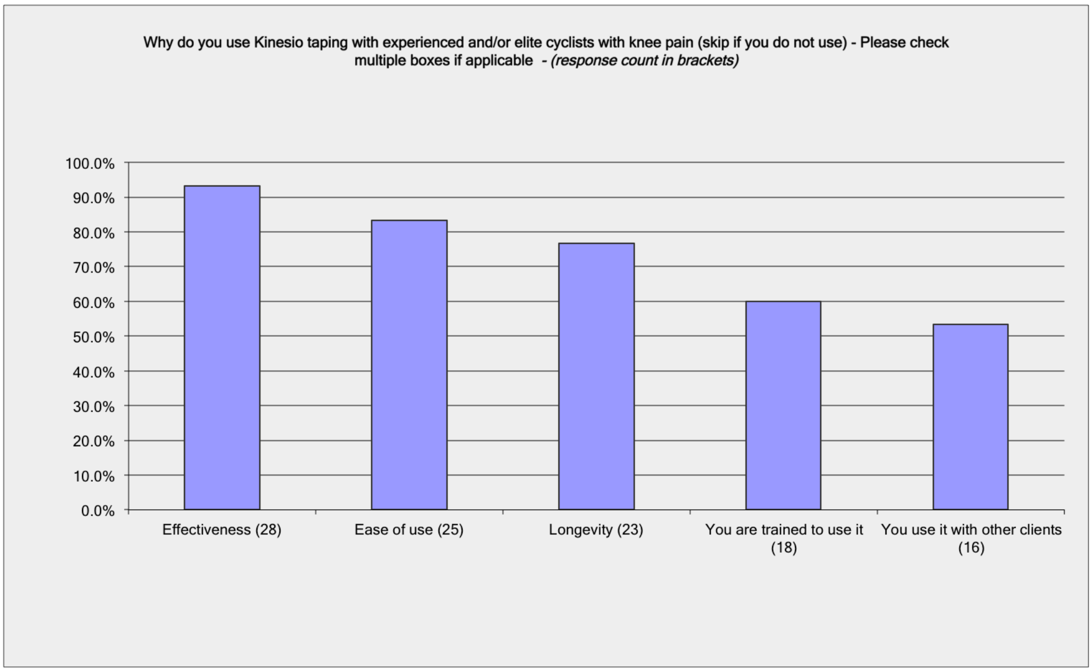

Figure 3.19 Kinesio taping use

3.8.16 Kinesio taping technique used

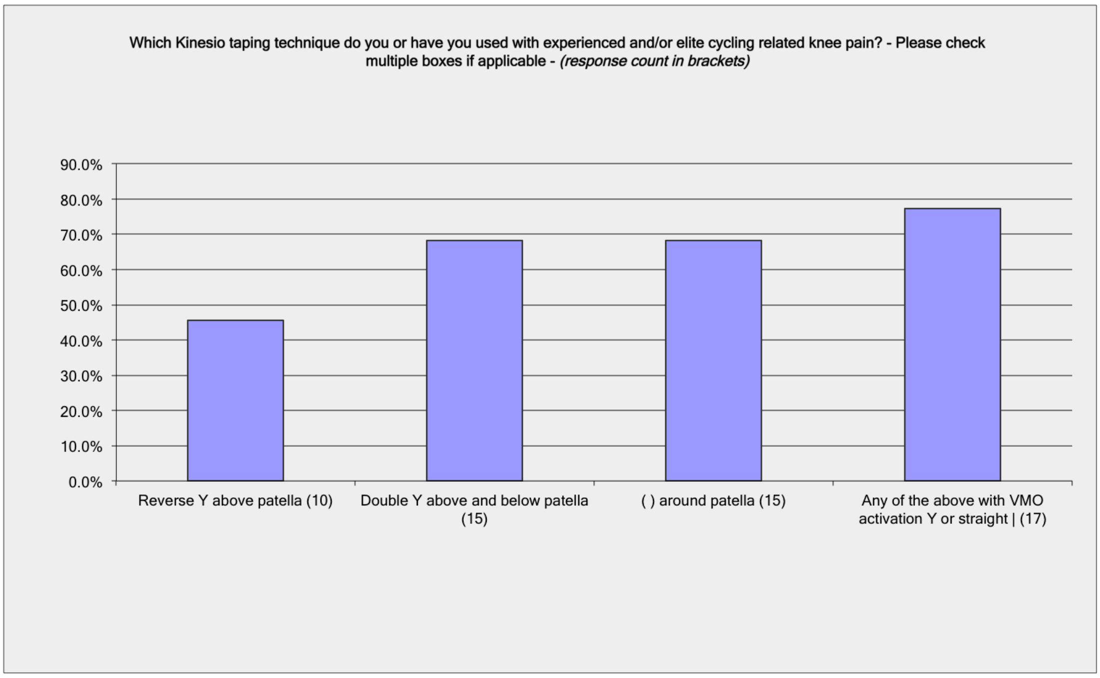

Figure 3.20 Kinesio taping techniques used

3.8.17 Initial examination of results and methodology development

Following the initial examination of the results of the online questionnaire (n=30), the respondents indicated no clear single taping technique preference of taping other than that of apply-test-reapply and adaptation to clinical findings. It was clear however that KTT tape was the favoured taping application with cycling related knee pain in the target group. The initial objective was to conduct further interviews however it was felt that this would not produce any deeper levels of required information relevant to the overall project. Considering the predominance for KTT it was decided that a further single question should be developed to allow the participants to choose their most utilised, or technique of choice with regard to KTT. The same original participants (all completed the final contact and personal details section) were contacted and subsequently completed the additional question. In hindsight, it would have been more effective to include a further specific question around a single preferred taping technique in the original questionnaire, developing on the question around taping techniques used (Figure 3.20). This in turn would have achieved the objective identifying a specific taping technique to be used in the subsequent biomechanical investigation. It is interesting that even with the pilot questionnaire this point was not identified. The single technique question was consequently designed and developed.

3.8.18 Preferred taping technique

It should be noted that there are indeed many variations of KTT technique used in the treatment of cycling related knee pain. The four techniques chosen for the additional question were based on the answers (KTT techniques) given in the initial questionnaire (Section 3.8.16 and Figure 3.20). These were based initially on work by Kase et al., (1998a, 1998b) and developed further from work by Chen et al., 2008 and Campolo et al., 2013. The preferred technique identified was to be used in the laboratory-based study. Both Twitter™ and Tweetdeck™ were utilised to determine a single technique. A direct question via the Twitter™ method would indicate a preference from the clinicians that would determine which technique to test during the subsequent biomechanical study. A specific question was asked to provide a single answer that clearly indicated a preferred taping technique (KTT) with regard to cycling related knee pain (Figure 3.21 and 3.22).

Question: If you were treating a cyclist with patello-femoral knee pain and a supply of appropriate length Kinesiology type tape, which of the following techniques would you choose?

1. Y with reverse Y above and below the patella
2. Simple ( ) with around the patella
3. ( ) with additional U below the patella
4. ( ) around patella with horizontal single strip __ across patella tendon

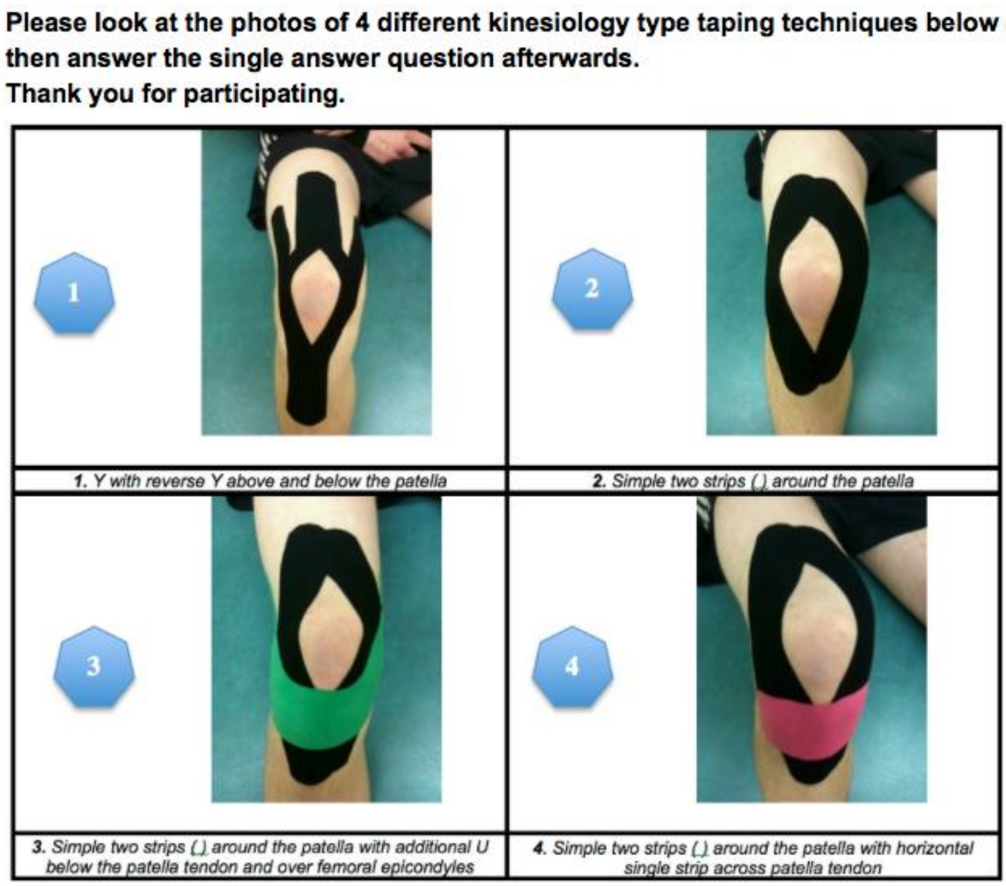

Figure 3.21 Single question figure from questionnaire

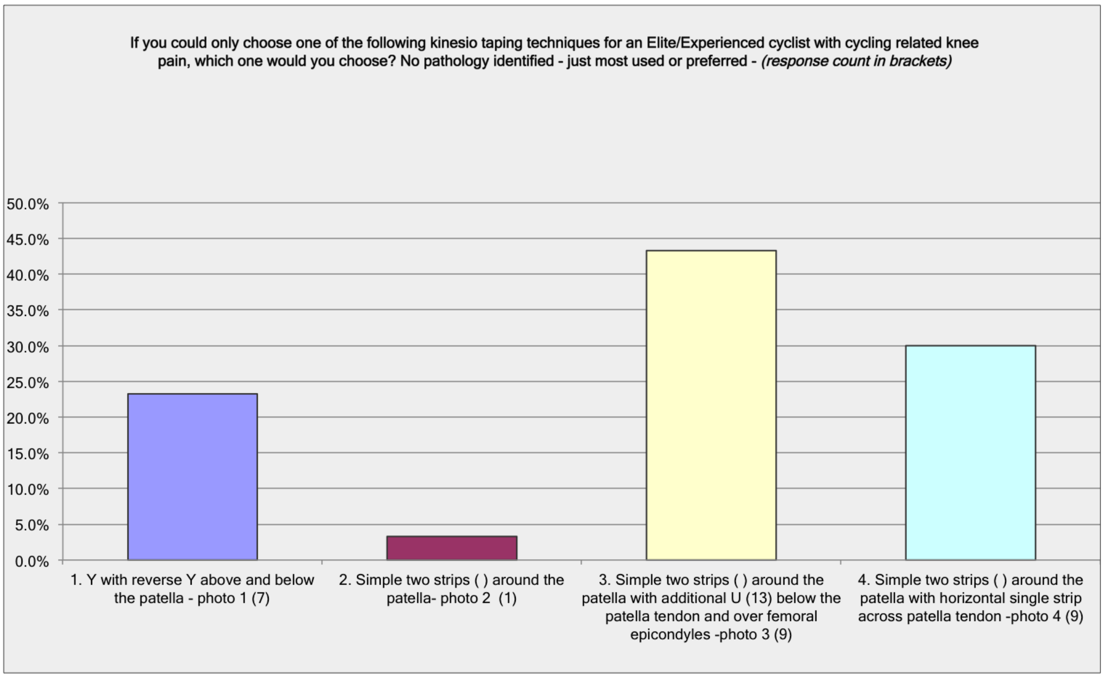

Figure 3.22 Single question results

3.9 Discussion, interpretation and projection towards the subsequent biomechanical study

From the results it appears that there is a clear preference for Kinesiology type taping, both in actual usage and its clinical effectiveness. Over 82% of respondents indicated that they use KTT with cycling related knee pain, compared to 36% who use McConnell taping (Figure 3.5). Although it could be argued that over 30% of respondents also use McConnell taping, there are additional factors that should be considered when determining that KTT is indeed the preferred taping with cyclists. In figure 3.14, 95% of respondents felt that KTT was either effective or very effective as opposed to the 89% of respondents who considered McConnell either not effective at all or to have only some effect. Furthermore, in figure 3.16, when considering general taping effects, 67% of respondents indicated 'that it works' was a very important outcome, and 27% saying this was 'important'. In figure 3.17, of those who use McConnell with cycling (only 30% of total respondents) 60% of these (only 6 from 30 total respondents in questionnaire) felt it was effective at all. Only 30% of McConnell users indicated its ease of use as a benefit and only 10% indicated any degree of longevity. In contrast to this, figure 3.19 indicates that over 90% of respondents felt that KTT was effective, 83% for its ease of use and 76% for its longevity. Consequently it can be concluded that although over 30% of respondents actually use McConnell, most feel that it is in fact limited in its effectiveness and that the additional responses (other than actual usage) are important in concluding which taping type to use in a cycling specific study. Perhaps this evidences that being trained to use a specific technique (predominantly clinically evidenced in ambulatory trials only) does not imply that it is effective in functional use. Providing this evidence from cycling specific clinicians contributes towards the reasoning behind testing a specific taping technique in the biomechanical laboratory based study. This subsequent investigation into the taping used in the specific field of elite and experienced cyclists is a natural progression from the findings from the online questionnaire and will provide clinical relevance for its end users regardless of its outcome. This relevance will be focused on whether specific taping techniques actually have any measurable biomechanical effect on elite and experienced cyclists both with and without knee pain at various resistance and powers. The biomechanical methodology proposed is broadly similar to that used in previously published studies by the author (Theobald et al., 2012, Sinclair et al., 2013b). A simple progression diagram (Figure 3.23) outlines the process from the online questionnaire question through to the biomechanical study.

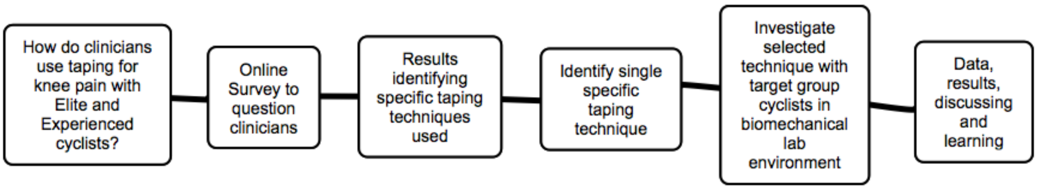

Figure 3.23 Progression from questionnaire to biomechanical study

The low level of effective McConnell tape usage from the questionnaire could be seen to be contrary to clinical practice outside the area of cycling as McConnell taping is a well-evidenced technique used with knee pain (Crossley et al., 2009, Salsich et al., 2002, Warden et al., 2008). It could be argued that the lack of formal training in McConnell taping alongside the more informal approach of Kinesiology type taping application (Section 3.8.6 – figure 3.10) could lead to its low level of usage in the area of cycling. However, in the past few years there has been an upsurge in KTT formal training courses available to all therapists. The training gap appears to have been filled in this respect (Figure 3.10). This training is widely available and marketed online with an abundance of online training videos as opposed to McConnell, which seems to require a more formal approach and is administered by a recognised practitioners' system. The evidence however, as to ease of use, effectiveness and longevity of kinesiology type tape from the questionnaire study (Section 3.8.15 – figure 3.19), based on a small but specific purposive sample of clinicians involved in treating elite and experienced cyclists indicates a clear preference for KTT. These results appear to signpost what is actually happening in the clinical field of cycling related knee pain and provide evidence that McConnell taping does not appear to be used in cycling populations or work well when exposed to the repeated and high degrees of movement that cycling demands.

Clinically the outcome goals (Section 3.8.2 - figure 3.6) from the respondents were broadly in line with the current thinking of classification of PFP (Powers et al., 2012). Pain was the highest specific percentile score at 58.3%, however, from a clinical perspective, 75% indicated that all the outcomes were dependent on clinical findings, which would represent a practical approach to the treatment of cycling related knee pain. The data from sections 3.8.2, 3.8.3 and 3.8.4 emphasised a clear adaptation or apply-test-reapply approach from clinicians' focus when using taping with cyclists. This effectively signifies that the clinician mostly assesses each cyclist in isolation and when appropriate applies the tape, then subsequently tests whether it has had a positive effect on knee pain before re-applying if required. When considered in respect to McConnell taping, which has a large body of evidence, this appears to be in line with accepted clinical practice (Aminaka and Gribble, 2005, Herrington, 2006). That said, its application to kinesiology type tape and resultant outcome measures have not been studied to date and hence cannot be seen as fully evidenced by the literature at this stage. Interestingly with 75% of clinicians using various clinical findings (Figure 3.6) to underpin their treatment protocol, one could possibly question the remaining 25% on how they justify their use of taping. Taping may simply be used as a placebo regardless of functional outcome or merely because the clinicians have been trained in the application and other clinicians use it. The pathologies treated also represented a broad spectrum, but notably again were in line with the current evidence base (Witvrouw et al., 2014, Powers et al., 2012). This wide spectrum of use for taping with all pathologies

(Figure 3.9) scoring within 25% of each other, and all in excess of 50%, underpins the clinically focused responses in section 3.8.2 (Figure 3.6) in that PFP is a multi-factorial pathology that often contains more than one classification in functional presentation.

When interpreting the two different taping techniques (KTT and McConnell) it was notable that clinicians felt that KTT was much more effective than McConnell (Section 3.8.10 – figure 3.14) and further exploration of each technique indicated some rationale behind this result. KTT's longevity scored 76.7% compared to McConnell's' 10%, KTT was 93.3% on effectiveness over McConnell 60% and ease of use for KTT was 83.3% over McConnell 30% (Sections 3.8.13 and 3.8.15 - figure 3.17 and 3.19). In both cases around 50% of respondents said they use the tape simply as they are trained to use it, which may mean that the other 50% have a more clinical focus to use taping or may suggest that formal training purely guides treatment. When considered with the number of clinicians who used McConnell (n=10) over KTT (n=30), then these percentile variances are even more comprehensive in highlighting KTT as the taping method of choice in cycling related knee pain in the target group. McConnell specific clinicians appear to use the medial glide (90%) in preference to the other techniques indicated (Section 3.8.14 – figure 3.18). This appears in line with McConnell's early work and subsequent evidence as to its use and clinical application (McConnell, 1996, Gilleard et al., 1998, Crossley et al., 2000). When questioned on specific KTT techniques used (Section 3.8.16), respondents appeared to utilise varying techniques during their clinical practice. The use of tape around the patella (68.2% - double Y above and below patella and ( ) around patella) would appear to reinforce the final single question

(Section 3.8.18 - figure 3.22) that determined a single preferred technique to take forward into the laboratory-based study. It is noted that there are a multitude of variations of all those techniques indicated and that these techniques also are clinician dependent regarding degree and direction of application. These variances are also applicable to McConnell taping and recognised in the evidence (McConnell, 1996, Crossley et al., 2000), which would support the use of a single clinician (the author) applying the tape in the subsequent biomechanical investigation.

Taping placebo effects were mentioned in three questions (Sections 3.8.7, 3.8.11 and 3.8.12) in order to gain different perspectives on the clinical importance and interpretation. Section 3.8.7 indicates that 43.3% of those asked have used taping as a neutral or placebo treatment and this was supported in section 3.8.11 with 11 respondents from 22 indicating that placebo only had an effect to some degree rather than a lot (Figure 3.16). Interestingly in section 3.8.12 (Figure 3.16), 15 out of 30 respondents measured its importance as not at all important and a further 10 as only quite important which appears in contrast to sections 3.8.7 and 3.8.11. Taken in context each question has its merits from a results perspective, but clinically this could be seen to represent an interesting adjunct as to how taping is used to supplement and support clinical treatment of PFP. Sections 3.8.11 and 3.8.12 developed the taping effects perspective from a perception and importance viewpoint. Interesting to the projected biomechanical investigation's objectives, 11 from 22 (50%) felt that taping provided some degree of direct biomechanical changes to the knee. If we are to project this study (questionnaire) towards and beyond any biomechanical investigation, then the development of future research from reporting any changes in the biomechanics in the knee will be a worthwhile outcome, and will allow clinicians to make evidence based decisions. Also reported in section 3.8.11 was a high perception of proprioceptive effects of taping, with 52.3% reporting it has a lot of effect and 47.6% reporting to some degree (Figure 3.15). Although difficult to measure reliably in cycling this effect undoubtedly will have some influence on the results of any three-dimensional based study regardless of any biomechanical changes reported. To date there does not seem to have been any cycling related proprioception studies undertaken and hence this is a possible area for future work.

Pain was felt to have a large effect and this was reinforced in section 3.8.9 with how the respondents measured success. Here (Figure 3.13), a decrease in both VAS score (58.3%) and functional cycling pain (62.5%) were reported as key measurements clinically. Interestingly the cyclists' degree of satisfaction (79.2%) with the outcome (Figure 3.13) was a major success criterion. This subjective measurement has a direct connection with sections 3.8.8 and 3.8.12 where success (Figure 3.12) is only sometimes (70%) and every time (30%) successful (no respondents reported taping as never successful) and that it works, is comfortable, easy to apply and reliable (Figure 3.16). Here, the results of the questionnaire support the selection of KTT as the tape of choice with cyclists and PFP as it is reported as easy to use, effective and achieving good longevity of use (Figure 3.19) as opposed to McConnell both reporting lower scores and respondents on ease of use and longevity (Figure 3.17).

Sections 3.8.9, 3.8.11 and 3.8.12 outline the variation in perceived outcomes, success criteria and importance of effects with clinicians using taping. This merely reinforces the requirement to understand the effects of taping on the joint involved in the action of cycling. When looking at the combination of these sections (Figure 3.13, 3.16, 3.16) we can see that clinicians measure success predominantly in the effects of taping on pain and, considering that most feel that KTT is very effective, this would indicate that pain reduction is often achieved. The literature supports this, albeit under short-term effects (Gonzalez-Iglesias et al., 2009, Thelen et al., 2008). The importance of pain inhibition and direct biomechanical changes are noticeable in section 3.8.11 (Figure 3.15), which underpins the requirement for the biomechanical study. If we can understand more clearly whether taping elicits changes in the kinematics of the knee and other joints, we can consequently begin to understand whether any pain reduction experienced by cyclists is directly related to biomechanical changes (or not).

When considering the unique contribution in the context of the subject field and methodologies used, the collected data from the questionnaire was not the only area considered. The new and potentially effective way of using the social networking media of Twitter™ produced a direct route to target specific participants and was shown to be a useful mode of recruitment. Even though the sample size of 30 participants could be considered relatively low, the purposive sampling negated a high number or responses due to the fact that the criteria specified both taping and clinical experience with experienced and elite cyclists. In fact the 30 participants represented a very specific group of specialist clinicians who worked with the target group (Section 3.3.2). The use of Twitter™ opens up access to a worldwide audience but requires careful management. This is made possible by selection of who can see information and that they fit the required criteria outlined. It could be speculated that a larger or more open subject field would attract the ‘wrong kind’ of participant and, due to its social nature would produce data that was not from the target group required. Recruitment was undertaken on Twitter™ through direct messaging (DM) and active monitoring of tweeting and re-tweeting (RT). The target groups were monitored using their publically available profiles as to whether they worked in the target area of cycling and physical therapy. Additional information was also collected to ensure target grouping was focused and is presented in table 3.1. Prior screening did not take place in any way and all participants were found to be in the target area. In turn, this requires further development to ensure that any degree of veto adheres to inclusion/exclusion criteria and does not weight or skew the results. The use of social media allows researchers to open up potentially fast and reliable access to target groups to provide quality data that can inform clinical work. Its use in the context of this work alongside recognised networking and recruitment was both effective and productive. Further work to produce recognised methods of using social media for research is required in order to establish its acceptance.

Practical use of taping in cycling is becoming ever more present with media coverage. Alongside this, evidence based practice related questions as to its effects have become more prevalent as this exposure has increased. Cyclists and clinicians asking the question, ‘what does this tape do and how does it do it’, cannot currently be answered with accuracy or authority due to the lack of good quality evidence. Progression from the online questionnaire to the biomechanical study is outlined in figure 3.24.

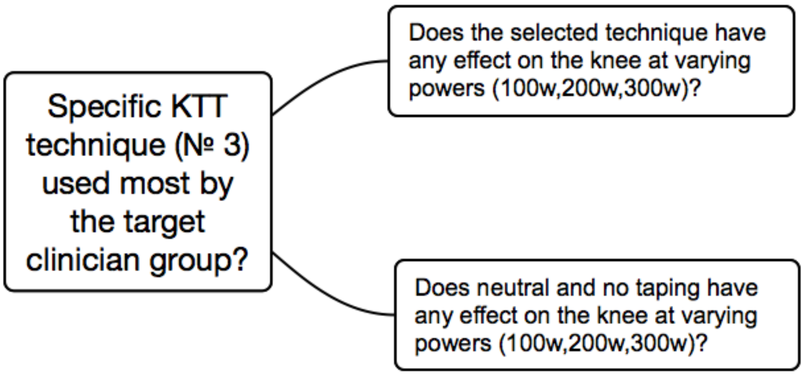

Figure 3.24 Progression from questionnaire to biomechanical study II

From the results of the online questionnaire we can answer the question of which tape is preferred (KTT), clearly however, remaining questions as to its effectiveness and efficacy remain and can be projected to the biomechanical study objectives:

- To measure any biomechanical changes around the knee in elite and experienced cyclists using the previously established taping treatment from the questionnaire at different power outputs.
- To measure asymptomatic cyclists and then compare these results with symptomatic cyclists.
- To determine the potential clinical impact of PF taping by examining the relationship between the efficacy and effectiveness of the treatments.

The results of the initial questionnaire (Section 3.8.16) did not produce a clear kinesiology type taping technique preference to use in the 3D laboratory based study (Figure 3.20). The subsequent single answer question (Section 3.8.18 – figure 3.21, 3.22) determined this technique and thus it was projected to be used in the biomechanical study. It is appreciated that there were in fact two techniques significantly highlighted from the four given, but for clarity it was decided that the predominant technique indicated from the single technique question (Figure 3.22) would be the technique chosen. This represented the majority of clinicians and considering the technique that was next in line (Figure 3.22, n=30%), both could be considered of the same category with only a small difference in design and application (Figure 3.21). With hindsight the questionnaire could have originally been designed differently to reflect this, however the original objectives were reflected in the design and clear outcomes were initially expected. The result of the additional question enabled the laboratory study to be focused on a specific Kinesiology type taping technique and to compare this to a neutral taping technique (Selfe et al., 2011) and no taping.

Considering that the number of clinicians using McConnell taping (Figures 3.5 and 3.18) with cyclists is relatively low (30% of respondents), and its rationale for use (Figure 3.14, 3.16, 3.17,3.19) is somewhat inconclusive/ineffective compared to KTT, its inclusion in the ensuing biomechanical investigation would appear to lack validity. Although 30% of respondents using a taping type (McConnell) could be seen to rationalise its use, it is crucial to take into account that of these 30%, most feel it is of limited effect (discussed initially in this chapter). This effectiveness is deemed very important and KTT related responses not only indicate a much higher percentage usage, but also indicate a very high effectiveness response rate which pre-disposes KTT as clinically much more effective than McConnell tape with cyclists. It is important that the techniques used in the biomechanical study are relevant to practical application in the field. Alongside a KTT technique and a neutral tape the biomechanical study will allow a unique opportunity to investigate how taping affects the knee joint in sagittal, coronal and transverse planes.

The strengths of this online questionnaire revolve around the specificity of the target group of clinicians (respondents) and the resultant information gained as to perceived effects of taping and its use with cycling related knee pain in elite and experienced cyclists. This was designed to enable projection towards the subsequent biomechanical investigation and ensure that the methodology was targeted at the correct taping type, an appropriate taping technique and applicable biomechanical measurement that would produce results focused on the aim and objectives outlined in section 2.5. A limitation could be seen to be an arbitrary low number of respondents (n=30) and, at times, the ability for respondents to answer multiple fields in some questions. When collated, this produced some variation in responses and initially some lack of clarity, especially with the KTT technique type (Section 3.8.16 – figure 3.20). However, this was addressed with the subsequent single question (Section 3.8.18). In conclusion, the specific online questionnaire addressed its objectives in design and scope, informed the subsequent biomechanical study of the type of taping to use (KTT) and in addition reported key perceived effects and uses of taping (pain and biomechanical changes at the knee).

Key points to inform the laboratory based biomechanical study:

- KTT identified as the preferred taping used with PFP in elite and experienced cyclists.
- McConnell is not used extensively so therefore does not require inclusion.
- Specific KTT technique to be used in the lab-based study was identified.
- Pain, proprioception and biomechanical changes are the main perceived effects of taping with cyclists and PFP.
- Placebo (neutral) taping also has a perceived effect and application and therefore should also be included in the biomechanical study as a comparison to KTT specific technique.

CHAPTER FOUR – Biomechanical Laboratory-Based Investigation

To investigate the biomechanical efficacy and clinical effectiveness of patella taping treatments in elite and experienced cyclists with and without Patello-femoral Knee Pain.

4.1 Development of Laboratory-Based Study Question

The initial question was developed from a patient's enquiry during treatment. Following taping a cyclists knee, and simply stated as 'what does this tape do then'? The answer was 'I honestly don't really know'. The development stage of the study spanned a further six months of discussion and resulted in a formal presentation to the University. Previous work (Theobald et al., 2012, Sinclair et al., 2013b) provided a broad template as to how the laboratory based study would be undertaken and its exact development was determined through further testing and pilot work (Section 4.2).

4.1.1 Considerations from the clinician online questionnaire

The questionnaire results highlighted some outcome measures (notably pain and proprioception) that were not possible to measure reliably during the laboratory-based study. Pain was a priority outcome measure and with the symptomatic cyclists this was covered with a numerical pain scale measurement. It was noted that 30 seconds of cycling (per test - 9 in total) might not indicate a true reflection of pain scores as often the onset of pain comes with time and fatigue. Neither factors were possible to measure during this study due to design. Proprioception was also not possible to measure accurately during the biomechanical study due to the nature of the testing and current unavailability of reliable proprioception testing protocols whilst on a static bicycle. Figure 4.1 outlines the simplified considerations from the qustionnaire when projecting the findings.

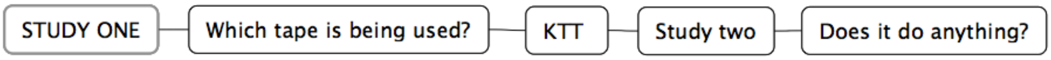

Figure 4.1 Online questionnaire considerations

4.2 Pilot study and Development of Methods

In order to determine the final protocol of the biomechanical investigation, the following pilot study work was undertaken (Figure 4.2).

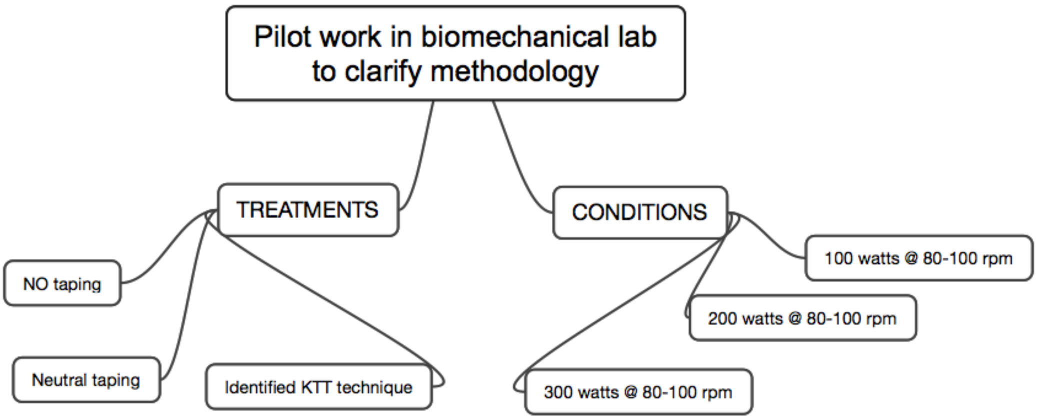

Figure 4.2 Biomechanical study - pilot work

4.2.1 Introduction

To establish the exact protocol for the laboratory based study testing, a pilot study was deemed useful in order to practice set up procedures, testing equipment, data capture and analysis. This learning would be projected to the main study to ensure smooth running, reliability and repeatability. Ethical approval from UClan Faculty of Health & Social Care Ethics Committee (BuSH 107) was gained in the autumn of 2012.

4.2.2 Participants

Five healthy participants were recruited and measured in the Movement Analysis Laboratory at the University of Central Lancashire (UCLan) across three separate dates. This allowed for testing of equipment set up, software familiarisation, testing of taping technique/application and development discussions around methodology with participants and supervisors. The subjects were all male, which removed any gender variables that may exist such as supplementary issues related to PFP incidence (Boling et al., 2010). Pilot participants had a mean age of 34 (SD 3.53) and range of 29-38, a mean mass of 76.2 kg (SD 6.26) and range of 66-82 kg. Subsequent data analysis was for familiarisation purposes only and none of this original data was used in the main study data. Two of the pilot study participants were however re-tested in the main study as asymptomatic participants. The participants for the pilot study were elite or experienced cyclists from both the cycling community and university staff and conformed to the criteria of this study (Section 4.4.3).

4.2.3 Methods

Overview

The methodology for the pilot testing had been broadly developed in previously published work by the author (Theobald et al., 2012). This work differed in that it used PF bracing and McConnell taping techniques at varying powers (lower than utilised in this study) and a single set cadence (80rpm) to investigate effects around only the knee, and specifically with asymptomatic cyclists. Measurement of power and cadence used different equipment from this proposed investigation, however it largely established a base-line working method, familiarisation of lab set up and calibration for cameras, which in turn required much further development during this pilot work.

4.2.4 Cycle ergomentry

The testing comprised the participants personal bike being attached to a Tacx™ turbo trainer (Tacx™, Wassenaar, Netherlands - figures 4.4 and 4.6), which allowed the rider to be studied while cycling in a static frame. Each participant used a standardised rear wheel to maintain continuity on static trainer resistance performance (Figure 4.6). Tyre pressure was checked and maintained at 100psi in accordance with the static trainers manufacturing recommendations (Tacx™, Wassenaar, Netherlands). Participants' personal bikes were used in order allow a more field based representation of the cyclist's cycling action. A single wheel skewer from the turbo trainer manufacturer was used during every test, this ensured a safe and stable fixation of the bike to the trainer frame. An associated riser block (Figure 4.4) was also used to raise the front wheel of the bike to the level of the rear trainer frame (Figures 4.4 and 4.6).

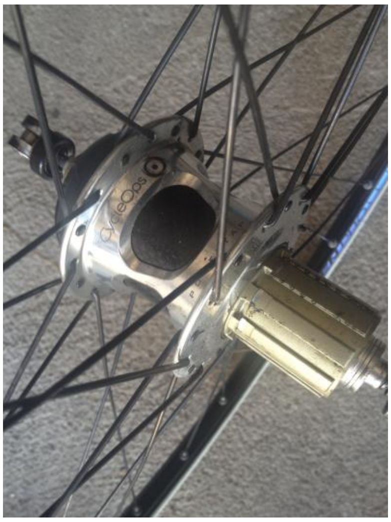

Figure 4.3 Powertap™ wheel

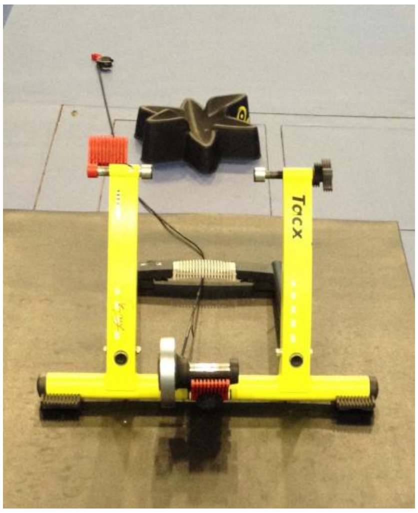

Figure 4.4 Tacx ™ trainer and riser block

Figure 4.5 Garmin 510™ & mount

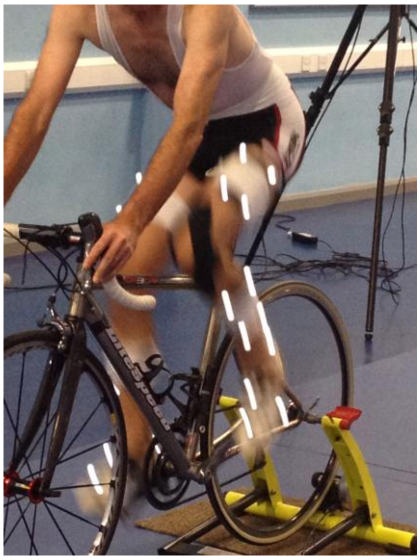

Figure 4.6 Tacx ™ static cycling trainer

4.2.5 Power and cadence measurement

Power and cadence were measured in watts using a Cyclops Powertap™ hub (Saris Ltd, Madison, USA) built onto a Mavic open pro 700c rim (Mavic SAS Ltd, Metz, France - figure 4.3), (Bertucci et al., 2005a, Duc et al., 2007, Hurst and Atkins, 2006). Power and cadence ‘on bike’ measurement and monitoring was via a Garmin 510 ANT+ (Garmin Ltd, Kansas, USA). The study specific Garmin™ 510 sensor was fitted to the participant’s bike using an ‘out front’ clamp for the handlebars (Figure 4.5). Cadence was measured through the Powertap™ hub (Figure 4.3). Power testing was at 100, 200 and 300 watts to represent a broad range of power production for elite and experienced cyclists, and in line with previous research (Bini, 2012, Tamborindeguy and Rico Bini, 2011, Bailey et al., 2003, Mora-Rodriguez and Aguado-Jimenez, 2006). Visually this was monitored by a 3 second average by the participant (Garmin™ 510 sensor) to maintain constant power allowing the cyclist to assess and monitor accurately during the test. Cadence for the pilot work was initially fixed at 90 revolutions per minute (rpm) using a Garmin™ 510 sensor with Powertap™ wheel (Mora-Rodriguez and Aguado-Jimenez, 2006) (Callaghan, 2005b). Further development of this cadence measurement can be found in section 4.3.

Taping conditions were Kinesiology type taping application (from online questionnaire study), neutral taping technique (Callaghan et al., 2002, Selfe et al., 2008, Selfe et al., 2011) and no taping. See section 4.7 for specific application methods.

4.2.6 Movement analysis system

Camera location and positioning

The Movement Analysis laboratory was located in the Brook Building at The University of Central Lancashire, Preston, UK. The three-dimensional kinematics were captured using a ten-camera Oqus 3 motion capture system (Qualisys AB Medical, Sweden). The cameras were placed in a broad circle around the participant (figure 4.7). In the initial trials the camera positions were determined in order to be far enough away (from the bike) to capture the full volume of the participants' pelvis and lower limb movements, whilst seated on the bike, at the same time close enough to maximise camera resolution.

The camera placement was developed from previous studies by the author (Theobald et al., 2012, Sinclair et al., 2013b) and during the pilot studies. A large proportion of the markers used during these studies were on the lower limbs of the participant. The camera height was adjusted for each participant; consequently lost tracking of the markers was not a significant problem. Prior to calibration, the cameras were positioned as close as possible to ensure minimal data loss during collection and improve tracking accuracy. Experimentation of the height variations that would produce the most reliable data took place across three pilot tests. From this it was determined that each individual would require a different camera height, depending on their bike size and personal height. After each initial test the data points were checked through the 30-second test to maximise tracking accuracy and analysis. The goal was for 100% capture of all markers. The daisy chain method of arranging the cameras linked the cameras sequentially (Figure 4.7). Each infra-red camera captures data when a marker lies within its field of detection. In order to track a specific marker two or more cameras were required to triangulate the marker's 3D co-ordinate position within the data collection area. With this set-up each marker could be seen by at least three cameras. Hence loss of data from any one camera would have a negligible effect on the data overall.

Figure 4.7 Movement analysis camera set up (UClan)

Camera set-up and camera sampling frequency

A capture frequency of 250hz was selected in line with previous studies into both cycling and lower limb three-dimensional movement studies (Fonda et al., 2015, Momeni et al., 2014, Richards, 2008, Sinclair et al., 2012, Winter, 2005). Although the highest important frequency to measure the coronal and transverse planes of movement in order to capture the subtle movements in the coronal and transverse planes is not currently known, this sample frequency allows maximum possible measurement frequencies up to approximately 165hz. At 80rpm the cyclist produced 1.33 revolutions/seconds, which in turn produced 333 samples per revolution. With 30 seconds of data collection time this produced 7,500 frames of data per test. Thus, according to the Nyquist sampling frequency, 250 Hz was deemed more than adequate to assess important movement patterns during cycling.

The variety of reflective markers and marker clusters (figure 4.8) were placed in the data collection area on the saddle of the bike and surrounding floor area to ensure the cameras would collect data at the required height. The threshold values for the camera system were adjusted manually on each camera to allow clear visualisation of each of the markers to avoid any merging or missing markers. This enabled accurate tracking of the markers during the study. Any reflective articles or surfaces in the collection area were covered (example in figure 4.13, right posterior upper femur) to avoid “ghosts” during data collection. These included items such as reflective material from cycling clothing, reflection from metallic sections of bike etc.

Figure 4.8 Reflective markers

Calibrating image space

To determine that the area covered during this calibration covered the movement volume of the pelvis and lower limb markers placed on the participant, the capture system and the data collection area was evaluated prior to testing, as per the manufacturer's protocol and previous studies (Theobald et al., 2012, Sinclair et al., 2013b, Richards, 2008, Selfe et al., 2008, Whatman et al., 2011). Prior to the wand movement testing a metal right-angled frame (length 750mm) with markers permanently attached was positioned in the data collection area in line with a fixed force platform to orientate the laboratory co-ordinate system (Figure 4.11). Following this, by moving a wand of markers (Figure 4.11) of known length (298.1mm) through a number of movement patterns (straight lines, figure of eight and stirring actions - figures 4.9 and 4.10), the movement volume was calibrated by the software.

Figure 4.9 Wand movement of calibration

Figure 4.10 Wand movement in testing area

The laboratory co-ordinate system was positioned XYZ cardan sequence in line with The International Society of Biomechanics (ISB) Joint Coordinate System (Winter, 2005, Wu et al., 2002), the positive x-direction was orientated forwards in front of the cyclist, the positive y-direction positioned to the left of the cyclist and the positive z-direction orientated upwards towards the roof in relation to the cyclist (Figures 4.21, 4.22 and 4.24). This co-ordinate system is in keeping with previous published studies (Sinclair et al., 2014, Sayers and Tweddle, 2012). The maximum error in the calculation of the wand trajectory over 30 seconds of data (the residual value) during any trial, and irrespective of movement, was 0.8mm. The software manufacturer QTM, state that a residual value of less than 2mm is acceptable for data collection. Consequently, the accuracy of the data collected in this study lies within the manufacturer's recommended limits.

Figure 4.11 Calibration set up and calibration wand/frame

Data filtering

In order to eliminate errors (or noise), filtering the data is required in order to leave the true signal unaffected (Winter, 1990). This ‘noise’ is deemed low frequency and so in order to allow the higher frequency (marker movements) to be accurately determined the 4th order zero-lag is utilised (Yu et al., 1999).

The kinematic data in this biomechanical study was filtered using a 4th order 10 Hz Low-pass Butterworth digital filter cut off frequency, previously determined as suitable for the impact phase of movement based investigation (Sinclair et al., 2013a, Yu et al., 1999, Hanaki-Martin, 2010). This smoothing or filtering operation was undertaken in order to remove small random digitizing errors.

Anatomical modeling and marker sets

Reflective markers were placed on the foot, shank, thigh, and pelvis based on the Calibrated Anatomical System Technique (Cappozzo et al., 1997). From this the anatomical frame was defined. See figures 4.18 to 4.23 for detailed marker placement and Qualisys screenshots. Kinematic data were exported to Visual3D (C-Motion Inc, USA). Passive reflective markers were placed on participants to reconstruct the movement of the underlying bone in three-dimensional space. The cycling model was based upon the Calibrated Anatomical Systems Technique (CAST) (Cappozzo et al., 1997) whereby a rigid cluster of at least three non-collinear markers is used to track the movement of a body segment. These are referenced to the anatomical end-points of a segment by the means of a static calibration.

Marker placement

It was essential to test the protocol of marker placement for both longevity and reliability, alongside consistent visibility to the cameras. Pelvic clusters, femur and lower shank marker plates and movement related single markers (figure 4.8) were secured by both double-sided tape and appropriate lengths of super-wrap (Figures 4.12 to 4.15).

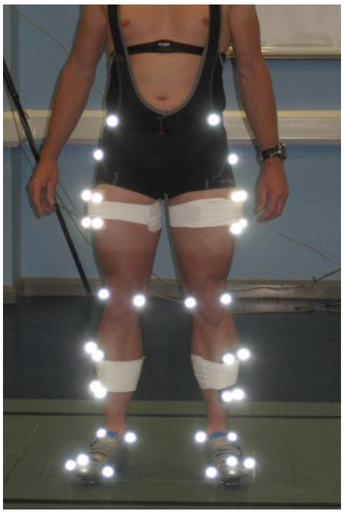

Figure 4.12 Anterior markers

Figure 4.13 Posterior markers

(2x PSIS and pelvic cluster indicated)

Figure 4.14 Lower shank markers

Figure 4.15 Shoe/foot markers

Measuring the pelvis was important when comparing joint movements and therefore marker placement was crucial. Locating single dynamic placement markers on the Anterior Superior Iliac Spine (ASIS) proved unsuccessful as the action of cycling in relative hip flexion caused the markers either to become unsighted or drop off. Hence, during the testing, a pelvic cluster with four markers was used but was also initially prone to some movement, which led to inaccurate tracking and inter-testing reliability. This was assessed by cross-referencing each marker set (within Qualisys™ software) when the plate positioning was judged to have moved by either the author or participant.

Adhesive markers were also placed above and below the plate to indicate any movement visually after each test. Subsequently a longer securing belt was utilised, and this longer wrap of belt provided a more secure placement, which made the movement more negligible. This was preferable to repeating any static testing and ensured that the testing process was both optimised for the participant and accurate with regard to measurement and analysis. Initially, to provide potential upper body positional mapping, acromial markers were included. As these proved difficult to maintain with movement inter-tests they were deemed surplus to requirements for this study and were abandoned as a useful measurement placement.

A single clinician applied the markers to ensure consistency and therefore reducing intra-operator error (Cappozzo et al., 1997, Bini and Diefenthaeler, 2010).

Anatomical model

Detailed annotated representation of these markers can be found in figures 4.19 to 4.21. To generate the anatomical model of the markers participants stood in the centre of the movement area in the anatomical position (Figure 4.16, 4.17). A static calibration was then recorded for one second. This allowed the computer software to produce a calculated model of the skeleton for visual interpretation, and define the anatomical body segments (figure 4.18).

Figure 4.16 Static markers

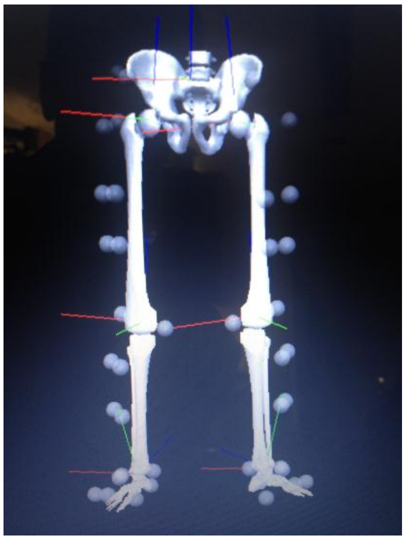

Figure 4.17 Static Visual 3D

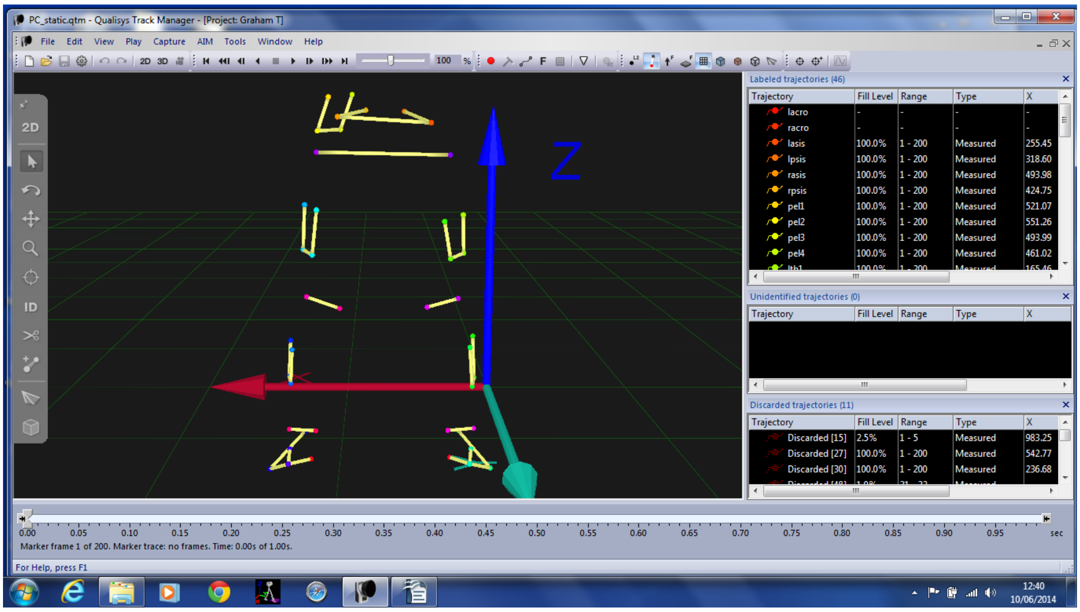

Figure 4.18 Anterior QTM screenshot - Static

Post anatomical model calibration the malleoli, epicondyles, medial foot, greater trochanter and anterior superior iliac spine (ASIS) markers were removed (Figures 4.19 and 4.20). This was for two reasons. Firstly, it was likely that some of the medial markers would come into contact with the bike during the testing and, secondly, these markers were only required for the anatomical model. **Note**: The ASIS markers were not initially removed but during pilot work they were either lost due to hip flexion during testing or fell off. Their removal did not affect data collection or the modelling process due to the use of the pelvic cluster.

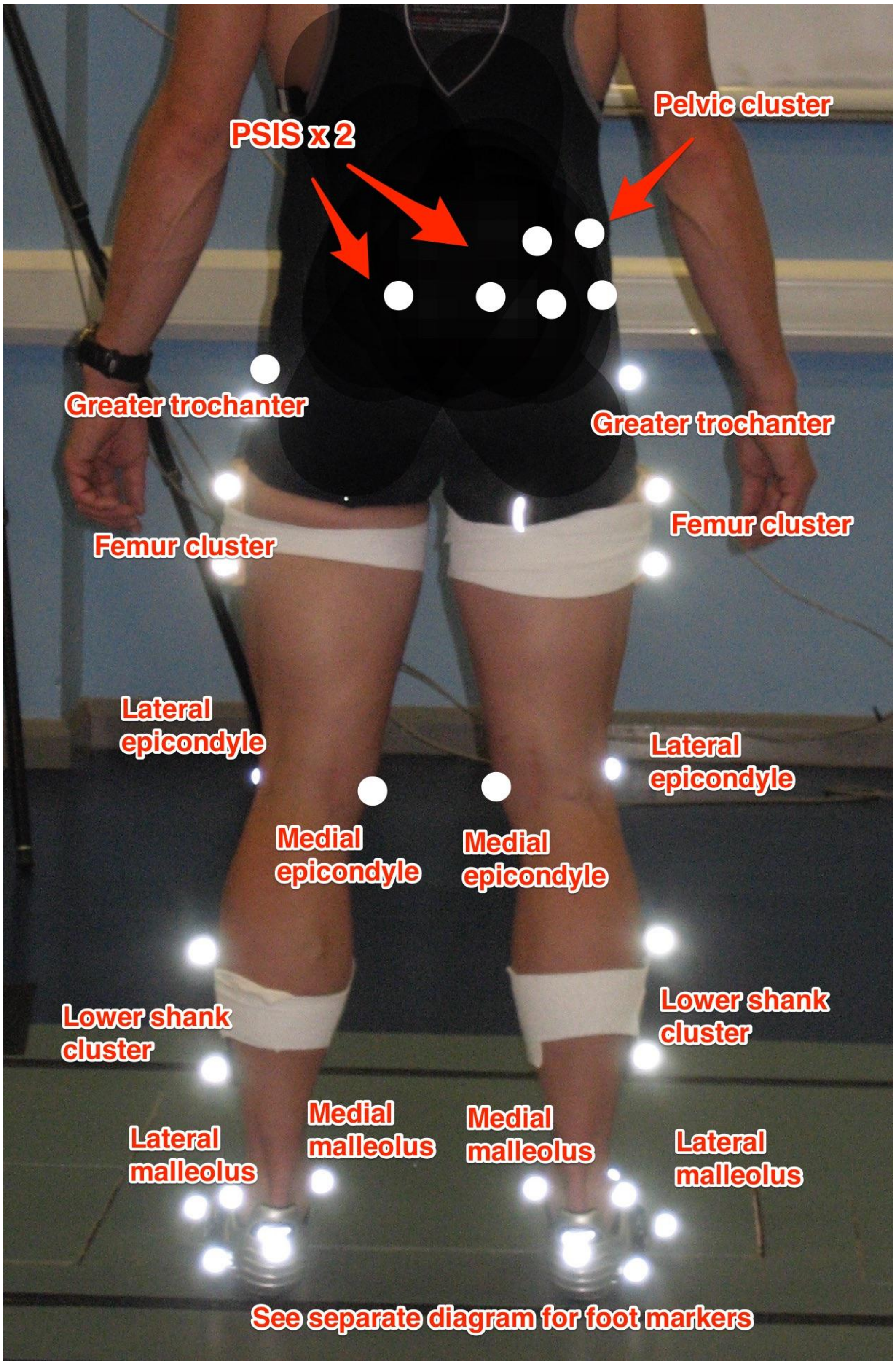

Figure 4.19 Detailed posterior markers

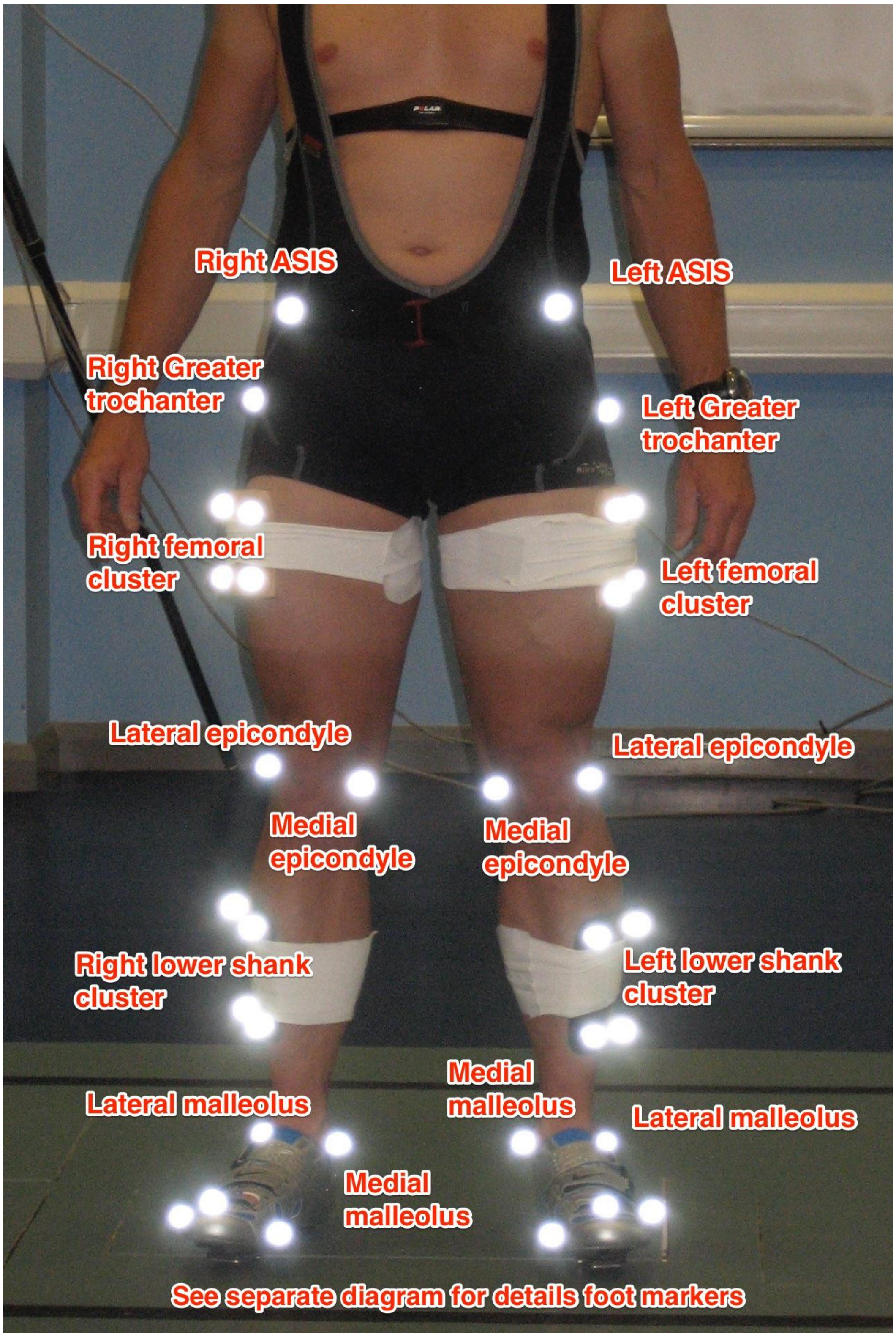

Figure 4.20 Detailed anterior markers

Figure 4.21 Detailed shoe markers

The resultant dynamic marker set is outlined in detailed annotated figures 4.22 and 4.23. Each segment was defined by anatomical markers/clusters situated proximally and distally to the knee. The ankle/foot was defined proximally by lower leg/shank (tibia/fibula) cluster and distally by medial/lateral forefoot, superior forefoot, and calcaneus. The knee was defined proximally by the femoral cluster and distally by the lower leg/shank (tibia/fibula) cluster. The hip was defined proximally by the pelvic cluster and PSIS and distally by the femoral cluster.

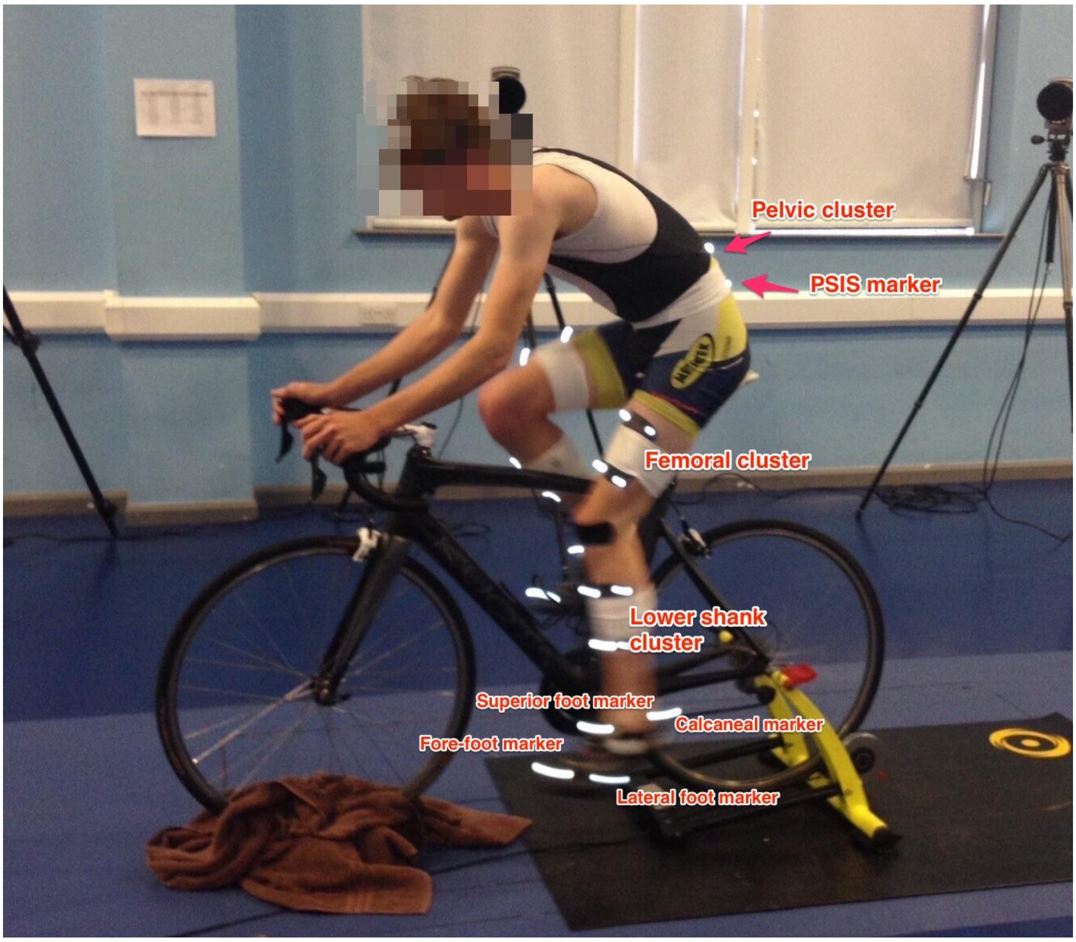

Figure 4.22 Dynamic markers

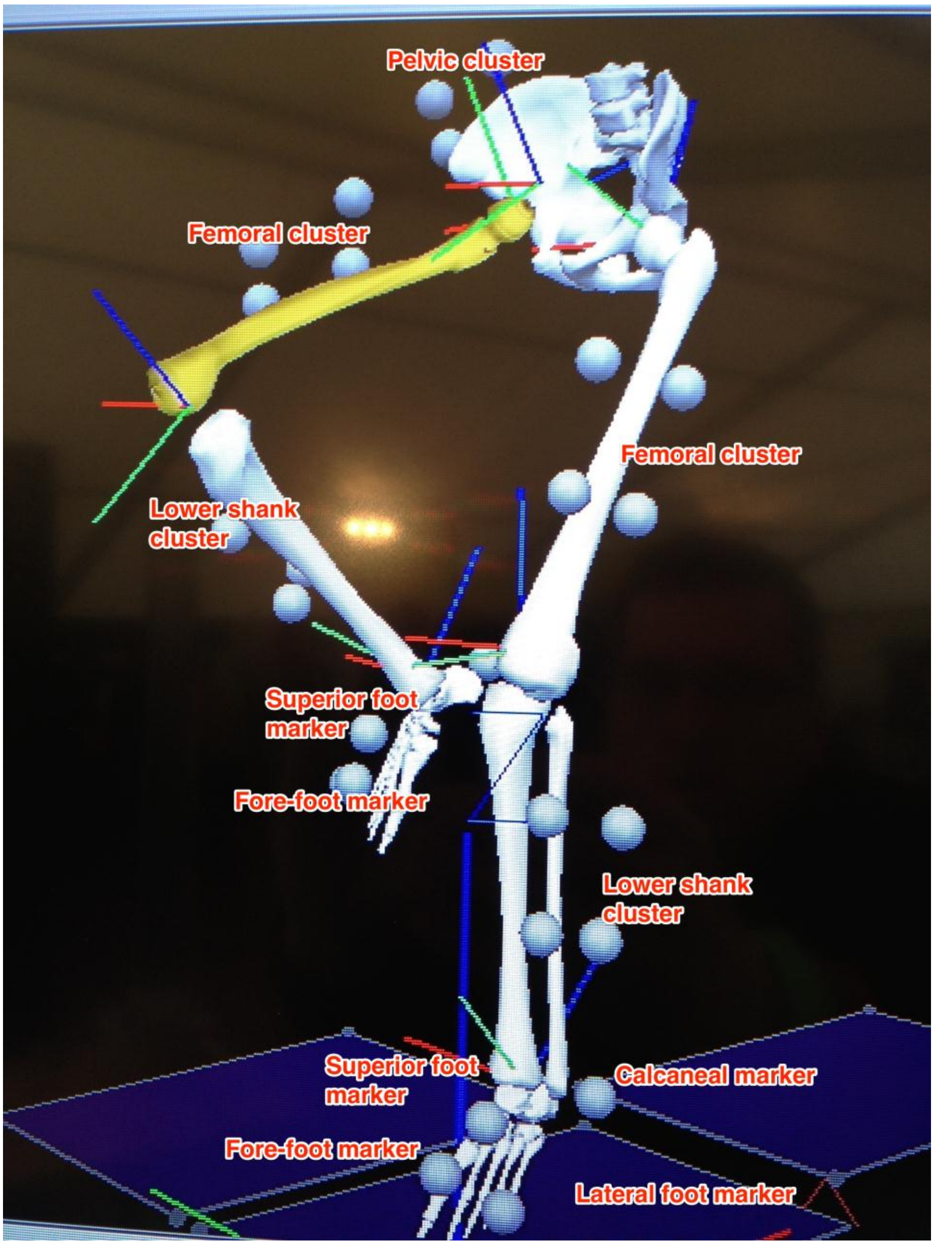

Figure 4.23 Dynamic Visual 3D

Calculation of joint angles

Joint angles are defined as the orientation of one segment relative to another segment. Because we are working with three-dimensional space, there are a series of rotational transformations involved in the calculation. Visual3D (C-Motion Inc, USA) allows the user to choose any two segments in which to measure a joint angle. These do not always have to be connected. In practice, joint angles are calculated as the transformation from one segment (A) to another segment (B) using the local coordinate system of segment B as the frame of reference. Figure 4.24 is a screenshot example from Visual 3D for calculation of right knee angle.

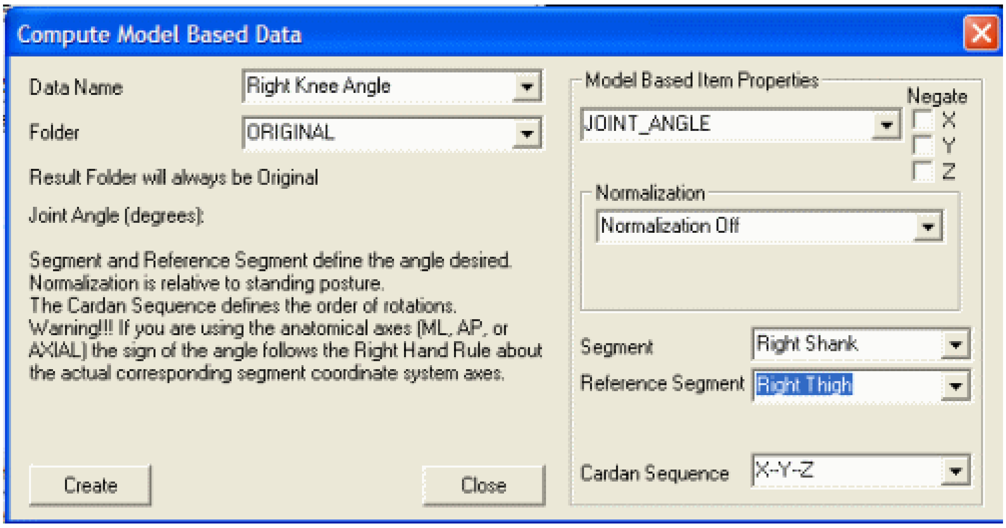

Figure 4.24 Joint angle calculation example from Visual 3D software

Joint angles were calculated via Visual 3D software (C-Motion Inc, USA) using a Cardan 'XYZ' sequence (figure 4.25), corresponding to the anatomical axes of motion in the sagittal, coronal and transverse planes (Winter, 2005, Wu et al., 2002). Joint kinematics were calculated as follows: knee angles were calculated as the shank relative to the thigh (tibio/femoral joint) co-ordinate system, hip angles as the femur relative to the pelvis co-ordinate system and ankle angles as the foot relative to the shank co-ordinate system. This is in line with the Joint Coordinate System (Grood and Suntay, 1983) where X = flexion/extension, Y = abduction/adduction and Z = axial rotation.

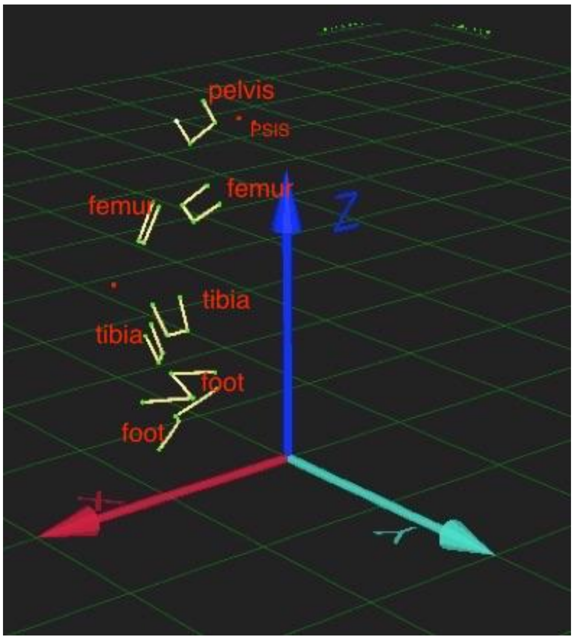

Figure 4.25 X,Y,Z lab axis screenshot in

Qualisys software

Examples of joint angles for one subject in sagittal, coronal and transverse planes can be seen in figures 4.26 to 4.28. This illustrates the patterns of movement normalised from 1-101 time points for one cycle across the knee joint movements of flexion/extension, abduction/adduction and internal rotation/external rotation of the knee joint during a 30 second cycle of data collection.

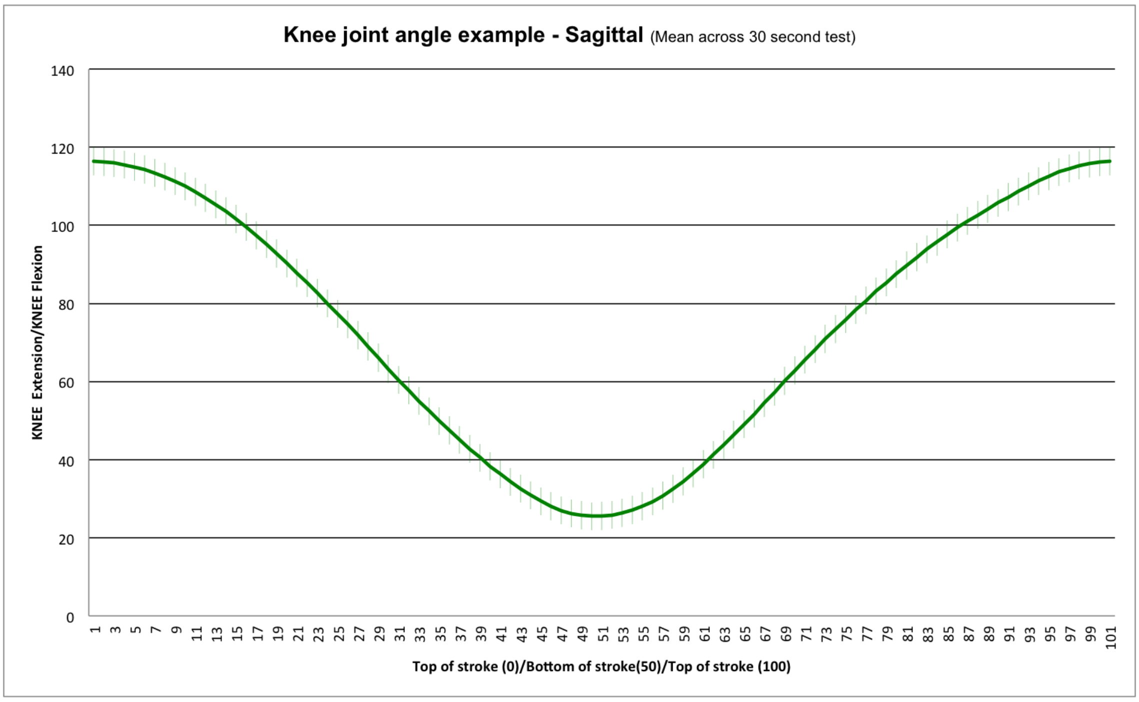

Figure 4.26 - Sagittal joint angle example (mean and SD)

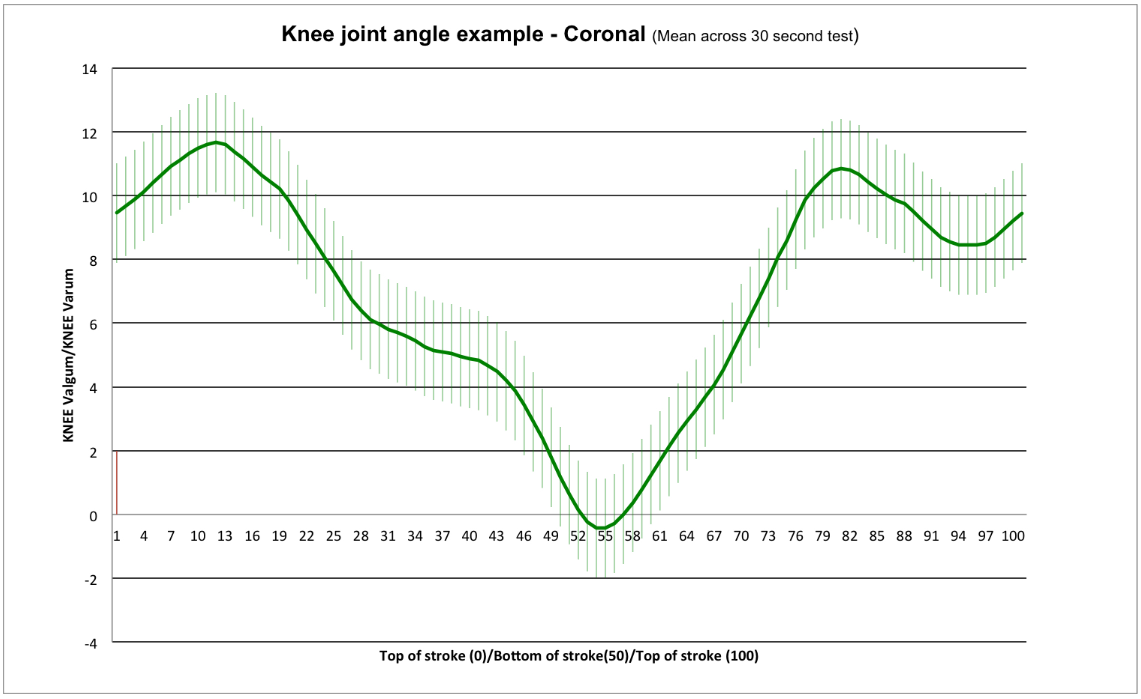

Figure 4.27 - Coronal joint angle example (mean and SD)

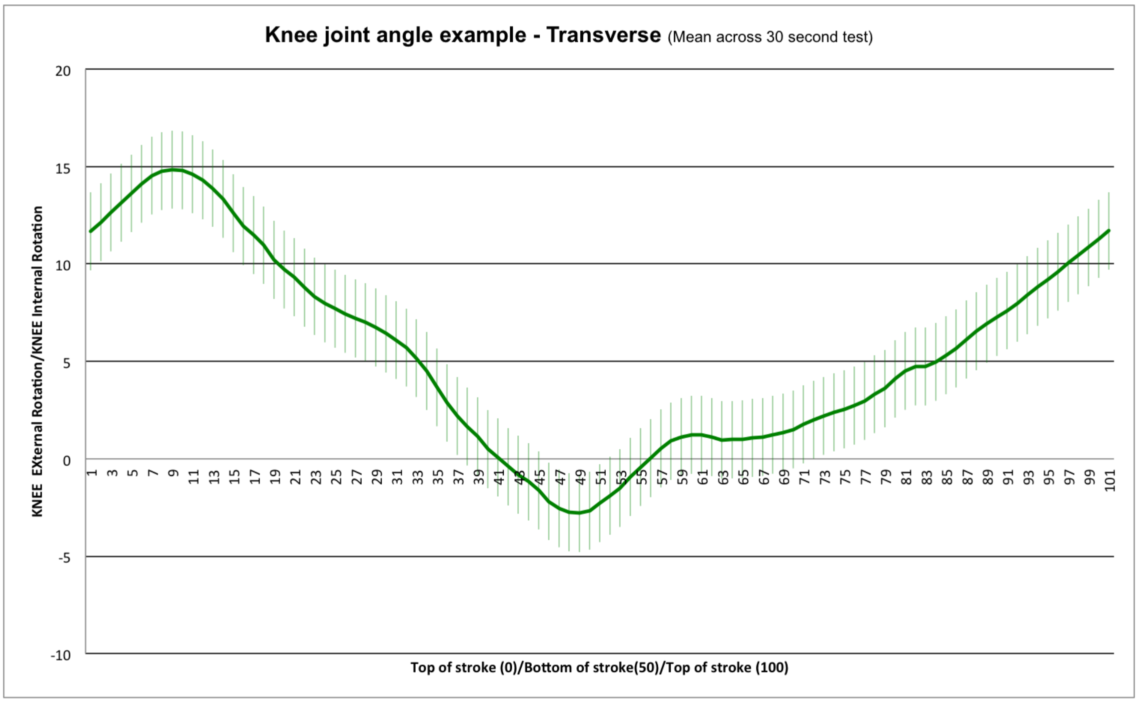

Figure 4.28 - Transverse joint angle example (mean and SD)

Dynamic testing

A visual check of the data quality was undertaken of the dynamic markers during the first randomised test for each participant. This comprised a detailed examination and cross reference of markers, any ‘ghost’ reflections during collection, and a run through of a complete 30 second test to ensure that all markers were present and visible for analysis. If the participant had to leave the bike or measurement area for taping or any other reason, the detailed examination of marker visibility was undertaken again after a 30 second randomised test. If any markers moved or dropped off during testing, the static test was repeated before dynamic testing was commenced. This only happened once during the entire testing process of 45 tests (data capture).

4.3 Pilot Study Learning and Application to Biomechanical Study

From the pilot study the following were identified and applied to the main study:

Cadence: This was reported difficult to maintain at precisely 90rpm. Using the available evidence it was decided to allow the cyclists to choose a cadence from 80 to 100 rpm as this is recognised to be the most efficient cadence for cycling performance at elite and experienced level (Abbiss et al., 2009, Bini et al., 2010b, Chavarren and Calbet, 1999, Rossato et al., 2008, Lucia et al., 2001b). This allowed individual gear selection that reflected normal pedalling and riding conditions for each participant. A somewhat variable cadence allowed participants to self-select their gearing ratio as this varied with each personal bike set up (gearing cluster). This was felt to be a valuable addition to the validity of the cadence measured.

Timings for set up and testing: These were adjusted from ninety minutes to two hours to enable each participant to arrive, be briefed adequately, and allow for setting up bike and systems.

Power analysis measurements: A secondary identically calibrated Powertap™ wheel. On one particular test, there was a complete failure in the calibration and output of the power device. This was resolved but not prior to having a timing imposition on the next participant. Arrangements were made to have an alternative wheel present at testing in case this scenario arose again. Both wheels were simultaneously calibrated at the beginning of each participant testing time period.

Alternative Garmin™ device: Following the issues of failure with the power device it was decided to pre-empt any problems (which did indeed happen in main testing) and have a secondary Garmin™ device present during all testing. This device was identical to the primary device and both were calibrated at the beginning of each participant testing time period.

The importance of using participants' own gearing and bike to increase face validity: To ensure that the testing was as realistic and practical to the participants own riding situation, it was decided to use their own rear cluster of gearing. This involved removing the cluster from the participant's bike and fitting it to the Powertap™ wheel. Time allowances were consequently made in the timings to allow for this change to the rear wheel. Using the same bike for each participant was felt to have been subject to difficulties in respect of the recognised gearing ratios uses by each cyclist. Although a single bike approach is repeatable and somewhat convenient, its reliability in reproducing each participant's specific cycling preferences could be questioned.

Marker placement and stability of pelvic belt: Pilot testing allowed for practice and experience in anatomically reproducible placement of markers on the participants. It was felt that a double wrap velcro band allowed sufficient stability of the pelvic markers to ensure no movement of the markers during multiple tests. Once applied there was no detectable movement in this belt during the testing procedure.

ASIS marker placement: The ASIS (Anterior Superior Iliac Crest) markers (x2) repeatedly became dislodged, fell off or caused unreliable data analysis post testing. They appeared to be lost/dislodged due to the repeated nature of hip flexion during testing. Their removal did not affect data collection or the modelling process as alternative markers were sufficient to produce a pelvic model (pelvic cluster and PSIS x 2 – figure 4.18).

Electromyography (EMG) consideration

A considerable area of interest in cycling related research has been that of muscle recruitment patterns using electromyography (EMG) data from knee-associated musculature such as VM and the quadriceps group. Consideration of this data collection method was undertaken by the author to establish whether its inclusion in the laboratory-based investigation would provide further valid and useful data that would underpin and positively contribute to the study. This work was done during the pilot phase prior to main testing. It is generally accepted that multiple muscle co-activation occurs throughout the pedaling action and that the degree of this co-activation differs in position and ability (Faria et al., 2005a, So et al., 2005, Chapman et al., 2006). With regard to incline and posture, Duc et al., (2008) found that although various positions did not significantly affect the muscular activity, it did change the EMG measured timing of the muscle activation. It should be noted that this was one of few studies that utilised a treadmill based ergometer system rather than the stationary cycle method that has traditionally been the preferred method of testing (Li and Caldwell, 1998, Bieuzen et al., 2007, Bini et al., 2011). It is clear from the abundance of work in this area that muscle recruitment patterns vary from individual to individual and are directly related to position, cadence and resistance. Its inclusion in the main study would undoubtedly have contributed interesting comparison data to the 3D biomechanical work around the knee with the different taping techniques. However that said, the pilot work was vital in establishing whether the EMG sensor placement would interfere with the taping techniques. Should this happen then EMG could not be used.

It was decided to experiment with EMG sensor placement due to the quantity of previous research into Vastus Medialis /Vastus Lateralis (VM/VL) activation (Bennell et al., 2010, Bieuzen et al., 2007, Cowan et al., 2002, Ng, 2005, Ng and Wong, 2009) and also the previous work undertaken with cycling and EMG measurement (Suzuki et al., 1982, Marsh and Martin, 1995, Ryan and Gregor, 1992, Rouffet and Hautier, 2008, Matsuura et al., 2011). During the pilot testing it became apparent that the placement of the VM/VL EMG wireless transmitters would be directly under the KTT application. Considering the potential influence of KTT to skin sensitivity and possible associated muscle effects, despite the interesting prospects of EMG measurement, its inclusion may have a significant enough effect on the taping study so as to negate or significantly alter the results. It was therefore decided not to measure VM/VL, see Figure 4.29 for placement interference illustration. Although consideration was given to other EMG placements such as gluteus medius, its inclusion without measurement of the vasti group was considered unlikely to produce any clinically useful data. Also during testing, the placement of the gluteal medius EMG sensor became repeatedly dislodged. Future work with EMG and KTT would be an interesting development of this study.

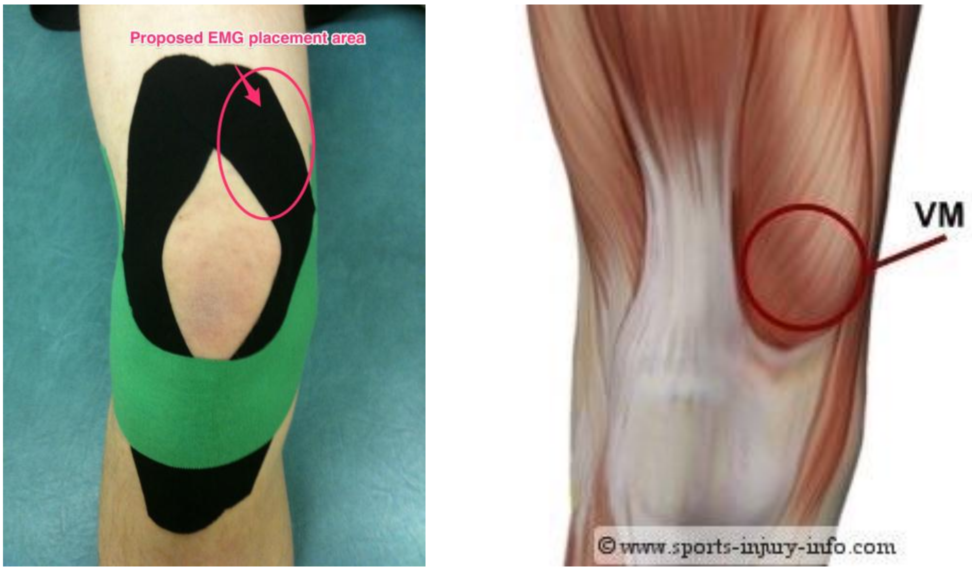

Figure 4.29 KTT and potential EMG (VM) placement

4.4 Biomechanical Laboratory-Based Study methods

This section outlines the methods undertaken for the proposed investigation. The initial methods have been described in the pilot methods' section previously, alongside the development from that work.

4.4.1 Recruitment

Following ethical approval from the Faculty of Health Research Ethics Committee at the University of Central Lancashire (BuSH 107), recruitment was via local network, social network-Twitter™, an advert at the University (see appendix 20) and also the same advert in local bike shops and via local cycling clubs websites.

4.4.2 Participant information and communication

Participant information was given by direct email attachment, a website link where a direct download could be obtained, and also by printing off and posting direct to the participant should it have been required. All participants completed consent forms and verbally confirmed when arriving at the laboratory that they had read and understood the information and what they were being asked to undertake. They were also made aware that they could stop testing at any point. Consent forms, participant information forms, knee pain inclusion/exclusion forms, study poster and risk assessment forms can be found in appendices 17 to 21.

4.4.3 Participants

Participants were recruited from within the cycling community, professional contacts from both the researcher's clinical practice and consequent networking process, by utilising the social network Twitter™ and poster adverts (see appendix 20) at the University of Central Lancashire. The work was with elite and experienced cyclists predominately from the North and North West areas of the UK. Participants were identified using British Cycling guidelines of Elite, 1, 2, 3 and 4 category and gold/silver/bronze standard sportive cyclists (British-Cycling, 2012). Symptomatic participants were required to complete an inclusion/exclusion declaration that determined the nature of their knee pain (see appendix 19). This pain was required to be cycling related, not associated with recent acute trauma, and not part of any existing and diagnosed non-cycling related knee pathology such as CMP or other degenerative related pathologies. All participants were required to be included in line with the identified British Cycling related inclusion criteria. The recruitment process can be seen in a summarised diagram in figure 4.30.

Prior to participation in all studies, participants were informed both verbally and in writing of the test procedures and verbal informed consent was obtained before actual testing. Participants were also familiarised with the test equipment and protocol before testing took place. Prior to each testing day each participant completed a consent form (Appendix 18), read the participant information (Appendix 17) or indicated clearly they were happy to proceed without doing so. With symptomatic cyclists the conditions of participation were discussed in regard to previous pathologies and pre-existing injuries (see screening form in appendix 19). All participants nine individual tests (3 condition and 3 powers) were randomised using the website www.radomization.com prior to testing. There was no input or alternation from the randomisation of tests at any point during the study.

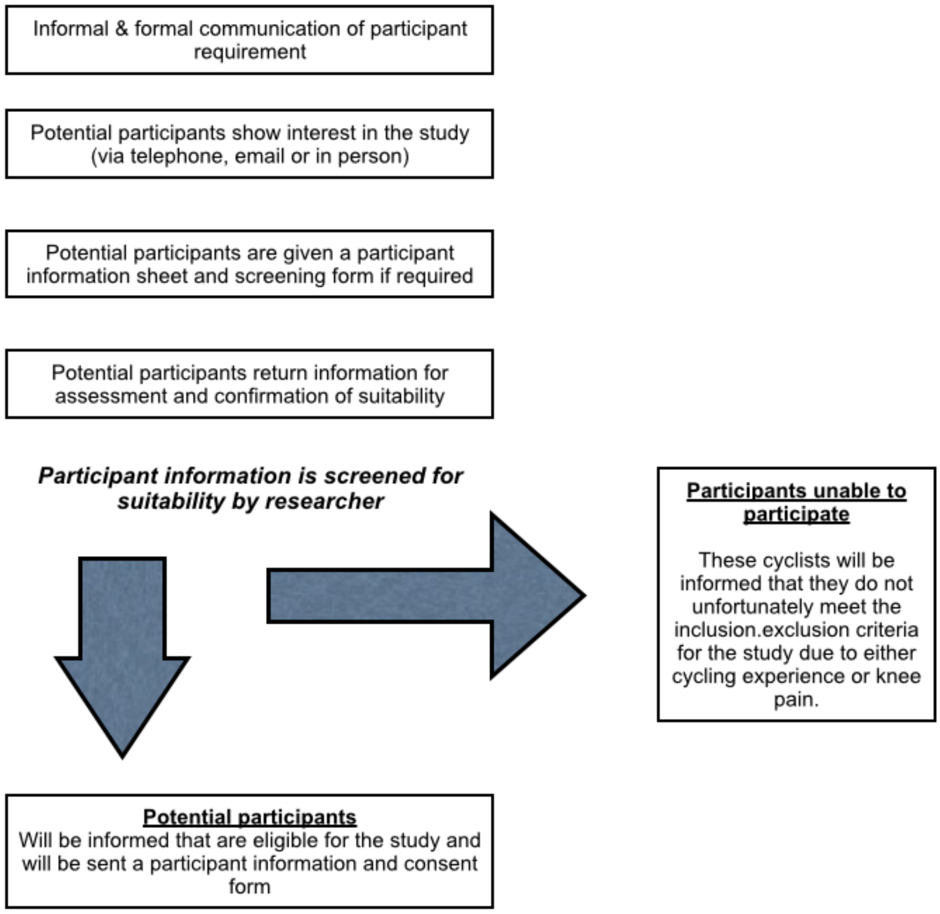

Figure 4.30 Participant recruitment flow diagram

4.4.4 Participant specific data

A total of 20 participants were recruited after the pilot testing phase.

Table 4.1 Participant details (n=20)

	Participant information			
Group	Age (Years)	Height (cm)	Mass (kg)	Elite/Exp'd
Asymptomatic				
1	46	178	76	Exp'd
2	22	183	70	Elite
3	54	174	70	Elite
4	42	178	66	Exp'd
5	52	174	65	Exp'd
6	53	180	87	Exp'd
7	32	175	67	Elite
8	35	178	70	Elite
9	48	176	81	Elite
10	32	174	69	Elite
11	39	172	72	Exp'd
12	26	180	71	Elite
Mean	42.67	177.33	72.44	Elite 7
SD	10.97	2.96	7.43	Exp'd 5
Symptomatic				
1	39	180	69	Elite
2	53	181	78	Exp'd
3	39	172	74	Exp'd
4	48	176	81	Elite
5	47	178	88	Exp'd
6	25	183	70	Elite
7	36	175	68	Elite
8	32	174	67	Exp'd
Mean	39.88	177.38	74.38	Elite 4
SD	9.17	3.78	7.42	Exp'd 4

4.4.5 Asymptomatic participants:

Twelve healthy male participants, (Table 4.1) were recruited. All subjects were free from any pain or pathology in line with the screening form. All were in the target group identified using British Cycling guidelines of Elite, 1, 2, 3 and 4 category and gold/silver/bronze standard sportive cyclists (British-Cycling, 2012).

4.4.6 Symptomatic participants:

Eight male participants with cycling related knee pain, (Table 4.1) were recruited. Exclusion criteria were predetermined, processed and administrated prior to testing (Appendices 17 and 19). All participants had unilateral cycling related knee pain and no pre-diagnosed conditions that would exclude them from testing. Five participants had left side cycling related knee pain and three had right side cycling related knee pain. Only one participant had disclosed pain as lasting for longer than the previous three months. All others reported onset of pain as within the three months prior to testing. No participants reported any pain prior to warming up for testing (base line). Pain before, during and after each test was recorded and reported in section 4.12 (Figures 4.37 to 4.40 and table 4.45). All were in the target group identified using British Cycling guidelines of Elite, 1, 2, 3 and 4 category and gold/silver/bronze standard sportive cyclists (British-Cycling, 2012).

4.4.7 Data Protection

Throughout the study all information collected was kept strictly confidential and in accordance with the Data Protection Act (1998). All data was coded using participant numbers. All identifying information was stored on a password-protected document on a University computer and deleted at the end of the study. Any screening forms requiring printing were stored in a locked facility that only researchers have access to. The data will be kept for up to five years and will then be destroyed. This information will not be passed onto any third parties or external companies. All data is stored separately from the screening forms.

4.5 Pain Measurement

It was felt that although 30 second testing may not indicate a true reflection of the pain induced by cycling, it was necessary to measure pain for both participatory levels of pain and also as an objective measurement of whether any treatment (KTT or neutral taping) initiated a reduction or increase in pain over the testing period. The pain perception results were monitored (Figure 4.37-4.40) during testing and also reported in the results section 4.12. A recognised Numeric Pain Scale (NRS) was selected for ease of use, validity, (Williamson and Hoggart, 2005, McCaffrey and Beebe, 1989) and adapted for cycling (Appendix 22).

4.6 Pre-Testing Procedure

Participants were given full instruction on use of the static trainer and the opportunity to practice on the turbo trainer in situ and warm up (prior to testing) for up to ten minutes. Cadence measurement (Garmin™ 510 sensor) was calibrated on each bike using manufacturer's instructions and checked via the Qualisys™ software with the participant in place, over a 30 second period (at 80-100rpm this equated to approx. 45 revolutions measured). Clarification of the participant's understanding of the required cadence, and how to interpret and maintain the required power using the on-bike Garmin™ 510 sensor, was clarified prior to testing using the 30-second cadence test described. The opportunity to cease testing remained throughout the procedure and could be initiated by either researcher or participant at any time.

Any reflective sections of clothing or equipment were identified during the warm up and taped to minimise any 'ghost markers' during data collection. All tests were measured for a duration of 30 seconds. Participants were allowed sufficient time to reach the required cadence (80-100rpm) before each test began. Where applicable (symptomatic), the numeric pain scale score was noted before, during and after each test.

Upon entry to the test area, the protocol was explained and any health and safety considerations outlined. The appropriate bike was set up, tested and warm up and acclimatisation were achieved prior to testing. All participants were allowed sufficient time to familiarise themselves with the operation of the static trainer and this was monitored throughout. Once markers were placed, a static measurement was taken to enable joint centres to be calculated (outlined previously). The relevant markers were then removed prior to dynamic measurement through specific testing.

4.7 Tape Application

To determine a repeatable and reliable application of the KTT the following methods were used:

For the application of the KTT technique (Figure 4.32) the subject was seated with a relaxed knee at approx. 90º of flexion (Kase et al., 1998a, Akbas et al., 2011). This procedure was used each time and applied by the author. For the KTT specific technique three lengths of KTT were cut and applied (Figure 4.31).

Length one was measured at 75% of circumference of participant's knee at the joint line and across the patella. Approximately 30% of stretch was applied to the KTT from 'off tape' (Kase et al., 1998a). 30% was subjectively attained from the manufacturer's guidelines that KTT comes 'off tape' (meaning off the backing tape) at 15% stretch (Figure 4.31) and consequent stretch levels can be applied from this point. The inside of the tape did not overlap the medial patella (Figure 4.32). The ends (4cm x 2) were anchored with zero stretch in accordance with recognised guidelines (Kase et al., 1998a, Chen, 2008). All ends were rounded to aid application and to minimise any lifting of tape during testing as per manufacturers recommendations (Rocktape™, Campbell, CA, USA). An illustration of tape length percentiles, ends and backing tape can be seen in in figure 4.31.

Length two was measured at 75% of circumference of participant's knee at the joint line and across the patella. Approximately 30% of stretch was applied to the KTT from 'off tape'. The ends (4cm x 2) were anchored with zero stretch in accordance with guidelines. The inside of the tape did not overlap the lateral patella (Figure 4.32).

Length three was measured at 75% of circumference of participant's knee at the joint line and across the patella. Approximately 30% of stretch was applied to the KTT from 'off tape'. The ends (4cm x 2) were anchored with zero stretch in accordance with guidelines. This length was applied under the inferior pole of the patella and around the femoral condyles (Figure 4.32).

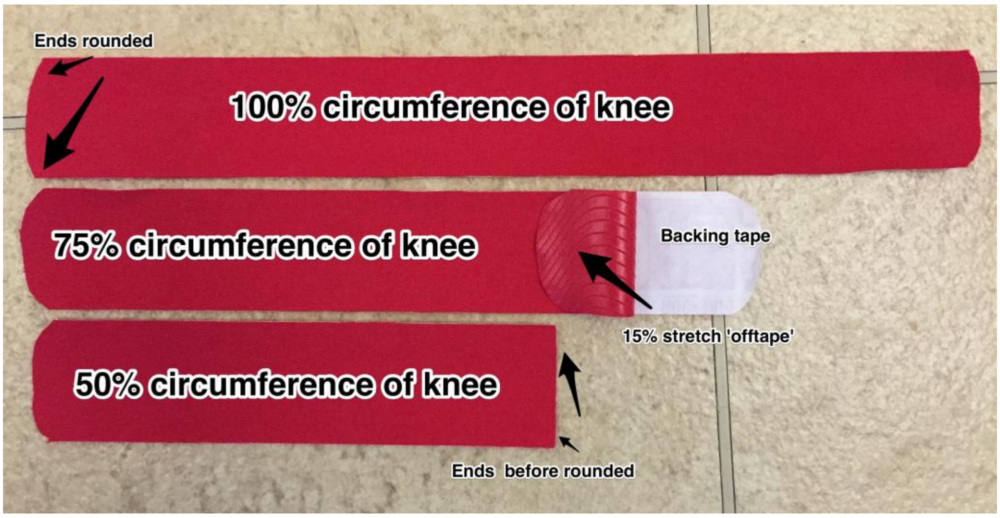

Figure 4.31 – KTT lengths of tape

For the application of the neutral taping technique the subject was seated with a relaxed knee at approx. 90º of flexion, the following procedure was used during each test and applied by the author. 1 length of KTT was cut and applied.

The neutral tape (Figure 4.31 and 4.33) was measured at 50% of circumference of participant's knee at the joint line and across the patella, which is in line with previous studies (Callaghan et al., 2002, Callaghan, 2012, Selfe et al., 2008). Zero stretch was applied KTT from 'off tape' tension. The tape was placed directly across the patella perpendicular to the vertical. The neutral tape application is pictured in figure 4.33.

Both right and left side were measured during data collection. However for asymptomatic participants only the taped (left) side were reported (Section 4.11). For symptomatic participants whose affected side was the right side, this was the side that was both taped and reported.

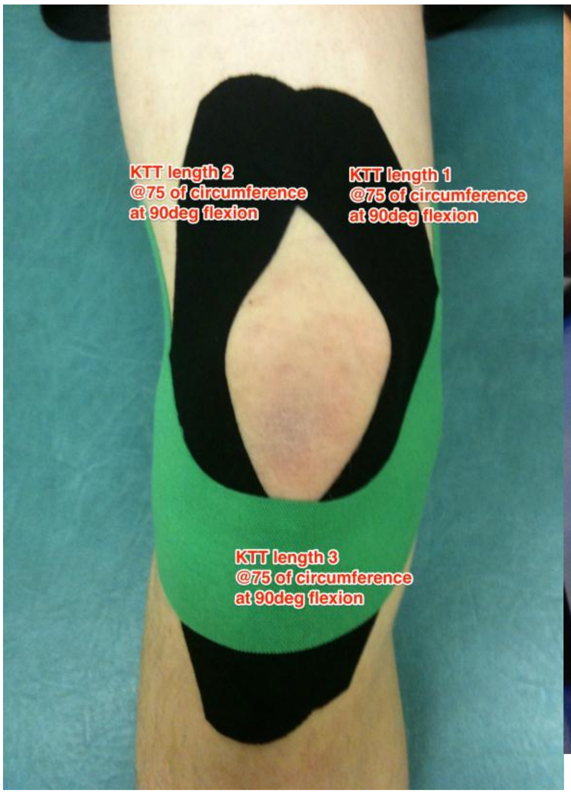

Figure 4.32 KTT application

Figure 4.33 Neutral tape application

4.8 Methods of Analysis

Joint angles were calculated using a Cardan "XYZ" sequence in conjunction with the International Society of Biomechanics (ISB) for the lower limb (Wu et al., 2002, Baker, 2003), corresponding to the anatomical axis of motion in the sagittal, coronal and transverse planes (Grood and Suntay, 1983). Movement of each segment was defined relative to the global co-ordinate system. All data was captured and processed using Qualisys Track Manager™ V.2.9 (build 1697) and then into specialist motion analysis software (C-Motion Visual3D™ Version 3.79.0). This produced a dynamic visual representation and carried out all the calculations to formulate a report template. Report templates for the hip, knee and ankle/foot were produced and the resultant data were exported in ascii file format for import to Microsoft excel™.

Data were imported into Microsoft Excel™ and reported in minimum (min), maximum (max) and ROM tables with full data sets for use with SPSS™ statistical analysis. Participants measured (taped) side was identified and indicated from initial testing through to reporting stage to clearly represent the investigation with reliability and accuracy. Kinematic patterns provided an initial visual perspective for all participants in each area measured and allowed any outlying participants that required identification (Appendix 23.1). Data from the Visual 3D™ software was exported to Microsoft Excel™ to extract min, max and ROM mean values for each participant. All statistical analyses were performed using SPSS™ v.22 (for mac).

4.9 Statistical Analysis

Data for conditions and powers were normally distributed. This was applied due to the data being measured multiple times and in addition a Shapiro-Wilk's test ($p>0.05$) undertaken with visual inspection of histograms, normal Q-Q plots and box plots showings approximate normal distribution. Skewness and kurtosis produced z-values between +/- 1.96. An analysis of variance (ANOVA) test was performed and a 0.05 level of significance used to explore the effects of asymptomatic/symptomatic, condition and power regardless of each other (n=20). This indicated any main effects of power, condition and pain/no pain. Further exploration was undertaken and reported via post hoc tests (α = < 0.05), which investigated any effects within each specific power and condition in the two groups separately. P-values were reported comparing the results of the knee, hip and ankle, across each treatment intervention (KTT, Neutral and No tape) at the three separate power levels (100W, 200W and 300W).

4.10 Statistical Power and Analysis

Based on previous studies (Selfe et al., 2008, Selfe et al., 2011, Theobald et al., 2012) on the effect of knee bracing on biomechanical parameters, mean differences have been greater than the standard deviations for several biomechanical parameters, e.g. the transverse plane range of motion 2.32 degrees with a standard deviation of 3.72 degrees. A statistical power calculation yields that with a 90% statistical power, and a significance level of 5%, the sample size needs to be greater than nine to produce a result. Therefore with a minimum sample size of 15 we would be able to detect any significant changes in the biomechanical parameters. Previous work utilising a similar protocol and methodology has produced accepted statistical differences and power calculations (Selfe et al., 2008, Sinclair et al., 2014).

4.11 Biomechanical Study Results

4.11.1 Results structure:

Results are reported by joint in the following sequence

1. **Knee**
2. **Hip**
3. **Ankle**

For each joint results are reported sequentially for the sagittal, coronal and transverse planes (Figure 4.34, 4.35 and 4.36)

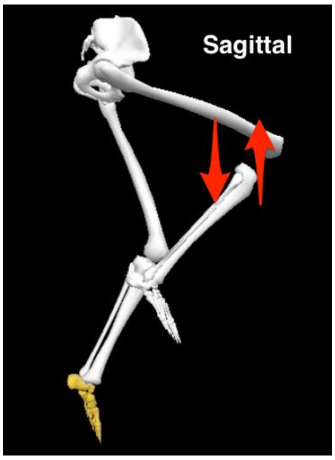

Fig 4.34 - Sagittal plane

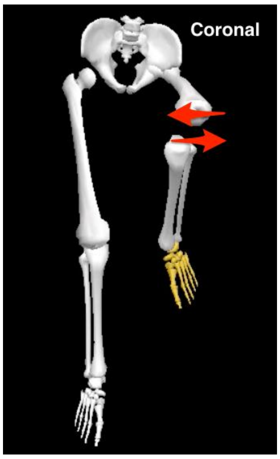

Fig 4.35 - Coronal plane

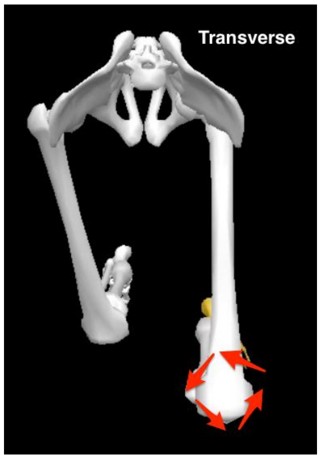

Fig 4.36 - Transverse plane

Table 4.2 (below) represents an overview of the variables measured and reported in this section.

Table 4.2 Overview of variables

Planes	Sagittal	Coronal	Transverse
Joints measured	Knee	Hip	Ankle
Conditions applied	KTT	Neutral tape	No tape
Participants	Asymptomatic	Symptomatic	
Powers measured	100W	200W	300W
Analysis	Descriptive (Min/Max/ROM)	Analysis of Variance (ANOVA)	Post hoc analysis

Only significant and notable results are presented in the following tables for each joint plane. Results include: Analysis of Variance and Post hoc tests exploring asymptomatic/symptomatic, conditions and power, all other results are located in the appendix.

There are three formats of analyses within each section (knee/hip/ankle)

1. **Min, Max and ROM tables:**
   a. Asymptomatic (n=12) - Min, Max and ROM tables:
      i. Mean values across each test are reported
      ii. Standard deviations for each test are reported
      iii. Narrative of notable trends and changes
   b. Symptomatic (n=8) - Min, Max and ROM tables:
      i. Mean values across each test are reported
      ii. Standard deviations for each test are reported
      iii. Narrative of notable trends and changes
2. **Analysis of variance (ANOVA) across all participants- n=20**
   (tables presented where significant only)
   a. Sagittal plane - ROM
      i. Between conditions (KTT/Neutral tape/No tape)
      ii. Between asymptomatic and symptomatic participants
      iii. Between powers (100W/200W/300W)
   b. Coronal plane - ROM
      i. Between conditions (KTT/Neutral tape/NO tape)
      ii. Between asymptomatic and symptomatic participants
      iii. Between powers (100W/200W/300W)
   c. Transverse plane - ROM
      i. Between conditions (KTT/Neutral tape/NO tape)
      ii. Between asymptomatic and symptomatic participants
      iii. Between powers (100W/200W/300W)

3. **Subsequent Post hoc analysis:**
   (tables presented where significant only)
   a. Asymptomatic - summary of affected conditions and powers in regard to statistical significant differences:
      i. ROM (SD)
      ii. Significant difference (sig)
      iii. Mean difference
   b. Symptomatic - summary of affected conditions and powers in regard to statistical significant differences:
      i. ROM (SD)
      ii. Significant difference (sig)
      iii. Mean difference

4.11.2 Results

KNEE results

Table 4.3 - **Asymptomatic** (n=12) **Sagittal** plane knee kinematics

CONDITION	POWER								
	100 W			**200 W**			**300 W**		
	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)
KT TAPE	117.69	34.54	83.15	117.63	33.74	83.88	117.77	33.12	84.65
SD	3.98	6.79	5.54	3.89	6.61	5.45	3.55	6.54	5.47
NEUTRAL TAPE	118.16	34.82	83.34	118.18	33.96	84.22	118.32	33.09	85.23
SD	4.21	6.83	5.38	4.38	6.89	5.03	4.54	6.66	4.84
NO TAPE	118.41	34.77	83.64	118.52	33.64	84.87	118.28	32.12	86.16
SD	4.80	6.69	4.95	4.71	6.87	5.20	4.68	7.02	5.78

Table 4.4 - **Asymptomatic** (n=12) **Coronal** plane knee kinematics

CONDITION	POWER								
	100 W			**200 W**			**300 W**		
	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)
KT TAPE	6.22	-0.11	6.33	5.84	-0.61	6.44	5.68	-1.09	6.77
SD	5.76	6.10	2.60	5.45	6.06	2.91	5.43	5.79	2.52
NEUTRAL TAPE	6.18	-0.14	6.32	5.77	-1.07	6.84	5.82	-0.89	6.71
SD	5.71	6.22	2.19	5.17	5.91	2.72	5.26	5.51	2.44
NO TAPE	6.50	-0.42	6.92	6.14	-0.85	6.99	6.10	-0.87	6.97
SD	5.86	6.24	2.47	5.60	6.03	3.02	5.35	5.68	2.70

Table 4.5 - **Asymptomatic** (n=12) **Transverse** plane knee kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)
KT TAPE	10.96	-3.46	14.42	10.73	-3.15	13.88	10.42	-3.04	13.46
SD	5.41	4.20	7.16	4.99	4.06	6.57	4.62	4.03	6.42
NEUTRAL TAPE	11.15	-3.44	14.59	11.21	-2.67	13.89	11.09	-2.43	13.52
SD	5.46	4.51	7.43	5.60	4.14	6.89	5.23	4.16	6.92
NO TAPE	11.01	-3.38	14.39	11.11	-2.74	13.84	11.19	-2.87	14.05
SD	6.54	4.20	7.36	6.17	3.97	7.19	5.45	4.31	7.53

POWER: The results indicate a gradual increase in sagittal and coronal ROM (tables 4.3,4.4) as the power increases (Asymptomatic). The transverse ROM (table 4.5) indicates a reduction with the associated increase in power (Asymptomatic). With sagittal movement the increase in ROM is seen predominantly in the Min (extension). As the power increases, the degree of extension increases. In the coronal plane the increase in ROM is seen into the MIN (valgum) movement: as the power increases the knee moves more medially towards the bike (Valgus). Transverse movement produces small amounts of movement with power increase, any changes are mainly seen in external rotation. As the power increases the knee extends more, moves medially and also externally rotates.

CONDITION: Taping appears to decrease the ROM, with the main effect being in flexion in the sagittal plane (table 4.3). In the coronal plane the taping reduces ROM also (table 4.4), with the main effect being in knee varus movement. Transverse plane movement is affected by very small amounts with internal rotation being reduced slightly by the taping conditions (table 4.5).

Table 4.6 - **Symptomatic** (n=8) **Sagittal** plane knee kinematics

CONDITION	POWER								
	100 W			**200 W**			**300 W**		
	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)
KT TAPE	117.88	33.67	84.20	117.85	33.31	84.54	117.49	32.91	84.58
SD	4.86	6.42	6.15	4.57	5.97	6.06	4.40	5.39	4.88
NEUTRAL TAPE	118.58	34.69	83.89	117.97	33.21	84.76	118.15	32.60	85.55
SD	5.14	6.51	6.59	5.33	6.99	6.19	5.57	6.51	5.62
NO TAPE	118.99	34.95	84.04	118.78	33.74	85.04	118.30	32.29	86.02
SD	5.88	7.23	6.67	5.70	7.37	6.76	5.74	6.76	6.38

Table 4.7 - **Symptomatic** (n=8) **Coronal** plane knee kinematics

CONDITION	POWER								
	100 W			**200 W**			**300 W**		
	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)	MAX Varum (Degrees)	MIN Valgum (Degrees)	ROM (Degrees)
KT TAPE	7.91	-0.08	8.00	7.13	-0.28	7.41	7.15	-0.94	8.08
SD	8.38	10.15	3.00	8.29	9.93	3.32	8.00	9.88	3.50
NEUTRAL TAPE	8.19	0.10	8.09	7.51	-0.13	7.63	7.57	-0.80	8.37
SD	8.33	10.20	2.72	7.69	9.64	3.24	7.54	9.54	3.66
NO TAPE	8.64	0.41	8.23	8.14	0.61	7.53	7.54	-0.16	7.71
SD	8.33	9.58	2.24	8.21	9.09	2.34	7.45	8.81	2.85

Table 4.8 - **Symptomatic** (n=8) **Transverse** plane knee kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)	MAX Internal R (Degrees)	MIN External R (Degrees)	ROM (Degrees)
KT TAPE	12.58	-3.75	16.33	11.81	-3.86	15.67	11.38	-3.67	15.04
SD	7.96	6.18	8.02	7.74	6.43	7.75	7.90	6.46	7.05
NEUTRAL TAPE	12.39	-3.34	15.73	12.33	-3.34	15.67	11.72	-3.47	15.19
SD	8.26	6.77	8.93	8.92	6.57	8.24	8.80	6.80	8.09
NO TAPE	12.55	-3.24	15.79	12.74	-3.68	16.42	11.71	-3.56	15.27
SD	9.16	6.41	8.96	9.23	6.42	8.22	9.38	6.79	8.57

POWER: In the sagittal plane (table 4.6), as with Asymptomatic cyclists, as the power increases the ROM appears to increase. However, with Symptomatic cyclists this increase appears less in comparison. In the coronal plane (table 4.7) ROM indicates a slight decrease across power (100-300w) in knee varum. Transverse movement (table 4.8) indicates a predominant decrease in ROM from 100w to 300w with the main decrease being in internal rotation movement.

CONDITION: As with Asymptomatic cyclists taping appears to decrease the ROM with cyclists with knee pain, again with the main effect being in flexion in the sagittal plane (table 4.6). In the coronal plane the taping reduces ROM also, with the main effect being in knee varus movement (table 4.7). As with Asymptomatic cyclists, transverse plane movement (table 4.8) is affected by similarly small amounts with internal rotation being reduced slightly by the taping conditions.

Analysis of variance (ANOVA) across all participants- n=20

SAGITTAL PLANE – ROM - KNEE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Between powers (100W/200W/300W)

No significant differences

CORONAL PLANE – ROM - KNEE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Table 4.9 - Between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig
Asymptomatic	6.700	-1.194*	**.005**
Symptomatic	7.894	1.194*	**.005**

Between powers (100W/200W/300W)

No significant differences

TRANSVERSE PLANE – ROM - KNEE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Between powers (100W/200W/300W)

No significant differences

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

ASYMPTOMATIC KNEE kinematics

Table 4.10 - Sagittal plane – Asymptomatic participants (n=12) – KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) No tape	200W	(1) 83.88 (5.45)	(2) 84.87 (5.20)	0.002	0.99
(1) Neutral ((2) No tape	200W	(1) 84.22 (5.03)	(2) 84.87 (5.20)	0.011	0.65
(1) KTT & (2) No tape	300W	(1) 84.65 (5.47)	(2) 86.16 (5.78)	0.005	1.51
(1) Neutral ((2) No tape	300W	(1) 85.23 (4.84)	(2) 86.16 (5.78)	0.041	0.93
Neutral tape	(1) 200W & (2) 300W	(1) 84.22 (5.03)	(2) 85.23 (4.84)	0.002	1.01
NO tape	(1) 100W & (2) 300W	(1) 83.64 (4.95)	(2) 86.16 (5.78)	0.005	2.52
NO tape	(1) 200W & (2) 300W	(1) 84.87 (5.20)	(2) 86.16 (5.78)	0.002	1.59

Table 4.11 - Coronal plane – Asymptomatic participants (n=12) – KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) No tape	100W	(1) 6.33 (2.60)	(2) 6.92 (2.47)	0.023	0.59

Table 4.12 - Transverse plane - Asymptomatic participants (n=12) – KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) Neutral & (2) No tape	300W	(1) 13.52 (6.92)	(2) 14.05 (7.53)	0.033	0.53
Neutral tape	(1) 200W & (2) 300W	(1) 13.89 (6.89)	(2) 13.52 (6.92)	0.042	0.37

Note: A visual comparison of significant differences across planes can be found in the appendix

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

SYMPTOMATIC Knee kinematics

Table 4.13 - Sagittal plane - Symptomatic participants (n=8) - KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) Neutral tape	300W	(1) 84.58 (4.88)	(2) 85.55 (5.62)	0.014	0.97
Neutral tape	(1) 100W & (2) 300W	(1) 83.89 (6.59)	(2) 85.55 (5.62)	0.026	1.66
NO tape	(1) 100W & (2) 200W	(1) 84.04 (6.67)	(2) 85.04 (6.76)	0.016	1.00
NO tape	(1) 100W & (2) 300W	(1) 84.04 (6.67)	(2) 86.02 (6.38)	0.002	1.98

Table 4.14 - Coronal plane - Symptomatic participants (n=8) - KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
KTT	1) 200W & (2) 300W	(1) 7.41 (3.32)	(2) 8.08 (3.50)	0.029	0.67

Table 4.15 - Transverse plane - Symptomatic participants (n=8) - KNEE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
NO tape	(1) 200W & (2) 300W	(1) 16.42 (8.22)	(2) 15.27 (8.57)	0.017	1.15

Note: A visual comparison of significant differences across planes can be found in the appendix

HIP results

Table 4.16 - **Asymptomatic** (n=12) **Sagittal** plane HIP kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)
KT TAPE	106.57	54.97	51.59	107.01	55.25	51.76	107.40	55.16	52.24
SD	9.60	11.30	4.02	9.13	11.28	3.46	8.51	9.99	2.99
NEUTRAL TAPE	107.52	55.96	51.56	107.79	55.95	51.84	107.38	54.83	52.54
SD	8.73	10.88	4.02	8.19	9.73	2.98	7.72	9.08	3.29
NO TAPE	106.94	55.24	51.70	107.44	54.98	52.46	108.18	54.89	53.28
SD	9.19	10.97	3.82	8.57	10.17	3.51	7.91	9.27	2.87

Table 4.17 - **Asymptomatic** (n=12) **Coronal** plane HIP kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Hip AB + (Degrees)	MIN Hip ADD – (Degrees)	ROM (Degrees)	MAX Hip AB + (Degrees)	MIN Hip ADD – (Degrees)	ROM (Degrees)	MAX Hip AB + (Degrees)	MIN Hip ADD – (Degrees)	ROM (Degrees)
KT TAPE	-7.53	-12.50	4.97	-7.44	-13.10	5.66	-6.86	-13.27	6.41
SD	3.52	2.73	2.96	3.92	2.63	3.51	4.03	3.43	4.36
NEUTRAL TAPE	-7.27	-12.97	5.70	-6.84	-13.62	6.78	-6.64	-13.72	7.08
SD	3.08	2.89	2.82	3.37	3.09	3.69	3.75	3.48	4.31
NO TAPE	-7.29	-12.34	5.05	-6.88	-13.03	6.14	-6.28	-13.23	6.95
SD	3.60	2.84	2.93	3.87	2.92	3.73	3.89	3.05	4.01

Table 4.18 - **Asymptomatic** (n=12) **Transverse** plane HIP kinematics

CONDITION	POWER								
	100 W			**200 W**			**300 W**		
	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)
KT TAPE	9.82	-0.17	10.00	9.79	-0.54	10.33	9.88	-0.83	10.71
SD	8.24	9.53	2.63	8.68	8.88	2.15	9.02	9.34	2.71
NEUTRAL TAPE	10.00	0.13	9.87	9.98	-0.25	10.23	10.04	-0.99	11.03
SD	8.63	9.72	2.19	8.38	9.07	2.48	9.49	9.21	2.56
NO TAPE	10.26	0.25	10.00	10.31	-0.43	10.74	10.45	-0.77	11.22
SD	9.26	9.70	2.27	9.30	9.77	2.86	9.81	9.90	2.88

POWER: With the Asymptomatic Hip, as the power increases (100w to 300w) the ROM indicates an increase (table 4.16). This sagittal increase appears to be in hip flexion rather than extension. In the coronal plane (table 4.17), ROM increases with power with the increase emanating from hip adduction. In the transverse plane (table 4.18) as the power increases, there is also an increase in hip ROM. This movement appears equally distributed across both external and internal rotation.

CONDITION: In the Asymptomatic cyclists hip, the sagittal plane (table 4.16) indicates a decrease in ROM without a clear pattern as to which movement (flexion/extension) is most affected. Coronal plane ROM (table 4.17) appears decreased by taping however once again without a clear pattern as to whether adduction or abduction is the most influenced by taping. The transverse plane (table 4.18) is largely unaffected by taping in the ROM results.

Table 4.19 - **Symptomatic** (n=8) **Sagittal** plane HIP kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)	MAX Flexion (Degrees)	MIN Extension (Degrees)	ROM (Degrees)
KT TAPE	100.24	50.26	49.98	100.88	50.61	50.27	102.45	51.77	50.68
SD	10.54	8.67	7.33	10.45	8.98	6.80	10.30	9.21	5.89
NEUTRAL TAPE	102.46	51.93	50.53	102.08	51.39	50.70	103.06	51.44	51.62
SD	11.61	10.67	6.60	12.04	10.25	5.68	11.71	9.85	6.34
NO TAPE	101.12	50.74	50.38	101.20	50.39	50.81	102.92	51.61	51.31
SD	11.57	9.69	6.77	10.90	8.02	6.48	12.20	8.97	6.67

Table 4.20 - **Symptomatic** (n=8) **Coronal** plane HIP kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX Hip AB + (Degrees)	MIN Hip ADD – (Degrees)	ROM (Degrees)	MAX Hip AB + (Degrees)	MIN Hip ADD- (Degrees)	ROM (Degrees)	MAX Hip AB + (Degrees)	MIN Hip ADD – (Degrees)	ROM (Degrees)
KT TAPE	-3.55	-7.43	3.89	-3.63	-7.71	4.07	-3.33	-7.67	4.34
SD	6.22	6.59	0.95	6.35	6.73	1.40	6.46	6.84	1.65
NEUTRAL TAPE	-3.57	-7.91	4.34	-3.67	-8.41	4.74	-2.96	-8.25	5.29
SD	5.76	6.49	1.55	5.68	6.92	1.78	6.11	7.05	1.94
NO TAPE	-4.47	-8.61	4.14	-4.36	-8.73	4.38	-3.74	-8.95	5.21
SD	5.41	5.79	1.42	5.37	5.84	1.73	5.49	5.79	2.46

Table 4.21 - **Symptomatic** (n=8) **Transverse** plane HIP kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)	MAX External R (Degrees)	MIN Internal R (Degrees)	ROM (Degrees)
KT TAPE	8.14	-1.22	9.36	8.44	-2.45	10.89	8.83	-2.82	11.66
SD	11.55	12.45	2.86	11.50	12.23	2.59	11.90	12.40	2.15
NEUTRAL TAPE	9.52	-0.32	9.84	8.87	-1.75	10.62	9.82	-2.00	11.82
SD	11.43	12.38	2.26	11.28	11.42	2.09	11.99	12.09	2.20
NO TAPE	9.64	0.32	9.32	9.97	-1.30	11.27	10.14	-1.67	11.81
SD	12.00	11.92	2.48	12.34	12.02	2.31	12.55	12.30	2.18

POWER: In the Symptomatic cyclists hip there is a general increase in sagittal ROM as the power increases, albeit less so in KTT (table 4.19). This is indicated by an increase in hip flexion rather than extension. In the coronal plane (table 4.20) an increase in power (100w to 300w) conveys an increase hip adduction and subsequent ROM. Transverse plane movement (table 4.21) increases ROM more considerably with power, with the main change being internal rotation.

CONDITION: In the sagittal plane (table 4.19), the Symptomatic cyclists hip decreases in ROM with taping. The change here being across both flexion and extension. In the coronal plane (table 4.20), taping appears to decrease ROM with this decrease being in both adduction and abduction. Transverse plane (table 4.21) indicates only very small amounts of movement with taping across ROM.

Analysis of variance (ANOVA) across all participants- n=20

SAGITTAL PLANE – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Between powers (100W/200W/300W)

No significant differences

CORONAL PLANE – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Table 4.22 - Between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig
Asymptomatic	6.083	1.595*	**.001**
Symptomatic	4.488	-1.595*	**.001**

Table 4.23 - Between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig
100W	200W	-.613	.279
	300W	-1.199*	**.035**
200W	100W	.613	.279
	300W	-.586	.301
300W	100W	1.199*	**.035**
	200W	.586	.301

TRANSVERSE PLANE – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Table 4.24 - Between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig
100W	200W	-.947*	**.041**
	300W	-1.642*	**.000**
200W	100W	.947*	**.041**
	300W	-.695	.133
300W	100W	1.642*	**.000**
	200W	.695	.133

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

ASYMPTOMATIC HIP kinematics

Table 4.25 - Sagittal plane - Asymptomatic participants (n=12) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) No tape	200W	(1) 51.76 (3.46)	(2) 52.46 (3.51)	0.040	0.70
(1) KTT ((2) No tape	300W	(1) 52.24 (2.99)	(2) 53.28 (2.87)	0.018	1.04
(1) Neutral (2) No tape	300W	(1) 52.54 (3.29)	(2) 53.28 (2.87)	0.026	0.74
Neutral tape	(1) 100W & (2) 300W	(1) 51.56 (4.02)	(2) 52.54 (3.29)	0.041	0.98
Neutral tape	(1) 200W & (2) 300W	(1) 51.84 (2.98)	(2) 52.54 (3.29)	0.006	0.70
NO tape	(1) 100W & (2) 200W	(1) 51.70 (3.82)	(2) 52.46 (3.51)	0.037	0.76
NO tape	(1) 100W & (2) 300W	(1) 51.70 (3.82)	(2) 53.28 (2.87)	0.025	1.58

Table 4.26 - Coronal plane - Asymptomatic participants (n=12) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) Neutral & (2) No tape	100W	(1) 5.70 (2.82)	(2) 5.05 (2.93)	0.051	0.65
(1) KTT & (2) Neutral tape	200W	(1) 5.66 (3.51)	(2) 6.78 (3.69)	0.021	1.12
(1) KTT & (2) Neutral tape	300W	(1) 6.41 (4.36)	(2) 7.08 (4.31)	0.044	0.67
KTT	(1) 100W & (2) 200W	(1) 4.97 (2.96)	(2) 5.66 (3.51)	0.018	0.69
KTT	(1) 100W & (2) 300W	(1) 4.97 (2.96)	(2) 6.41 (4.36)	0.015	1.44
Neutral tape	(1) 100W & (2) 200W	(1) 5.70 (2.82)	(2) 6.78 (3.69)	0.016	1.08
NO tape	1) 100W & (2) 200W	(1) 5.05 (2.93)	(2) 6.14 (3.73)	0.017	1.09
NO tape	1) 100W & (2) 300W	(1) 5.05 (2.93)	(2) 6.95 (4.01)	0.004	1.90
NO tape	(1) 200W & (2) 300W	(1) 6.14 (3.73)	(2) 6.95 (4.01)	0.008	0.81

Table 4.27 - Transverse plane - Asymptomatic participants (n=12) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) No tape	300W	(1) 10.71 (2.71)	(2) 11.22 (2.88)	0.045	0.51

Note: A visual comparison of significant differences across planes can be found in the appendix

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

SYMPTOMATIC HIP kinematics

Table 4.28 - Sagittal plane - Symptomatic participants (n=8) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) Neutral tape	300W	(1) 50.68 (5.89)	(2) 51.62 (5.89)	0.016	0.94
Neutral tape	(1) 200W & (2) 300W	(1) 50.70 (5.68)	(2) 51.62 (6.34)	0.023	0.92

Table 4.29 - Coronal plane - Symptomatic participants (n=8) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
Neutral tape	(1) 200W & (2) 300W	(1) 4.74 (1.78)	(2) 5.29 (1.94)	0.039	0.55
No tape	(1) 200W & (2) 300W	(1) 4.38 (1.73)	(2) 5.21 (2.46)	0.042	0.83

Table 4.30 - Transverse plane - Symptomatic participants (n=8) - HIP KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
KTT	(1) 100W & (2) 200W	(1) 9.36 (2.86)	(2) 10.89 (2.59)	0.000	1.53
KTT	(1) 100W & (2) 300W	(1) 9.36 (2.86)	(2) 11.66 (2.15)	0.004	2.30
Neutral tape	(1) 100W & (2) 300W	(1) 9.84 (2.26)	(2) 11.82 (2.20)	0.009	1.98
Neutral tape	(1) 200W & (2) 300W	(1) 10.62 (2.09)	(2) 11.82 (2.20	0.009	1.20
NO tape	(1) 100W & (2) 200W	(1) 9.32 (2.48)	(2) 11.27 (2.31)	0.001	1.95
NO tape	(1) 100W & (2) 300W	(1) 9.32 (2.48)	(2) 11.81 (2.18)	0.001	2.49

Note: A visual comparison of significant differences across planes can be found in the appendix

ANKLE results

Table 4.31 - **Asymptomatic** (n=12) **Sagittal** plane **ankle** kinematics

CONDITION	POWER								
	100 W			200 W			300 W		
	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)
KT TAPE	67.85	41.97	25.88	67.09	41.21	25.87	67.32	41.32	25.99
SD	7.41	8.59	6.56	7.62	8.84	7.03	6.20	8.56	6.36
NEUTRAL TAPE	68.11	42.19	25.93	68.47	41.98	26.49	68.62	41.71	26.91
SD	6.27	8.36	6.10	5.52	9.15	7.86	5.02	8.88	6.07
NO TAPE	68.18	42.08	26.10	67.64	41.89	25.75	68.49	42.24	26.25
SD	6.19	8.16	6.08	5.80	8.61	6.42	6.51	9.03	6.65

Table 4.32 - **Asymptomatic** (n=12) **Coronal** plane **ankle** kinematics

CONDITION	POWER								
	100 W			200 W			300 W		
	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)
KT TAPE	-2.08	-7.64	5.56	-2.04	-7.94	5.90	-1.89	-8.12	6.24
SD	4.43	4.08	1.72	4.66	4.36	1.67	4.09	4.31	1.65
NEUTRAL TAPE	-2.12	-7.52	5.40	-2.33	-8.06	5.73	-2.12	-8.23	6.11
SD	4.70	4.31	1.78	4.38	4.26	1.85	4.66	4.49	1.79
NO TAPE	-2.40	-7.86	5.46	-2.40	-7.94	5.55	-2.06	-8.15	6.08
SD	4.73	4.38	1.68	4.85	4.57	1.60	4.73	4.70	1.67

Table 4.33 - **Asymptomatic** (n=12) **Transverse** plane **ankle** kinematics

CONDITION	**POWER**								
	100 W			**200 W**			**300 W**		
	MAX External R + (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)	MAX External R + (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)	MAX External R + (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)
KT TAPE	9.87	4.84	5.03	9.92	4.76	5.17	10.00	4.82	5.18
SD	7.40	7.07	1.98	6.99	7.02	1.97	7.14	6.82	2.00
NEUTRAL TAPE	10.15	4.59	5.56	10.50	4.95	5.54	10.02	4.62	5.39
SD	7.17	6.91	2.04	7.31	6.92	2.42	7.17	6.83	2.34
NO TAPE	10.52	4.53	5.98	10.17	4.51	5.65	10.16	4.43	5.73
SD	7.33	6.45	2.29	7.29	6.70	1.97	6.79	6.55	2.17

POWER: With the Asymptomatic cyclists in the sagittal plane (table 4.31) there is very little change across power (100w to 300w). Neither plantar-flexion or dorsi-flexion exhibit any notable changes across power. The coronal plane (table 4.32) indicates a general increase in ROM with a power increase. This increase appears to be across both inversion and eversion rather than from a specific movement. The transverse plane (table 4.33) does not indicate any notable change across either movement; external rotation or internal rotation.

CONDITION: in Asymptomatic cyclists, with the taping conditions, the sagittal plane (table 4.31) does not indicate any notable pattern of movement in either movement, plantar-flexion or dorsi-flexion. In the coronal plane (table 4.32), there appears to be a general trend towards an increase in ROM with taping. This increase in ROM appears synonymous with a change in inversion of the ankle. Transverse plane movement (table 4.33) indicate a decrease in ROM with taping conditions. This decrease appears to be alongside a decrease in external rotation of the ankle.

Table 4.34 - **Symptomatic** (n=8) **Sagittal** plane **ankle** kinematics

CONDITION	POWER								
	100 W			200 W			300 W		
	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)	MAX Dorsi-Flex (Degrees)	MIN Plantar flex (Degrees)	ROM (Degrees)
KT TAPE	71.49	43.77	27.72	71.71	43.80	27.91	70.76	43.20	27.56
SD	7.55	9.47	9.58	5.98	9.14	10.12	4.75	9.66	8.75
NEUTRAL TAPE	70.91	43.82	27.09	71.55	43.51	28.04	70.74	43.76	26.98
SD	6.78	9.25	9.11	3.97	10.10	10.35	4.87	9.44	9.26
NO TAPE	71.25	43.70	27.55	70.63	43.50	27.13	71.91	44.54	27.37
SD	6.43	9.20	9.53	5.40	9.50	10.44	4.78	10.19	9.65

Table 4.35 - **Symptomatic** (n=8) **Coronal** plane **ankle** kinematics

CONDITION	POWER								
	100 W			200 W			300 W		
	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)	MAX Inversion (Degrees)	MIN Eversion (Degrees)	ROM (Degrees)
KT TAPE	0.49	-4.65	5.15	0.84	-4.73	5.57	1.28	-4.62	5.90
SD	5.54	5.35	2.10	4.97	5.42	2.25	4.82	5.33	2.32
NEUTRAL TAPE	0.54	-4.32	4.86	0.86	-4.76	5.62	1.07	-4.71	5.78
SD	5.29	5.32	2.01	4.98	5.45	2.34	5.09	5.58	2.25
NO TAPE	0.45	-4.72	5.17	0.85	-4.73	5.58	0.65	-5.13	5.77
SD	5.62	5.56	1.88	5.45	5.83	2.48	5.43	5.86	2.37

Table 4.36 - **Symptomatic** (n=8) **Transverse** plane **ankle** kinematics

CONDITION	POWER								
	100 W			200 W			300 W		
	MAX External R+ (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)	MAX External R+ (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)	MAX External R+ (Degrees)	MIN Internal R – (Degrees)	ROM (Degrees)
KT TAPE	13.51	7.39	6.12	13.31	7.42	5.88	13.58	7.31	6.28
SD	3.42	3.56	2.27	2.69	2.98	2.17	3.08	3.25	2.58
NEUTRAL TAPE	13.36	7.21	6.15	13.48	7.18	6.30	13.39	7.03	6.37
SD	3.07	3.42	2.65	3.56	3.87	3.21	3.36	3.74	3.09
NO TAPE	13.34	6.97	6.37	13.17	6.73	6.44	13.29	6.89	6.40
SD	3.27	3.83	2.81	3.22	4.21	3.05	2.89	4.05	3.16

POWER: With Symptomatic cyclists in the sagittal plane (table 4.34) neither the ROM, plantar-flexion or dorsi-flexion indicate any trend towards change across powers. With coronal plane movement (table 4.35) across powers the ROM appears to increase from 100w to 300w. The main increase in ROM is into inversion rather than eversion. The transverse plane (table 4.36) does not appear to signify a change across powers (100w to 300w) in ROM or external/internal rotation.

CONDITION: In the sagittal plane (Symptomatic) movement (table 4.34), no pattern of ROM movement with taping is indicated. Also neither plantar-flexion or dorsi-flexion are affected by power in a notable way. Coronal plane movement (table 4.35) taping also does not seem to indicate a trending change in ROM; inversion or eversion. Symptomatic cyclists in the transverse plane (table 4.36) appear to exhibit a decrease in ROM with taping. This is associated with an increase in internal rotation with taping.

Analysis of variance (ANOVA) across all participants- n=20

SAGITTAL PLANE – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Between powers (100W/200W/300W)

No significant differences

CORONAL PLANE – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Between Asymptomatic and Symptomatic participants

No significant differences

Table 4.37 - Between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig
100W	200W	-.393	.277
	300W	-.714*	**.049**
200W	100W	.393	.277
	300W	-.321	.373
300W	100W	.714*	**.049**
	200W	.321	.373

TRANSVERSE PLANE – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

No significant differences

Table 4.38 - Between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig
Asymptomatic	5.470	-.787*	**.034**
Symptomatic	6.257	.787*	**.034**

Between powers (100W/200W/300W)

No significant differences

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

ASYMPTOMATIC ANKLE kinematics

Sagittal plane - Asymptomatic participants (n=12) - ANKLE KINEMATICS
No significant differences across conditions or powers

Table 4.39 - **Coronal plane** - Asymptomatic participants (n=12) - ANKLE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) No tape	200W	(1) 5.90 (1.67)	(2) 5.55 (1.60)	0.008	0.35
Neutral tape	(1) 100W & (2) 300W	(1) 5.40 (1.78)	(2) 6.11 (1.79)	0.033	0.71
Neutral tape	(1) 200W & (2) 300W	(1) 5.73 (1.85)	(2) 6.11 (1.79)	0.030	0.38
NO tape	(1) 100W & (2) 300W	(1) 5.46 (1.68)	(2) 6.08 (1.67)	0.031	0.62
NO tape	(1) 200W & (2) 300W	(1) 5.55 (1.60)	(2) 6.08 (1.67)	0.006	0.53

Table 4.40 - **Transverse plane** - Asymptomatic participants (n=12) - ANKLE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) KTT & (2) Neutral tape	100W	(1) 5.03 (1.98)	(2) 5.56 (2.04)	0.004	0.53
(1) KTT & (2) NO tape	100W	(1) 5.03 (1.98)	(2) 5.98 (2.29)	0.001	0.95
(1) KTT & (2) NO tape	200W	(1) 5.17 (1.97)	(2) 5.65 (1.97)	0.044	0.48
(1) KTT & (2) NO tape	300W	(1) 5.18 (2.00)	(2) 5.73 (2.17)	0.010	0.55

Note: A visual comparison of significant differences across planes can be found in the appendix

Post hoc analysis:
Summary of affected conditions and powers in regard to statistical significant differences

SYMPTOMATIC ANKLE kinematics

Sagittal plane - **Symptomatic** participants (n=8) - ANKLE KINEMATICS
No significant differences across conditions or powers

Table 4.41 - **Coronal plane** - **Symptomatic** participants (n=8) - ANKLE KINEMATICS

Condition	Power	Mean ROM in degrees (SD)		sig	Mean diff
(1) Neutral & (2) NO tape	100w	(1) 4.86 (2.01)	(2) 5.17 (1.88)	0.035	0.31
Neutral tape	(1) 100W & (2) 200W	(1) 4.86 (2.01)	(2) 5.62 (2.34)	0.039	0.76
Neutral tape	(1) 100W & (2) 300W	(1) 4.86 (2.01)	(2) 5.78 (2.25)	0.040	0.92

Transverse plane - **Symptomatic** participants (n=8) - ANKLE KINEMATICS
No significant differences across conditions or powers

Note: A visual comparison of significant differences across planes can be found in the appendix

4.12 Pain Measurement Results

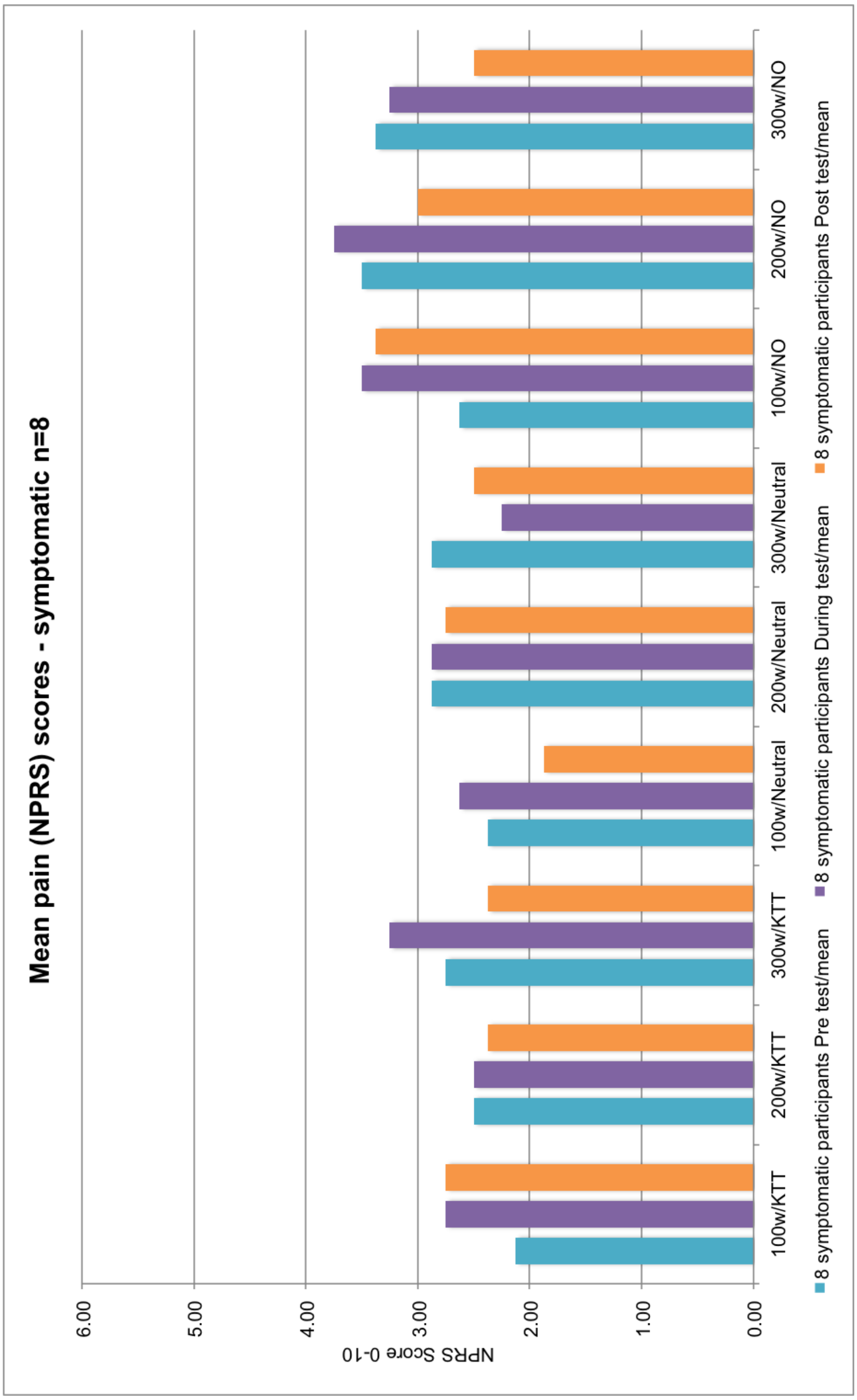

Figure 4.37 Numerical Pain Rating results from symptomatic participants (n=8)

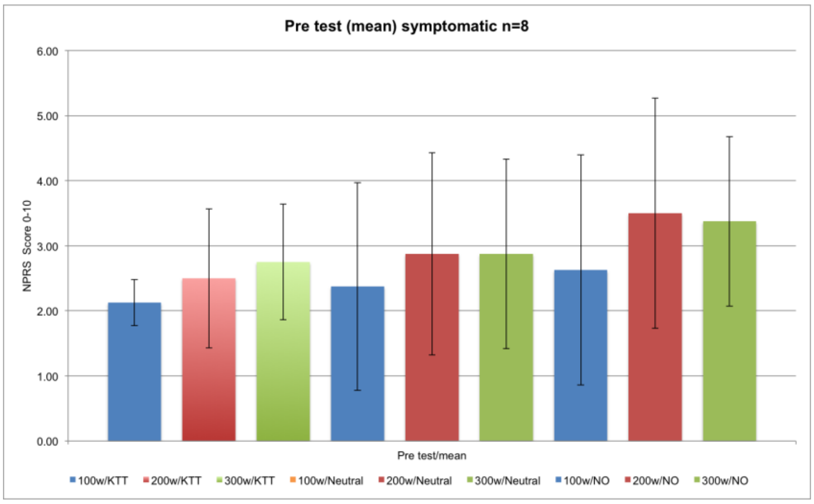

Figure 4.38 Pre (NPRS) test from symptomatic participants (n=8)

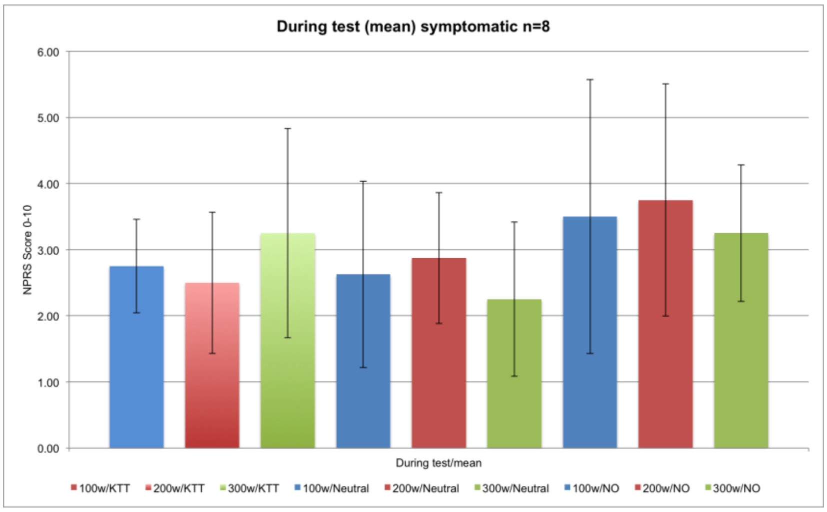

Figure 4.39 During (NPRS) test from symptomatic participants (n=8)

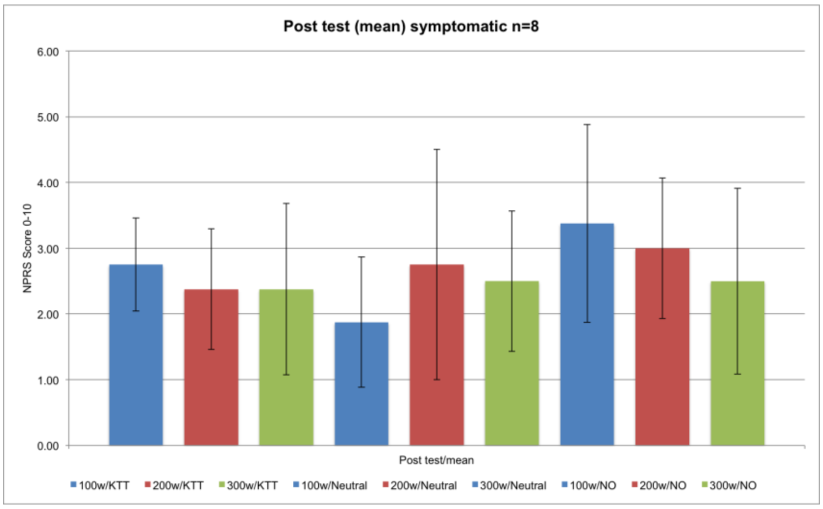

Figure 4.40 Post (NPRS) test from symptomatic participants (n=8)

Table 4.42 – Pain (mean) scores (pre/during/post)

PAIN	KTT	NEUT	NO	*Mean*
100W	2.75	2.75	3.5	*3*
200W	2.5	2.75	3.75	*3*
300W	3.25	2.25	3.25	*2.91*
Mean	*2.83*	*2.58*	*3.5*	

Figures 4.37 to 4.40 indicate a small increase in pain response during the data collection phase of each test. This could be somewhat expected due to the increase in patello-femoral forces during the power production phase of testing with symptomatic cyclists. Pain post testing was reduced in all but two cases. Overall however, there was a mean reduction in pain with taping (19% KTT and 26% neutral) (table 4.42) compared to that of no taping. This could be seen to be in line with the evidence base in that it is essentially short term (testing time frame). Interestingly table 4.45 indicates that at 200W there was a large percentage change (33%) between KTT (2.5) and no taping (3.75) in the mean pain response across pre, during and post testing. The protocol did not allow fatigue to become a factor and hence it is unclear whether KTT or neutral tape has a positive effect on knee pain after longer timescales of cycling. It should also be considered that the pre, during and post-test NPRS measurement could in fact be biased by the very nature of the testing. For example, if the randomisation of the tests moved from no tape at 300W to taping at 100W this may have a certain implication on pain from a decrease in power and placebo of taped knee. Alternatively the effect may reduce as the power increases. In summary, the mean pain scores were noticeably less with taping across the three measurements with a somewhat expected small increase during data collection power phase.

Note on outlier in data

During the analysis of the results an outlier was noted in the knee kinematic data. When the outlier was removed the significant difference in the coronal plane at the knee changed to not being significant. It was noted that this change was minimal, restricted to the knee and more specifically the coronal plane. The statistics were recalculated and these data can be viewed in Appendix 21. One could argue that one or two more symptomatic participants would have brought the results back to significance. Although the cyclist started and finished his coronal movement from different positions, the ROM was not majorly different from the remaining symptomatic participants. Another notable point with the outlier would be that he was the only participant to have an acute-on-chronic presentation due to the fact that his knee pain initial onset was 12 month's previously and had since resolved and reoccurred. This may be relevant to his movement patterns.

Key findings from the clinician online questionnaire:

- KTT identified as the preferred taping used with PFP in elite and experienced cyclists.
- McConnell is not used so therefore does not require inclusion.
- Specific KTT technique to be used in the laboratory-based study was identified.
- Its malleability and longevity are valued highly.
- Pain and biomechanical alterations are important goals of treatment.
- Pain, proprioception and biomechanical changes are the main perceived effects of taping with cyclists and PFP.

Key findings from the biomechanical study:

- Symptomatic cyclists have more movement in the coronal plane (valgum/varum) of the knee (instability).
- Symptomatic cyclists have less coronal (ABduction/ADduction) movement in the hip.
- Symptomatic cyclists have more ankle transverse (IR/ER) movement
- Neutral taping elicits as many changes as the specific KTT technique from clinician responses (questionnaire) and therefore technique may be somewhat irrelevant.
- The hip indicates more significant effects than the knee and in turn than the ankle, which indicates a proximal to distal pattern of changes through taping of the knee.
- Regarding clinical testing, 200 and 300 watts appear to produce more measurable pain effects.

CHAPTER FIVE: DISCUSSION & INTERPRETATION

5.1 Interpretation and Discussion of the Biomechanical study

The main focus of this project is the cyclists' knee and the effect of taping. The testing in the laboratory produced a large quantity of data for analysis and so it is of value to put this into some degree of context. Although clinical practice allows us to consider isolated joint movements, when the human body moves in activities such as cycling we also need to consider a wider perspective when interpreting the data clinically. Although the upper body is predominantly fixed, the lower kinetic chain is contributing towards the activity, hence while the results produced varying differences in isolated kinematics and ROM, the clinical implications should be considered and interpreted with this entire kinetic chain in mind. This study is the first to be carried out to explore the effect of taping in cycling. This forms a starting point for understanding how the cyclist moves and how functional movement is affected by taping, both with symptomatic and asymptomatic cyclists. Each of the participants had their own style of riding, habitual positions, gearing, musculature and history. However, this underpins the nature of combining scientific biomechanical data and a clinical perspective. The project highlights both the effectiveness and efficacy of taping and determines not only the biomechanical changes, but also the outcomes and implications from a cyclists' and clinicians' perspective

The initial questionnaire of clinical practice was undertaken to gain an understanding of the type of tape being used for cycling related knee pain by clinicians working with elite and experienced cyclists. Although this has been discussed in Section 3.9 it is worthwhile revisiting some key outcomes. The simple factor of what type of tape is being used was answered unreservedly from the questionnaire. Alongside this there were some interesting data that informed us as to why clinicians use tape in the way they do, and their therapeutic expectations and rationale behind its use. This not only provided useful data to clarify its use but also evidenced KTT as the primary tape used in cycling, and its underpinning reasoning. Although McConnell type taping forms a widely accepted treatment modality in PFP (Aminaka and Gribble, 2008, Crossley et al., 2001), and has been shown to improve pain in patients with PFP (Bockrath et al., 1993, Powers, 1998), this evidence is not linked to cycling directly. The questionnaire determined for the first time that KTT is the preferred tape for use with cycling and its longevity, ease of application and malleability were all found to be driving factors. Respondents to the questionnaire also indicated their rationale for using KTT. This included pain reduction, neuro-muscular and proprioceptive adaptation, placebo effect and altered biomechanics across the kinetic chain. Pain reduction has been shown to be effective in both McConnell and KTT (McConnell, 1996, Chen, 2008) and the biomechanical investigation adds unique evidence that this is also the case with cycling related knee pain, albeit over a short duration and across mean pre/during/post results. This short duration pain reduction has also been evidenced, (albeit not in cycling), by Thelen et al., (2008), Kaya et al., (2011) and Paoloni et al., (2011). Neuro-muscular and proprioceptive adaptation has also been measured previously and control has been shown to be affected by McConnell type taping (Selfe et al., 2011) using a step descent task.

If control is the consideration, then the exploration of the biomechanical changes with taping has added unique evidence that KTT also has effects in this area and this will be discussed in more detail later in this section.

Interestingly, the Selfe et al., (2011) study also used a neutral taping method similar to that used in this projects' biomechanical study (albeit rigid tape), which support the findings that there appears to be an effect on the knee when a simple neutral taping is used. This has not been previously shown with KTT and cycling. Altered biomechanics in PFP has received much attention over the past ten years since the onset of high-grade 3D equipment (Powers, 2003, Theobald et al., 2012). However, aside from Bini et al., (2012), whose work is notable in cycling despite not looking at PFP, the biomechanical investigation from this project is the only one of its kind to date to examine cycling related to PFP (with taping) in a biomechanical environment. The abundance of anecdotal and low quality online KTT evidence found by Beutel and Cardone (2014) illustrates the need for further investigation. This addition to the evidence base allows its use with cyclists to become more focused on empirical evidence.

From the findings of the questionnaire, the main aim of the laboratory-based investigation was to determine whether tape actually changed anything significantly around the knee from a biomechanical perspective. This directly addresses the biomechanical efficacy objective around KTTs' use with cycling related knee pain. The clinical implications of these were examined alongside the symptomatic individuals clinical effectiveness outcomes, leading to any associated learning and development of effective treatment in those with cycling related knee pain. The following sections outline and discuss the results of the biomechanical investigation in more detail in the individual joints investigated, the knee, hip and ankle. This is intended to permit consideration of the three individual joints prior to considering the overall kinetic chain movement patterns and any associated clinical implications.

5.1.1 The Knee: Taping effects and variations between symptomatic and asymptomatic cyclists

i. Taping effects

Although there were statistical differences (sagittal and coronal) between tape and no tape in the post hoc analysis (Table 4.10, 4.11, 4.13) there were no consistent findings across the tests (Symptomatic and Asymptomatic) that indicate a single taping technique produces biomechanical changes that can be reliably attributed to the specific taping application method. The analysis of variance (Appendix 22) did not show any significant changes between taping conditions. This being the case, it could be conceived that how you apply the tape to a cyclist is somewhat irrelevant, and perhaps this explains the abundance of various techniques employed currently by manufacturers and clinicians (Beutel and Cardone, 2014). This is underpinned by evidence investigating different taping applications and techniques with variable and inconsistent findings (Anandkumar et al., 2014, Campolo et al., 2013, Chen, 2008). The evidence appears to constantly question the exact mechanisms attributable to these effects. These could be due to neuromuscular and proprioceptive adaptation, placebo effect and consequent altered biomechanics across the kinetic chain. This is in line with the recent PFP research from the PFP consensus statements (Powers et al., 2012, Witvrouw et al., 2014). Overall (mixed methods), there were no changes between taping conditions (Table 4.11, 4.14, 4.17) whereas individuals appear to respond with subtle differences (repeated measures). Work by Callaghan et al., (2008) and Campolo et al., (2013) indicated that whilst no changes were found in one task, there were indications of altered effects in others such as proprioception (Callaghan et al., 2008), and squats (Campolo et al., 2013). This indicates that individuals seem to have varying responses to taping and PFP and that these responses may be much more complex than measured biomechanical changes.

The effect of tape on the knee is open to much conjecture, however from the results (Tables 4.3 - 4.8) it can be seen to influence control of movements such as flexion and extension (sagittal) and valgum/varum (coronal). Perhaps with flexion and extension (sagittal) this effect is more restrictive or controlling with the KTT condition, as the direction of tape is applied in a proximal to distal direction of the associated musculature (quadriceps). This is in contrast to a study examining KTT and quadriceps in those with PFP by Aytar et al., (2011) where no changes were found in joint position sense (JPS). Although Aytars' study used a different measurement method, the KTT application followed a similar protocol of application. Conversely, a study by Selfe et al., (2011) found that McConnell type taping reduced pain through changes in the coronal plane movement. This concurred with the laboratory-based studys' findings and, importantly, the methodology had many more similarities in design and application. Interestingly, in the biomechanical study, the neutral taping technique also produced changes and considering that the direction of tape in this case was opposite to that of KTT, its affect is more likely to be neuro-muscular or proprioceptive in nature. This again, is in agreement with work by Selfe et al., and Callaghan et al., (2012).

Supporting the controlling effect, essentially both asymptomatic and symptomatic cyclists have similar sagittal ROM (Table 4.3, 4.6). This may indicate that clinically we should not be looking to achieve an effect in this range of motion with taping, and perhaps any changes here are not related to the knee pain but simply ROM variations alongside power changes. Alongside this, it should be noted that cycling offers a restricted movement based environment to work within, and therefore clinical changes and effects are somewhat limited by this. An interesting development of this theory may be to test a simple knee support (tubi-grip), which would perhaps also control the ROM in a similar way. There is no evidence in cycling specific studies using simple elastic knee supports, however work with knee braces have produced interesting changes in pain, control, proprioception and PF stress (Aktas and Baltaci, 2011, Crossley et al., 2001, D'Hondt N et al., 2002, Powers et al., 2004, Worrell et al., 1998). In a study by Finestone et al., (1993), they investigated both a rigid brace and a simple elastic support (similar to tubi-grip) and found that the sleeve reduced pain more effectively than the brace or no treatment. They did not however measure or record and changes in movement such as in this projects' investigation. Although both braces and elastic supports are not utilised in elite and experienced cycling simply because of their more restrictive effects, they may provide an indication of whether restriction/control affects pain and movement or simply movement alone. They may also provide a useful comparison to the effects of taping.

Within the knee results there is also an interesting change in ROM measurement from KTT to no tape (Decrease in ROM from no tape to KTT) in the sagittal and transverse planes with both asymptomatic and symptomatic cyclists, particularly at 200 and 300 watts (Table 4.3, 4.5, 4.6, 4.8), with KTT having the lowest ROM, then, increasing through neutral to no taping in that order (for example: Table 4.3, 300W: KTT=84.65, Neutral=85.23 and No=86.16). Considering that all testing was randomised and cycling produces very repeatable movement patterns, this is an intriguing result and perhaps once again reflects the controlling effect of the tape conditions. Seemingly the more tape applied (KTT vs. neutral) the more the controlled the effect (Sagittal and coronal). When considering the pain results (Figure 4.37 to 4.40) there is a decrease (mean across pre-during/post 30 sec tests) in pain with KTT and neutral taping compared to no tape, and this is reflected by a difference in ROM (Sagittal and coronal). Table 4.37-40 (Section 4.12) indicates this. Once again, this highlights the multi-faceted nature of the taping effect. The resultant controlling effect of the KTT application (proximal to distal) could simply be attributed to its directional application. However, the direction of application and technique of the neutral taping was very different from that of KTT and in fact applied at 90 degrees to KTT, across the patella itself. The controlling effects of this condition (McConnell type taping) has previously been shown by Selfe et al., (2012) and Theobald et al., (2012) to produce significant changes and these effects were determined to be linked to proprioception and neuromuscular responses. This appears to be supported by previous work indicating a proprioceptive effect being influential in tapings efficacy with PFP (Callaghan et al., 2002, Callaghan et al., 2008).

ii. Asymptomatic and symptomatic cyclists

The control of the knee in the coronal plane by KTT is consistent across cyclists with and without knee pain (Table 4.4, 4.7). Although these are only statistically significant in one comparison (Table 4.11), there may be a trend or pattern that suggests a clinically important difference between cyclists with and without knee pain. If we include the important finding that symptomatic cyclists' had significantly more coronal movement (P=0.005 or 17.8% difference) than asymptomatic cyclists (Table 4.9) then this indication may in fact be, in its simplest format, that tape controls the knee sufficiently to reduce stress on the associated articular surfaces such as the PFJ and tibio-femoral joint (TFJ). This increase in symptomatic coronal kinematics has been shown previously by Bailey et al., (2003), however to date the comparison with asymptomatic has not been investigated. Work by Fulkerson et al., (1992) identified that tibio-femoral movement in both the coronal and transverse planes influence PFJ movement. This influence occurs in the ROM of cycling (<90º and >30º) where rotation increases as the knee is extended (transverse) and adduction and abduction (coronal) also occurs during the power stroke (Ericson and Nisell, 1987). With the patella in direct contact with the condyles in flexion, it acts as a fulcrum and thus, any increased movement in the coronal and transverse planes may increase the stresses encountered on the contact areas during the cycling action. Work by Bini et al., (2010b, 2011, 2012, 2013) and Tamborindeguy et al., (2011) in cycling specific studies have also indicated these increased tibio-femoral/patello-femoral forces and stresses encountered with varying knee angle and power outputs. Patello-femoral (PF) stress has also been shown to increase loaded functional movements by Farrokhi et al., (2011) and considering recent work with KTT by Chen et al., (2008) and collaborated PFP evidence from Powers et al., (2012) we can conclude that the findings in this aspect are in agreement with the current evidence.

In the coronal plane (varum/valgum), asymptomatic cyclists have less ROM (17.8% difference) than symptomatic (Table 4.9) and this is also significant (p=0.005). This indicates that symptomatic cyclists are less stable and/or have decreased control in their movements. This corresponds with similar effects of the step descent evidence with PFP (Selfe et al., 2008, Selfe et al., 2011, Powers et al., 2012, Richards J, 2015). This finding is important in that it has not been measured previously with cyclists, and also its correlation to previous work (albeit non-cycling) may indicate that instability, or lack of control, crosses functional boundaries and its treatment may also benefit from similar clinical modalities and approaches. This lack of control, or controlling effect, has previously been described by Edin (2001), as possibly being 'due to altered somatosensory inflow from the knee joint'. Both Edin and Selfe also suggested that this effect may be linked to 'Type III slowly adapting afferents' becoming stimulated by varying degrees of strain around the skin of the knee, thus stimulating cutaneous receptors. Although not fully understood, and unable to be effectively measured with accuracy, these factors are undoubtedly part of the PFP conundrum.

There was only one significant difference (post hoc) between conditions (KTT and neutral, 0.97º change) with the symptomatic cyclists (Table 4.13) whereas with asymptomatic there were four differences (KTT/No = 1.51º to 0.99º change and Neutral/No tape = 0.65º to 0.93º change) between both forms of taping and no tape across all three planes (Table 4.10). This may indicate that cyclists without knee pain are more sensitive to the tape on their skin and are in fact adapting to its presence. In turn, this may mean that those with knee pain appear less sensitive to movement changes because they are more concentrated on the pain itself. It is intriguing that those (symptomatic) with tape applied indicated a clear pain reduction but without significant changes in knee movement. Alongside this, those with knee pain have more significant differences (post hoc) in the coronal plane (Tables 4.13) between powers (KTT and no tape), hence they may be more sensitive to the power change and the associated increase in muscle force produced across the PFJ contact areas. If we are to try to elicit a measurable change using taping, then a clearer understanding of whether control or pain is the driver of the symptomatic cyclists reaction to the tapes' effects is required. This has been alluded to earlier regarding bracing and supports. Longer duration of testing will also undoubtedly assist answering this question, as this will allow endurance and fatigue to become a factor, this has been shown to be so previously (Bailey et al., 2003, Milligan, 1996, Burke, 2003, Dettori et al., 2006).

iii. Additional effects

There may also be a neuro-muscular and proprioceptive response from the tape being applied to the skin (Schneider, 2000, Anandkumar et al., 2014). This sensory output, leading to pain reduction, was alluded to by the clinicians in the online questionnaire (Section 3.8.5. figure 3.9, and section 3.8.11. figure 3.15). Thus, by applying KTT clinically we may be affecting the available range so as to offload the mechanical structures involved. This may also explain why there are statistically significant differences in the sagittal plane between taping and no taping (Tables 4.10, 4.13), in particular with the higher powers and not coronal and transverse. The KTT may be giving information to the brain to allow increased control of movement by its application to the skin itself, and this may have an additional direct pain association/reduction. This controlling effect is represented by KTT having the lowest ROM in sagittal, coronal and transverse planes with asymptomatic cyclists (Tables 4.3-4.5). This is fundamentally the same in asymptomatic cyclists ROM across the three planes (Tables 4.6-4.8). This decreased movement through ranges may be part of a more complex neuromuscular effect (Merchant, 1988) or simply that pain is reduced because movement is controlled. This in turn, produces a perception by the cyclist of more control and therefore less pain. To this effect, tape consistently decreases ROM (Tables 4.3-4.5) with asymptomatic cyclists. This is less so with symptomatic cyclists, however there remains a trend here also (Tables 4.6-4.8). In 2005, Aminaka and Gribble called for stronger evidence to clarify the definition of neuromuscular effect of patellar taping. To date this remains somewhat elusive and both Powers et al., (2012) and Witvrouw et al., (2014) continue the call for further work in this area in their comprehensive consensus statements. There is little doubt that the changes around the knee found in this study have some degree of neuromuscular input, though to what degree this is happening in cycling is open to suggestion.

If the cyclist with knee pain does have a functional instability then this may possibly be identified, or even predicted at an early stage and any patterns identified then applied to preventative strategies and screening protocols. Tape appears to decrease ROM (stabilise) with coronal movement in asymptomatic cyclists (Table 4.4) but only at 100 watts. Perhaps this result would be more remarkable in recreational cyclists as it is a much lower power and unlikely to be a functional performance related power to elite and experienced cyclists (Wilber et al., 1995, Wanich et al., 2007). Although not significant (p=0.146), symptomatic cyclists also have more movement in the knee in the transverse plane (Appendix 22). The combination of increased movement in both the coronal (1.194º or 17.7% difference) and transverse (1.676º or 11.4% difference) planes may indicate a torsional effect that produces altered forces across articular structures in the knee, and consequently pain. If taping restricts or changes the control of these planes of movement then its effects may be explained with more clarity. These effects are undoubtedly multi-factorial, however, we now have a clearer idea of the differences between those cyclists with and without knee pain and so can perhaps apply tape with more evidence based clinical reasoning than previously.

5.1.2 The Hip: Taping effects, proximal and distal implications and variations between symptomatic and asymptomatic cyclists

There were 27 significant effects across all participants at the hip, 17 significant effects at the knee, and 12 significant effects across all participants at the ankle (Table 5.1). This indicates that there is a proximal to distal effect of taping on cyclists, which is in line with current evidence of control of the hip being an indicator of PFP and its treatment (Powers et al., 2012, Witvrouw et al., 2014). This is also supported by evidence that taping can increase control and loading of the knee (Derasari et al., 2010, Warden et al., 2008) and therefore PF contact areas (Farrokhi et al., 2011). In the most recent PFP consensus statement (Witvrouw et al., 2014) there is a call for more research to investigate the proposed proximal to distal involvement further. Recent work has identified a close relationship between hip function and PFP including gender specific, trunk mechanics, fatigue and gluteus medius activation. Both interesting and relevant is a more recent study by Bazett-Jones et al., (2013), whose findings contrasted with those changes found in this investigation in the coronal and transverse plane. It is worth noting that they used runners (to fatigue) and hence this weight bearing variant may be the predisposing factor to their contrasting results.

Other notable recent research in the hip to knee relationship and taping is a study by Hendry et al., (2014) who found that whilst rigid tape had an effect on both knee and hip joint forces, KTT did not. This was in agreement with Howe et al., (2014) but in contrast to this projects' biomechanical indications. This proximal to distal relationship may be key to understanding preventative or rehabilitative strategies to cycling related knee pain. As with the current literature around PFP, control of the hip alongside that of the knee may also prove to be a way forward with cycling. This approach follows a logical format by its focus on a larger movement ranging joint (the hip) with larger multi pennant musculature adding to the controlling factors of the knee joint, and ending distally with two smaller joints (the ankle). When we consider the entire kinetic chain, this logic demands further evidence, however, in light of the results of this study, also demands more serious consideration and applied research to cycling related knee pain.

Table 5.1 – Significant effects summary

	Sig effects		Sig effects		Total
Asymptomatic hip	17		10	Symptomatic hip	Hip = 27
Asymptomatic knee	10		7	Symptomatic knee	Knee = 17
Asymptomatic ankle	9		3	Symptomatic ankle	Ankle = 12

The results indicate that as the power increases (100W to 300W), the hip produces an increase in ROM across all planes of movement (Tables 4.16-4.21). This would indicate that as this large group of musculature produces more power, the joint moves further towards its end range. This is reinforced by the majority of the significant differences being across powers, and not conditions (Tables 4.23, 4.24, 4.25, 4.26, 4.30) in the hip. Previous work by Bailey et al., (2003), Bini et al., (2010), Tamborindeguy et al., (2011), and Theobald et al., (2012) have also found variances between power and kinematics, however none of these studies have looked at the hip kinematics in relation to its distal joints and power.

Interestingly, when we look at the hip joint it appears from the results that there is a decrease in ROM (1.59º in coronal and 1.41º in sagittal) between symptomatic and asymptomatic cyclists (Tables 4.22 and appendix 22), symptomatic cyclists' having lower ROM. Coronal plane results were significant (p=0.001 and 26.2% change), and sagittal close to significant (p=0.060). This is irrespective of the condition and power as the ROM increases with power across all conditions, but notable in that the proximal joint to the knee (hip) appears to have a decreased ROM to those of asymptomatic cyclists. This may in fact indicate that those cyclists with, or perhaps predisposed to cycling related PFP have less movement in the hip, or simply that those with PFP are more sensitive to the knee pain and that, in turn, produced some degree of adaptive hip ROM pattern response. Hip contribution to the cycling action has been measured in previous studies (Mornieux et al., 2007, Bini et al., 2010a) and although a reduction in hip ROM was found, this was deemed to be fatigue related due to the methods used. There have been no studies measuring hip kinematics in relation to taping for PFP to date, and notably fatigue played no part in the laboratory-based investigation due to the testing time and design methods. In contrast to this projects' biomechanical findings, a study by Souza and Powers, (2009) found that those with PFP (female runners) had increased hip ROM in both coronal and transverse planes and interestingly this was related to a increase in muscle activity in the gluteals. Whilst this projects biomechanical investigation did not measure muscle activity, it remains possible that with cyclists the opposite is happening.

There is also a trend across the conditions indicating a controlling pattern at the hip with tape in asymptomatic cyclists (Tables 4.16-4.21). Once again, perhaps this control is linked to the pain decrease and sensitivity alluded to by the clinicians responses from the questionnaire, thus meaning that symptomatic cyclists (Table 4.29) have fewer changes at the hip (coronal) as they have more pain at the knee and are in fact more sensitive to this (pain). Asymptomatic cyclists may have more changes at the hip (Table 4.26) due to a response to the tape at the knee (control/restriction), rather than pain. It is possible that an increased sensitivity to knee pain (symptomatic) directs an alternative movement pattern to compensate (reduction in hip ROM). Conceivably related to the earlier suggestion that tape application technique is somewhat irrelevant, there were variable significant differences between conditions in the coronal plane across the hip (Table 4.26/4.29). These were again inconsistent and with no measurable pattern identifiable. As mentioned previously, the hip results produced the most significant effects (Table 5.1), which indicate a proximal control question that is in line with current research (Cichanowski et al., 2007, Powers et al., 2012, Witvrouw et al., 2014). The question remains as to whether the increase movement of the knee produces the decreased movement of the hip or vice versa. Future research into active and passive ROM prior to testing may indicate whether a relationship is in fact evident. Measuring passive range of movement (PROM), and active range of movement (AROM) in those with cycling related knee pain may indicate a pattern that can be attributed to those experiencing pain during cycling. Little evidence is available in measurement of hip ROM in those with PFP (Cibulka and Threlkeld-Watkins, 2005), however it is rational to assume that hip joint movement has some degree of relationship to PFP alongside muscle activity. In a recent study by Roach et al., (2014), a significant difference was found in passive hip extension in those with PFP (Thomas test) although no differences were found in rotation of the hip. This appears in line with the findings of this study in both the sagittal and coronal planes, yet it is notable that to date (excluding this biomechanical investigation) there have been no cycling related studies investigating this issue.

From a functional perspective it is interesting that with cyclists the hip in fact has less movement. With gait and running based studies, when the foot is fixed and full weight bearing, the hip would appear to be a more controllable axis to movement and therefore rehabilitation focus on the hip seems to produce positive results (Dolak et al., 2011, Thijs et al., 2011, Nakagawa et al., 2013). Perhaps with cycling, where the kinetic chain is not linked to full weight bearing, this factor is somewhat more variable, although to date there has been no cycling specific work in this area. Reduced ROM in the hip may indeed correspond with the predominance of cycling related specific knee pain over hip pain. However, it is also possible that cyclists with knee pain do in fact have stiffer hips. This requires further investigation in order to provide clarity as to whether there is indeed an anatomical and physiological link to why some cyclists may be pre-disposed to knee pain.

5.1.3 The Ankle: Taping effects, proximal and distal implications and variations between symptomatic and asymptomatic cyclists

With asymptomatic cyclists taping appears to somewhat reduce the plantar-flexion/dorsi-flexion movement without any significant changes (Tables 4.31). Cyclists with knee pain conversely do not appear to follow this sagittal ROM pattern (Table 4.34), which may be a result of the adaptive response to the pain and control of the tape from the proximal joint (knee). Studies have previously shown changes in ankle ROM during cycling (Peveler et al., 2012, Bini et al., 2010a, Ruby et al., 1992b), but in contrast to this investigation these did not compare symptomatic and asymptomatic cyclists. To date there have been no studies showing the effect of KTT on the ankle ROM with cycling related knee pain. Bini et al., (2010) indicated an increase in dorsi-flexion and overall ROM with a cycling related study to exhaustion, however there were no pathologies or conditions involved. Other studies on ankle ROM looked at taping of the ankle rather than the knee (Simon et al., 2013, Briem et al., 2011, Halseth et al., 2004).

Interestingly the inversion/eversion (coronal) movement of the ankle/foot (asymptomatic) increases with taping of the knee (Table 4.32). Therefore, with asymptomatic participants as the knee ROM (coronal) decreases, the ankle/foot ROM (coronal) increases. This may be indicative of the principle of the floating cleat strategy. There are varying degrees of movement required in each individual during the cycling action. If taping restricts one such ROM (knee) then, if available (cleat float movement), the ankle may 'take up' this required movement to facilitate less pain (Gregor and Wheeler, 1994, Burke, 2003, Gregersen et al., 2006, Faria et al., 2005b, Silberman et al., 2005) . Floating cleats are proposed to alleviate knee pain to some degree (Boyd et al., 1997, Paton, 2009, Ramos-Ortega et al., 2014). However the abundance of this research appears to be anecdotal and marketing-led with no identifiable studies supporting these claims. It is possible that KTT application controls the knee sufficiently to, in effect, direct the ankle/foot to move more to accommodate the ROM (coronal and transverse) required by the pedal stroke. It may be interesting to direct future work into whether various cleat float systems have any positive or negative effect on knee ROM with taping.

The significant change between cyclists with pain and those without (Table 4.38) was that symptomatic participants had increased transverse ROM in the ankle (0.79º) compared to those who were asymptomatic; this was a 14.3% change (p=0.034). It is possible that clinically we could endeavour to identify this through screening based measurement. It is notable that should this merely be a consequence of the sensitivity to pain in the knee, the ankle/foot may simply be moving more in the available cleat movement to facilitate a more aligned/controlled knee. Although at the distal end of the kinetic chain, the ankle is worthy of attention. Further work should incorporate this joint due to it being fixed (albeit with degrees of float) to the pedal and thus being very much part of the drive of the pedal stroke. Different cleat systems allow varying amounts of float (from zero to 15 degrees) which may allow the distal part of the kinetic chain to effectively accommodate movement variances such as knee and hip coronal movements. The participants in the biomechanical study employed a varying degree of pedal systems, cleat position on the shoe and amounts of available float. These were not measured or noted other than make and model (Asymptomatic: 4 x Speedplay™ zero, 6 x Shimano™ SPDR, 2 x Look™ keo. Symptomatic: 2x Speedplay™ zero, 6 x Shimano™ SPDR).

Although orthoses were not involved in this study it is worth noting that, as with weight bearing and gait related evidence there is increasing interest in cycling specific orthotics in relation to knee pain (O'Neill et al., 2011, Yeo and Bonanno, 2014). Interesting to this study, Barton et al., (2012b) reported a relationship between ankle eversion and hip adduction in those with PFP. This increase in eversion and hip adduction is broadly in line with the results from this project (Table 4.17, 4.20, 4.32, 4.35) albeit with both asymptomatic and symptomatic cyclists. Cycling shoes worn by elite and experienced cyclists have extremely rigid carbon fibre soles, and are traditionally a very tight fit with ratchet straps to tighten the shoes against the foot and ankle. This is considerably different from running shoes where the foot has more freedom for movement and therefore more likelihood to be affected by orthoses. To date research into multi-segment foot biomechanics with cyclists has been very limited (Bousie et al., 2013, O'Neill et al., 2011) and these are even scarcer when investigating the relationship with PFP.

5.1.4 Pain considerations from symptomatic cyclists results

Although it is worth noting that pain was only measured in respect to a single 30-second test and clinical presentation is often based on much longer duration of cycling, the results clearly indicate more pain (across mean pre/during/post results) when the knee was not taped (Figure 4.37 to 4.40 and table 4.42). This would appear to underpin the sensory and controlling nature of the taping effects from the biomechanical investigation discussed earlier. Neutral taping also reduced pain (across mean pre/during/post results), which in turn appears to reinforce that it does not appear to matter how you apply the tape, but that you apply it in some form or technique. Pain emanating from PFP has been described as ‘chronic idiopathic pain’ (Boling et al., 2010), however the true source of this pain is, as yet, not completely understood (Powers et al., 2012). Dye’s (2005) homeostasis theory goes some way towards accounting for the cause of pain; the theory proposes that increasing loads and forces disrupt normal pain-free function. However the exact mechanism that taping facilitates to reduce pain has caused much conjecture. Taping has been shown to improve proprioception in those with PFP and also alter PFP kinematics (Derasari et al., 2010, Selfe et al., 2011). Control of the TFJ has also been indicated by Selfe et al., (2011). With regard to patella contact areas, taping also appeared to offload the structures involved, which may in turn reduce pain. In KTT specific studies pain reduction on the knee (albeit short term) has been demonstrated by Aytar et al., (2011), Anandkumar et al., 2014 and Campolo et al., (2013), but whether the direct mechanical offload, or additional neuromuscular and proprioceptive adaptation, is the root mechanism of the pain reduction is still predominantly unconfirmed. This project's laboratory-based investigation has added to the evidence base in that it has demonstrated the short-term pain reduction of KTT in both specific and neutral technique (across mean pre/during/post results). In fact, the results are the first to be demonstrated with a cycling specific PFP study to date.

From the results of the online questionnaire it was clear that clinicians see pain reduction as a fundamental outcome measure and that they also see KTT as achieving this clinically. Their rationale and answers to the questionnaire also agreed with the current evidence in that they are unclear of the exact mechanism of pain reduction. Taping demonstrated a mean (across pre-during/post tests) pain reduction (KTT by 19% and neutral by 26%) however the greatest amount of change was seen at 200W where there was a change of 33% between KTT and no taping. It was noted by the participants (albeit informally during testing) that 100 watts power was somewhat difficult to maintain and, in light of this, it may be that this power (100W) is in fact negated as a productive testing power to elicit a notable response in the target group of elite and experienced cyclists. If this is indeed the case then clinically it could be argued that a power of at least 200W be recommended for using the apply-test-retest protocol indicated by clinicians online responses (Section 3.8.3, figure 3.7). This would appear to be in agreement with other work in cycling with the target group of elite and experienced cyclists (Arkesteijn et al., 2012, Bailey et al., 2003, Mornieux et al., 2007, Theobald et al., 2014). Although pain was measured, future research into cycling related knee pain and taping may require a more functional and longevity based approach in order to determine the effects of taping on pain. This work may indeed be both field and laboratory based.

General observation on taping technique application

The exact technique of KTT application does not appear to be critical, as neutral taping appears to elicit as many changes as the specific technique identified in the initial online questionnaire. Neutral taping had as many significant changes as KTT with no identifiable pattern or biomechanical regularity. It may therefore be an indication that, indeed, any tape application (KTT) simply controls the knee and/or evokes an increased sensory effect on the muscular activity (outlined earlier) that is one of the underpinning mechanisms to this control. This sensory awareness of KTT on the knee has been previously shown to affect both strength and pain (Anandkumar et al., 2014). If this lack of specificity in application is the case, then we are conceivably required to identify this prior to clinical application to cyclists requiring taping for knee pain. Likewise, perhaps manufacturers also have a degree of responsibility to communicate this. Recent KTT reviews by Montalvo et al., (2014), Parreira et al., (2014) and Williams et al., (2012) broadly agree with this and also recommend increased evidence based clinical communication as to its proposed effects. Because tape appears to control the knee to some degree in both the sagittal and coronal planes (Table 4.3, 4.4, 4.6, 4.7), this indicates that pain reduction is both mechanical and sensory (Hosp et al., 2014, Campolo et al., 2013). The question could therefore be posed as to whether the tape is directly affecting the movement and therefore indirectly decreasing the pain, or is it purely a sensory perception and not mechanical at all. Both may in fact be true. The results indicate that changes did in fact take place due to the two taping applications rather than by placebo. Pain was reduced, biomechanics altered, and ROM decreased. In isolation, these factors may indicate a placebo effect, however combined they demonstrate that KTT may in fact illicit a real change in those with cycling related knee pain. Its specific technique of application appears open to much variation and is indeed questionable as to any degree of specificity.

5.2 The clinical considerations of biomechanical efficacy vs. clinical effectiveness in cycling related knee pain and taping

When considering the biomechanical efficacy and clinical effectiveness of taping it is essential to integrate and synthesise the findings of both studies. This is in consideration of the fact that the project journey began by determining whether and/or how clinicians currently use taping, and then progressed to investigating whether the taping actually achieved some of these proposed effects in a controlled laboratory setting, with both symptomatic and asymptomatic elite and experienced cyclists. KTT was clearly the tape of choice and the proposed effects included (mean) pain reduction, biomechanical changes, placebo, stability, control and muscular adaptation. Although the investigation did not answer all the questions asked of it with complete clarity and determination, to be able to project the results forward into clinical learning we must consider how clinicians can interpret and use the information gained from the results, and in some way enable them to make reasoned decisions for evidence based practice.

i. Symptomatic knee movement

The symptomatic knee moves more (1.19°) in the coronal plane (17.8% change) than the asymptomatic cyclists knee (Table 4.9) and therefore this may be clinically relevant to its effective treatment. This increase in movement appears to emanate from the maximum point of the ROM (Table 4.7), which is in effect a varus knee movement, where the knee moves laterally, and the ankle/foot inverts and externally rotates at the top of the power stroke (Tables 4.35, 4.36). This indicates that the knee moves from a more lateral position and moves medially, producing more torsional movement through the main power production of the pedal stroke. Although coronal and transverse plane movements with PFP participants have been investigated previously (Callaghan et al., 2008, Powers et al., 2012, Selfe et al., 2008, Selfe et al., 2011), these studies were not cycling based and so any similarities should be reflected on clinically with this consideration in mind. Also, although a call for further research into these altered mechanics has been made by comprehensive consensus statements, (Powers et al., 2012, Witvrouw et al., 2014), to date, these consensuses have not included cycling related investigation. Variations in coronal and transverse kinematics may be the cause of increased PF stress on the cartilage and associated structures (Farrochi et al., 2011, Powers et al., 2014, Tamborindeguy et al., 2011). Clinically this may indicate that a more genu varum gait predisposes the cyclist more likely to have cycling related knee pain or is perhaps simply related to the cycling action adopted by the participants in this study. If the clinician can recognise that those with more coronal and/or transverse knee movement are either experiencing, or likely to experience, knee pain, then perhaps there is a way of clinically measuring this movement. Modern smartphones and handheld tablet devices often used in sports injury clinics are currently able to capture up to 120 frames per second (FPS) and so it may be possible to compare the affected side to the unaffected side and implement an evidenced based rehabilitation protocol based on current knowledge for PFP (Lankhorst et al., 2013, Witvrouw et al., 2014, Boling et al., 2006). Inter-participant measurement may, however, be symmetrical and if this is indeed the case, we currently only have this study's measurements to guide us from a ROM perspective. Also, it is possible that clinical accuracy may present a barrier. This would indicate that further work is required to enable clinicians to utilise a database of clinically identifiable measures that may indicate whether coronal and transverse movements are abnormal. If clinically based video capture is unable to identify any anomalies, then it may also be possible to use previously utilised step down and stability based tasks to identify any instability in the knee of the cyclist (Selfe et al., 2011, Lee et al., 2012, Bolgla et al., 2008). There are clearly opportunities to contribute further to a knowledge base of cycling specific knee pain pathologies should a protocol be developed in the future. Further research is undoubtedly required to ascertain whether it is possible to screen actual/potential knee pain from a clinical setting either on or off the bike.

Alongside this, and projecting the results to a clinical perspective, it could be that if a seat is too low, cyclists with increased knee valgum/varum movement may be more susceptible to knee pain because the knee is directed further into increased flexion and potentially into more varus movement (Bini et al., 2010c, Tamborindeguy and Rico Bini, 2011). This would in effect direct the knee in a lateral to medial coronal movement across a greater ROM, creating more torsion and potentially more pain. Although this is very unlikely with elite and experienced cyclists, as their set up is likely to be within the acceptable boundaries (Faria et al., 2005a), recreational cyclists may in fact often have a lower set up due to inexperience (Salai et al., 1999). Clinically this is a potential area for future research with PFP and there may in fact be some correlation with the target group tested in this study (biomechanical). Dissemination of this work through publication will aid clinical understanding in this area.

ii. Proximal indications (hip)

Considering that the hip is a very topical area in the evidence base as a focal point for rehabilitation for PFP, the symptomatic cyclists' hip is notable in that it moves less (Table 4.22) in the coronal plane (1.59° or 26.2% change). Therefore, with symptomatic cyclists, as they begin the pedal stroke (flexion) they are less abducted, and at the end of the power stroke (extension) are less adducted, thus giving a tighter ROM (Tables 4.20) at the hip joint. This effectively indicates that the hip is straighter through the power generation phase of the pedal stroke with the knee moving through a greater ROM from a lateral to medial direction. To date, research into hip kinematics with cyclists is limited almost exclusively to performance (Neptune and Hull, 1995, Bini et al., 2010a) and investigations related to PFP and taping in cyclists' non-existent.

Considering the objectives of this study were to measure and determine changes in the knee, hip and ankle related to PFP and taping, this knowledge is new and unique work that adds to the currently available research in the area of PFP. Although there are no data around passive measurements of symptomatic cyclists' hip ROM, it remains plausible that, as with knee movement, those cyclist's either experiencing or pre-disposed to cycling related knee pain have tighter or stiffer hips than those asymptomatic. Again, further research is required to establish any link, but clinically, this may provide interesting future work that may prove useful in both pre-habilitation and rehabilitation work. Although the transverse plane knee results did not indicate a significant difference (appendix 22.8), the symptomatic cyclists knee had more transverse movement (11% change). The cyclists' also began the pedal stroke with more internal rotation than the asymptomatic cyclists (Tables 4.5, 4.8). Clinically this may indicate cyclists with knee pain have stiffer hips that in turn force the knee into more torsional movement, to allow the pedal stroke to be completed with the correct amount of power to overcome the resistance from the gearing. If this were accurate then it would indeed be clinically valuable. Screening protocols may possibly be devised, researched, measured and quantified, and treatment directed from findings as clinical outcome goals. A firm base of objective measures from those with cycling related knee pain would be an obvious development to ascertain whether significant variances exist between those with and those without knee pain.

iii. Distal considerations (ankle)

When considering the lower kinetic chain, the symptomatic cyclist's ankle/foot moves more (Table 4.38) in the transverse plane (0.79° or 14.3% change), which may indeed be a biomechanical adaptation or, in fact, be indicated by the available active range of movement (AROM). This increased movement may be produced from a combination of sub-talar and talo-crural joint movement, with most of this movement being indicated towards external rotation at the bottom of the power stroke (external rotation is reduced in asymptomatic). This distal change's effect on the knee is not entirely clear due to the foot being tightly enclosed and fixed on a cleat that has variable adjustments. These variants were specific to each cyclist's habitual movement patterns during the cycling action. Previous work with distal mechanics and PFP have indicated greater tibial IR in those with PFP (Noehren et al., 2012), which interestingly appears to contrast with that of Powers et al., (2002). Also, an increase in rear-foot eversion may be linked to hip adduction in those with PFP (Barton et al., 2012b), however, in line with this biomechanical analysis, there does not seem to be any current evidence that substantially links distal factors with PFP (Noehren et al., 2013, Witvrouw et al., 2014).

As with the hip, it may be possible to measure any changes in ankle ROM clinically, and this data in turn used to quantify whether there is indeed a relationship between ankle ROM and cyclists with knee pain. Clinically we may be able to address this increased movement with an alteration or adjustment in pedal/cleat type or pedal/cleat action. If symptomatic cyclists move into increased knee varum and the ankle/foot externally rotates further, then by facilitating more movement (or perhaps controlling it using cleat mechanisms currently available such as the Speedplay™ zero system) at the ankle we may be able to stabilise the knee through its ROM. The ankle in a symptomatic cyclist may in effect be required to move more and hence consideration of available cleat movement would be justifiable as an associated clinical outcome strategy (Paton, 2009, Ramos Ortega et al., 2012). If the symptomatic cyclist's ankle requires more movement then this may reinforce pedal float anecdotal evidence, in that changes in float can often be an effective way to achieve less knee pain (Silberman et al., 2005, Asplund and St Pierre, 2004).

The results demonstrate that the knee moves more (coronal) in symptomatic cyclists, also the ankle moves more (transverse), so if the ankle is free to move this may in effect, straighten the knee and reduce the coronal movement, thus making it more similar to the asymptomatic cyclist's data. This, alongside work on hip stability and mobility could be a clinical development objective. If we allow the ankle/foot to move more in the transverse and coronal plane it may allow the patella to track more effectively producing less stress on the articular structures, thus decreasing knee pain. It is important, however, for the clinician to fully understand any treatment using alterations in pedal cleat tension, float and positioning. Depending on experience and understanding, this may be a challenge to non-cycling based clinicians, and therefore further work in this area, to quantify the options available is required to facilitate an evidenced based protocol that can be disseminated as being repeatable and reliable.

iv. Proximal to distal control in regard to pain

It is possible that a knee with instability in the coronal plane is a knee more likely to be painful when cycling. This is valuable if we can clinically measure it and use it as a predictor to cycling related knee pain. Considering the evidence base indicates that control of the knee appears to emanate from the hip, then control of the knee from the hip may help decrease knee pain. This would be in line with current research in running based and weight bearing related PFP. A rehabilitation programme for the hip to increase mobility and control may offer options to both the clinician and cyclist. If a tighter/stiffer hip is one causal factor in cycling related knee pain then clinically it may be that creating more functional (knee) movement, that is also under control during said function (pedaling action), will allow the knee to achieve a coronal pattern closer to that found in the asymptomatic cyclists. As outlined in the results discussion of the hip, measurement of active range of movement (AROM) and passive range of movement (PROM) to create a knowledge base would enable clinical decisions to be made with more purpose and logical rationale.

From the results, taping clearly has some effect on knee pain (across mean pre/during/post results), but this effect does not appear to depend specifically on the exact technique of application of KTT. Thus, the clinical implications of these unique findings can be applied to good effect. Considering the abundance of available techniques that propose an effect on pain, clinicians may be wise to be attentive to proximal and distal factors together with the tape application itself. Alongside these implications, it seems that 200 watts produces the greatest effect on pain (33% change) and therefore if the clinician intends to apply the test/apply/retest protocol indicated by the clinicians’ responses to the online questionnaire, then doing so at this power would appear justified. Modern methods of cycling power measurement mean that clinical testing at this power is both accurate and reliable (Hurst and Atkins, 2006). The biomechanical investigation undertaken in the project provides unique evidence that 200W may facilitate the most reliable effects in pain when measured clinically.

On reflection, it would have been interesting to measure muscular activity through EMG analysis. In light of the results of this project, measurement of the controlling hip musculature such as gluteus medius/maximus, and also the medial and lateral quadriceps (KTT placement allowing), may indicate a change in muscle activation that reflects the changes seen in ROM. This addition may also provide noteworthy data to help indicate which areas were functioning differently in symptomatic cyclists and thus provide potential rehabilitation indications. With the advancements of wireless EMG provision this area of research may be open to further work in a clinical setting. An understanding of which muscles may be contributing towards knee pain will allow clinical rehabilitation to be more focused with cyclists experiencing knee pain. Although EMG has limitations such as crosstalk from other muscles, determination of muscle on-off times and skin/fascia influence (Rouffet and Hautier, 2008, Albertus-Kajee et al., 2010, Egana et al., 2010) to date has been limited to laboratory-based work. More mobile wireless systems are now available for field based use and if accuracy can be achieved it would be useful to integrate 3D biomechanical and muscle activity data. This knowledge would undoubtedly be extremely useful in a rehabilitation setting.

Finally, with regard to pain, inclusion of field based pain testing to investigate the longer term (endurance duration) pain relief of KTT would have been an interesting adjunct to identifying KTT's effects from a clinical perspective. Its short-term (acute) effects seem evidenced (Tsai et al., 2010, Song et al., 2014, Kalron. A, 2013) however, with cyclists, short term is often initial pain on the bike and testing in the laboratory does not appear to consider any degree of endurance (such as in excess of two hours). Further work on how KTT affects pain over longer rides is crucial in allowing future studies to be planned and implemented. The treatment of cycling related knee pain from a clinical perspective remains a multifaceted problem. Essentially, decreasing the pain is a fundamental objective; however understanding the contributing factors is also essential in uncovering the layers of movements that may be causal to the repetitive nature of the issue. It is possible that development of a recognised pain score protocol for cycling related knee pain could aid clinical interpretation of this problem. Simple measurement of pain with clear parameters, that are cycling focused, will enable the clinician to work with the cyclist to identify patterns that can be addressed.

Chapter Six: Conclusions and Further Work

6.1 Conclusion

In conclusion, based on the findings from the questionnaire we know that KTT is the preferred tape used with cycling related knee pain. The actual taping application technique however does not seem to be crucial in attaining change at the knee, hip or ankle joints. The study has also determined that there are variations between cyclists with knee pain and those without. With symptomatic cyclists, the knee appears less controlled in the coronal plane, the hip moves less (coronal) and the ankle moves more in the transverse plane. This indicates a proximal to distal pattern in line with the evidence base and that the contact areas in the PFJ and TFJ are potentially under increased stress with symptomatic cyclists. There are differences between the conditions and powers tested, however these have no identifiable pattern that pre-disposes them to any clinical implication. Neutral taping elicits as many changes (pain and biomechanical) as the specific KTT technique and therefore technique may be somewhat irrelevant in the clinical setting. Regarding clinical testing, 200 watts appears to produce more measurable pain effects.

Recollecting that biomechanical efficacy is the capacity to produce a biomechanical change, and clinical effectiveness being the capability of producing a clinical outcome, the results lead us towards further work around these findings and establish an evidence base to develop, both clinically and in the biomechanical laboratory setting. Symptomatic knees with more varus/valgus movement may be an identifiable clinical finding either actively or passively, whilst restriction in the hip joint may also be a clinical indicator. The increased movement in the transverse plane of the ankle indicates further research around cleat movement during the pedal stroke. Further work is also required for potentially screening cyclists with decreased hip movement and for those who may be predisposed to, or experiencing knee pain. This pain, which is seen to exist more in those (symptomatic) where no tape is applied, requires further research to determine its exact nature and onset, either in a more functional environment, or over a longer time period. This would elicit more fatigue related functionality, representing more realistic road specific cycling activity. The protocol from this study may be utilised in future experiments to determine additional clinical predictors and implications.

Finally, it is important to 'close the circle' from initial conception to conclusion of this project. The initial question of 'does the tape do anything' proposed requires the clinician to consider the results from a pragmatic standpoint and enable clinical reasoning to be applied to cycling related knee pain. Taping clearly does something from a pain and movement perspective, however it is likely that this effect is not what the anecdotal rhetoric presumes. If the intent is to use the tape to elicit specific biomechanical change then this is difficult to justify and measure, even more so clinically. If the expectations are purely around pain then it is likely that pain will be decreased using KTT. Determining the underpinning movements across the kinetic chain that are causing the PFP appear somewhat elusive at this point in time.

6.2 Thesis strengths and limitations

The strengths of this project lie in its logical structure, firstly to identify and clarify taping procedure and application, followed by a robust protocol using recognised biomechanical testing procedures. This logic was determined from a practical clinical question that underpinned the entire project, 'does tape do anything'. Its entire underlying principle has a clinical background and application that has been specifically envisioned to allow clinicians to make practical decisions around taping efficacy and effectiveness when treating cycling related knee pain. Without this, one could argue as to its usefulness to the cyclist or the clinician. This rationale, although in its infancy, is designed to facilitate progression and development from a research perspective. This will notably enhance the evidence base and allow clinicians to add to this collective in many ways. There are multiple factors that provide unique and significant contributions to knowledge in the subject area, and these have been highlighted. To date there have been no studies done in this specific area.

It should be taken into account that as with a lot of sports, cycling is predominantly an outdoor activity, and one which combines musculoskeletal movements alongside bike movement, atmospheric variances, surface changes and gradient disparities. All of these factors could not be considered during the laboratory testing and therefore it could be argued that the true nature of cycling related knee pain was not measured. This is of course, not entirely achievable in a controlled setting. The protocol was robust, reliable and repeatable and to this end the findings can be relied upon as accurate within the boundaries of the testing environment. Although clinically the exact protocol is dependent on certain equipment being available, the results have been interpreted in order to allow their use with as much practical clinical application as possible. It should also be recognised that cycling related knee pain is often fatigue based and therefore the pain results could be seen to be somewhat limited in their usefulness due to the small timeframe of data collection. Because onset is not always immediate it may be that the results from the laboratory-based investigations' pain measurements are not entirely representative of all levels and degrees of cycling. Accurate measurement was however dependent on the protocol and methodology being repeatable and reliable. This ensured the biomechanical data was robust.

6.3 Further work

Although the outcomes of these studies have produced results that allow us to make a degree of interpretation as to their implications for cycling related knee pain, the entire journey of this project has also opened up additional areas of interest such as variances between symptomatic and asymptomatic cyclists, the associated kinematics of the hip and ankle, the influence of different power and specific KTT techniques on the knee, and their consequent opportunities for future work. The study is representative of a unique contribution to science in that it is a starting point on which other can build. Its findings have been a progression in understanding whether taping has any effect on the knee, both with and without pain, during cycling. From the results and previous work we have an understanding of how asymptomatic cyclists move from a biomechanical perspective. The work on symptomatic cyclists with knee pain requires further investigation to confirm the findings and examine the variances in movement patterns across a larger group. The dissemination of this work to the scientific and clinical population has been initiated through abstract publication (Theobald et al., 2014b, Theobald et al., 2014a), presentation at the Science of Cycling Symposium at the Australian Institute of Sport in Varese, Italy (July 2014), two poster presentations at the 2014 World Congress of Cycling and both poster and oral presentation (Winner of Best Professional Abstract, 2014) at the 2014 Medicine of Cycling conference in Colorado Springs, USA. Further information on this work can be found in Appendices 1 to 9.

It may be that undertaking screening of cyclists clinically for association between these variances will enable us to undertake research into whether we can use clinically measurable differences to identify injury prediction and therefore possible prevention. This screening would require an adapted pain scoring system for cycling, and a reliable and repeatable ROM measurement system that allows for collection of larger group numbers. Determination of any variances in ROM in the hip, knee or ankle with symptomatic cyclists will inform further biomechanical investigations. There will undoubtedly be a requirement for additional field and laboratory work to look further at pain effects of KTT as it is clearly a factor used in its clinical rationale (online questionnaire responses). Endurance being a predominant factor of cycling means that this is a key area that requires further work alongside the more biomechanical based studies in the laboratory setting. Additional investigation into the longevity of KTT's effects will add to the growing evidence base and broaden the understanding as to its underpinning mechanisms of achieving pain reduction. Once this work has been progressed it is a logical step forward to include rehabilitation strategies to predict and prevent injury in more longitudinal based work.

Appendices

Publications, presentations and invited posters by author from this and other related work.

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BOOK OF ABSTRACTS

Open Access

An online survey using social media investigating the use of kinesiology type tape and McConnell type tape with clinicians who treat cycling related knee pain

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Abstract

Background: The Tour de France will undoubtedly showcase various cycling related injuries in its Yorkshire opening stages in 2014. Patello-Femoral Pain (PFP) is responsible for over 25% of all road cycling injuries and over 65% of injuries in the lower limb (Callaghan, 2005: Journal of Bodywork and Movement Therapies, 9, 226-236). Alongside trauma related pain it remains the main injury affecting experienced and elite cyclists and is commonly treated using taping (broadly categorised into McConnell and kinesiology type tape - KTT). To date it is unknown as to the extent and rationale behind the use of tape in cycling related knee pain.

Purpose: To determine clinicians' current use of taping in elite and experienced cyclists with cycling related knee pain in order to inform a 3D motion analysis study into current taping techniques. To date very little work has been undertaken in this area and although it is presumed that taping is used extensively throughout cycling, it is unknown as to how much it is actually used and the rationale behind its use.

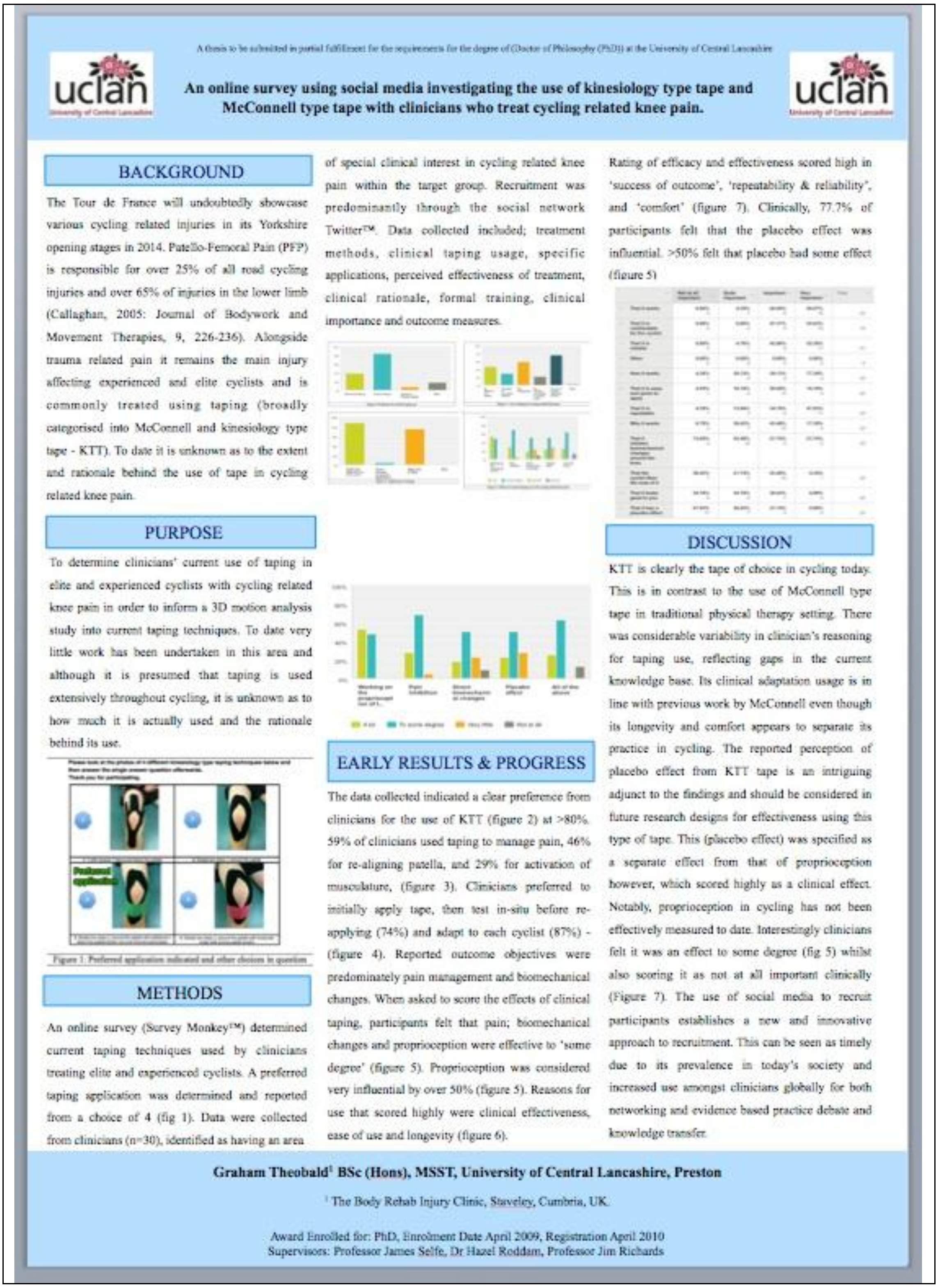
Methods: An online survey (Survey Monkey™) determined current taping techniques used by clinicians treating elite and experienced cyclists. A preferred taping application was determined and reported from a choice of 4 (fig 1). Data were collected from clinicians (n=30), identified as having an area of special clinical interest in cycling related knee pain within the target group. Recruitment was predominantly through the social network Twitter™. Data collected included; treatment methods, clinical taping usage, specific applications, perceived effectiveness of treatment, clinical rationale, formal training, clinical importance and outcome measures.

Results: The data collected indicated a clear preference from clinicians for the use of KTT (figure 2) at >80%. 59% of clinicians used taping to manage pain, 46% for re-aligning patella, and 29% for activation of musculature, (figure 3). Clinicians preferred to initially apply tape, then test in-situ before re-applying (74%) and adapt to each cyclist (87%) - (figure 4). Reported outcome objectives were predominately pain management and biomechanical changes. When asked to score the effects of clinical taping, participants felt that pain; biomechanical changes and proprioception were effective to 'some degree' (figure 5). Proprioception was considered very influential by over 50% (figure 5). Reasons for use that scored highly were clinical effectiveness, ease of use and longevity (figure 6). Rating of efficacy and effectiveness scored high in 'success of outcome', 'repeatability & reliability', and 'comfort' (figure 7). >50% felt that placebo had some effect (figure 5).

Discussion: KTT is clearly the tape of choice in cycling today. This is in contrast to the use of McConnell type tape in traditional physical therapy setting. There was considerable variability in clinician's reasoning for taping use, reflecting gaps in the current knowledge base. Its clinical adaptation usage is in line with previous work by McConnell even though its longevity and comfort appears to separate its practice in cycling. The reported perception of placebo effect from KTT tape is an intriguing adjunct to the findings and should be considered in future research designs for effectiveness using this type of tape. This (placebo effect) was specified as a separate effect from that of proprioception however, which scored highly as a clinical effect. Notably, proprioception in cycling has not been effectively measured to date. Interestingly, clinicians felt it was an effect to some degree (fig 5) whilst also scoring it as not at all important clinically (Figure 7). The use of social media to recruit participants establishes a new and innovative approach to recruitment. This can be seen as timely due to its prevalence in today's society and increased use amongst clinicians globally for both networking and evidence based practice debate and knowledge transfer.

Conclusions. KTT appears the preferred application in cycling related knee pain. The data provide a clear rationale for the testing of specific taping techniques and indicate how clinicians are currently using taping in the treatment of cycling related knee pain. These results give a clear focus for a follow up study, which would aim to determine the biomechanical efficacy and clinical effectiveness of KTT. This work would determine any biomechanical changes in the PFJ during cycling as well as looking at any effects from neutral and no tape. In addition, a focus on pain and placebo would be interesting outcome measures of future work.

2 Associated poster presented at the 2nd World Congress of Cycling Science, 2nd/3rd July 2014, Leeds Yorkshire, UK



3 Abstract (2) published in Journal of Cycling Science 2014

2nd World Congress of Cycling Science, 2nd and 3rd July 2014, Leeds

J Sci Cycling. Vol. 3(2), 64-67

BOOK OF ABSTRACTS

Open Access

An online survey using social media investigating the use of kinesiology type tape and McConnell type tape with clinicians who treat cycling related knee pain

G Theobald [1]✉, J Selfe [2], J Richards [2] and H Roddam [2]

Abstract

Background: The Tour de France will undoubtedly showcase various cycling related injuries in its Yorkshire opening stages in 2014. Patello-Femoral Pain (PFP) is responsible for over 25% of all road cycling injuries and over 65% of injuries in the lower limb (Callaghan, 2005: Journal of Bodywork and Movement Therapies, 9, 226-236). Alongside trauma related pain it remains the main injury affecting experienced and elite cyclists and is commonly treated using taping (broadly categorised into McConnell and kinesiology type tape - KTT). To date it is unknown as to the extent and rationale behind the use of tape in cycling related knee pain.

Purpose: To determine clinicians' current use of taping in elite and experienced cyclists with cycling related knee pain in order to inform a 3D motion analysis study into current taping techniques. To date very little work has been undertaken in this area and although it is presumed that taping is used extensively throughout cycling, it is unknown as to how much it is actually used and the rationale behind its use.

Methods: An online survey (Survey Monkey™) determined current taping techniques used by clinicians treating elite and experienced cyclists. A preferred taping application was determined and reported from a choice of 4 (fig 1). Data were collected from clinicians (n=30), identified as having an area of special clinical interest in cycling related knee pain within the target group. Recruitment was predominantly through the social network Twitter™. Data collected included; treatment methods, clinical taping usage, specific applications, perceived effectiveness of treatment, clinical rationale, formal training, clinical importance and outcome measures.

Results: The data collected indicated a clear preference from clinicians for the use of KTT (figure 2) at >80%. 59% of clinicians used taping to manage pain, 46% for re-aligning patella, and 29% for activation of musculature, (figure 3). Clinicians preferred to initially apply tape, then test in-situ before re-applying (74%) and adapt to each cyclist (87%) - (figure 4). Reported outcome objectives were predominately pain management and biomechanical changes. When asked to score the effects of clinical taping, participants felt that pain; biomechanical changes and proprioception were effective to 'some degree' (figure 5). Proprioception was considered very influential by over 50% (figure 5). Reasons for use that scored highly were clinical effectiveness, ease of use and longevity (figure 6). Rating of efficacy and effectiveness scored high in 'success of outcome', 'repeatability & reliability', and 'comfort' (figure 7). >50% felt that placebo had some effect (figure 5).

Discussion: KTT is clearly the tape of choice in cycling today. This is in contrast to the use of McConnell type tape in traditional physical therapy setting. There was considerable variability in clinician's reasoning for taping use, reflecting gaps in the current knowledge base. Its clinical adaptation usage is in line with previous work by McConnell even though its longevity and comfort appears to separate its practice in cycling. The reported perception of placebo effect from KTT tape is an intriguing adjunct to the findings and should be considered in future research designs for effectiveness using this type of tape. This (placebo effect) was specified as a separate effect from that of proprioception however, which scored highly as a clinical effect. Notably, proprioception in cycling has not been effectively measured to date. Interestingly, clinicians felt it was an effect to some degree (fig 5) whilst also scoring it as not at all important clinically (Figure 7). The use of social media to recruit participants establishes a new and innovative approach to recruitment. This can be seen as timely due to its prevalence in today's society and increased use amongst clinicians globally for both networking and evidence based practice debate and knowledge transfer.

Conclusions. KTT appears the preferred application in cycling related knee pain. The data provide a clear rationale for the testing of specific taping techniques and indicate how clinicians are currently using taping in the treatment of cycling related knee pain. These results give a clear focus for a follow up study, which would aim to determine the biomechanical efficacy and clinical effectiveness of KTT. This work would determine any biomechanical changes in the PFJ during cycling as well as looking at any effects from neutral and no tape. In addition, a focus on pain and placebo would be interesting outcome measures of future work.

4 Associated poster presented at the 2nd World Congress of Cycling Science, 2nd/3rd July 2014, Leeds Yorkshire, UK

5 Abstract (1) accepted at the 2014 Medicine of Cycling Conference in Colorado Springs, USA

(http://www.medicineofcycling.com/conference/)

ABSTRACT

An online survey using social media investigating the use of kinesiology type tape and McConnell type tape with clinicians who treat cycling related knee pain.

G. Theobald[1], J. Selfe[2], J.Richards[2], H. Roddam[2]

[1]The Body Rehab Injury Clinic, Staveley, Cumbria, United Kingdom. [2]University of Central Lancashire,School of Sport, Tourism & the Outdoors, UCLan, Preston, United Kingdom.

Background: PatelloFemoral Pain (PFP) is responsible for over 25% of all road cycling related pain and over 65% of pain related to the lower limb. Alongside trauma related pain it remains the main injury affecting experienced and elite cyclists and is commonly treated using taping (broadly categorised into McConnell and kinesiology type tape - KTT).

Objective: To determine clinicians' current use of taping in cyclists with cycling related knee pain in order to inform a 3D motion analysis study into current taping techniques.

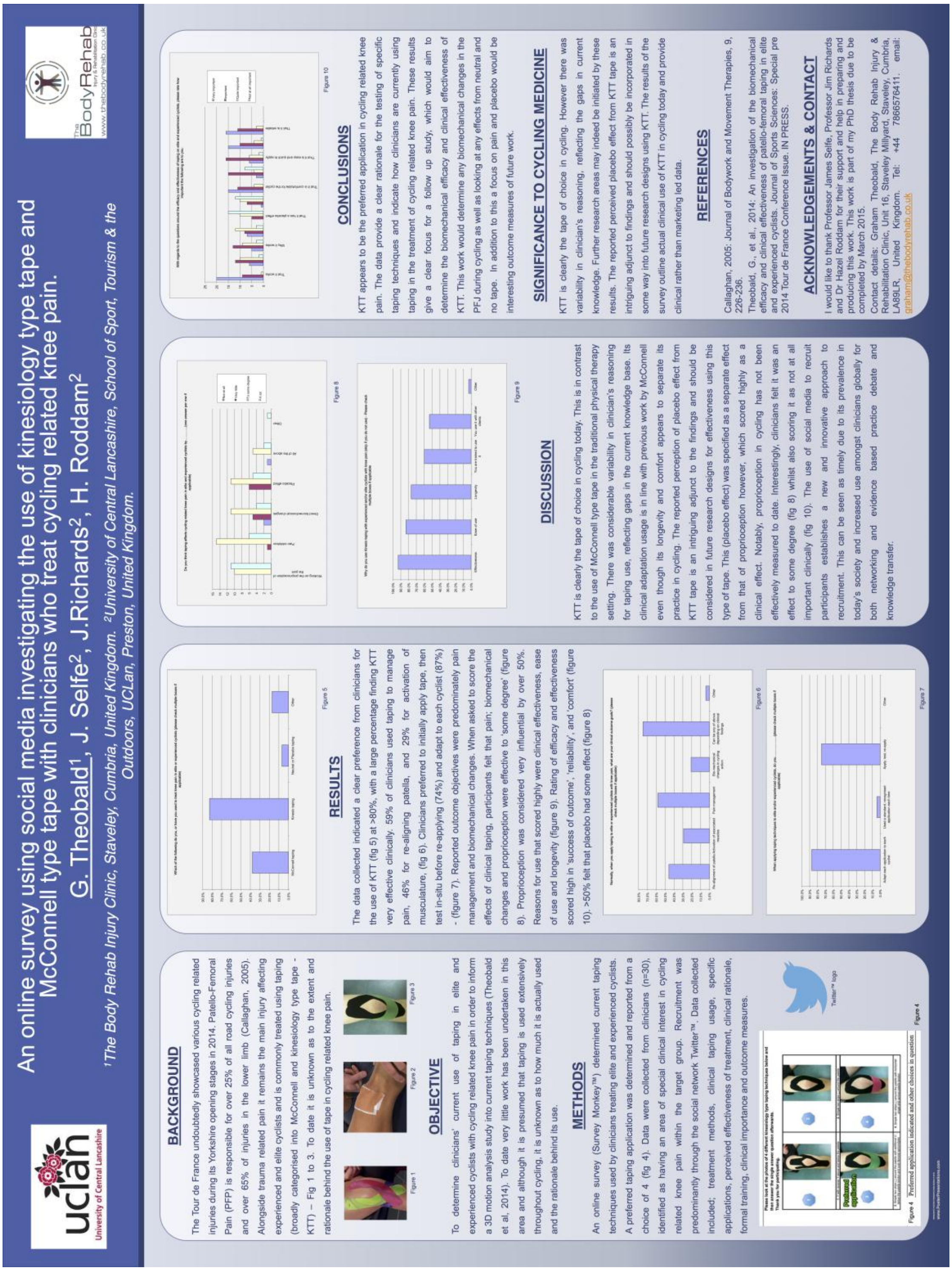
Methods: An online survey (Survey Monkey™) determined current taping techniques used by clinicians treating elite and experienced cyclists. Preferred taping technique was determined from a choice of 4 (fig 1). Data were collected from 30 clinicians, identified as having an area of special clinical interest in cycling related knee pain. Recruitment was predominantly through the social network Twitter™.

Results. A clear preference emerged for the use of KTT (>80%). 59% of clinicians used taping to reduce pain, 43% for re-aligning patella, and 29% for activation of musculature. Clinicians preferred to initially apply tape, then test in-situ before re-applying (73%) and adapt to each cyclist (88%). Reasons for use that scored highly were clinical effectiveness, ease of use and longevity. Rating of efficacy and effectiveness scored high in 'success of outcome', 'repeatability & reliability', and 'comfort'. Clinically, 77.7% of participants felt that the placebo effect was influential (all refer to figure 1).

Significance to cycling medicine: KTT is clearly the tape of choice in cycling. However there was variability in clinician's reasoning, reflecting the gaps in current knowledge. Further research areas may indeed be initiated by these results. The reported perceived placebo effect from KTT tape is an intriguing adjunct to findings and should be incorporated into future research designs using KTT. The results of the survey outline actual clinical use of KTT in cycling today and provide clinical rather than marketing led data.

6 Associated poster presented at the 2014 Medicine of Cycling Conference in Colorado Springs, USA

(http://www.medicineofcycling.com/conference/)



7 Abstract (2) accepted at the 2014 Medicine of Cycling Conference in Colorado Springs, USA

(http://www.medicineofcycling.com/conference/)

ABSTRACT

An investigation of the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists

G. Theobald[1], J. Selfe[2], J.Richards[2], H. Roddam[2]

[1]The Body Rehab Injury Clinic, Staveley, Cumbria, United Kingdom. [2]University of Central Lancashire,School of Sport, Tourism & the Outdoors, UCLan, Preston, United Kingdom.

Background: Kinesiology type taping (KTT) is used widely within elite cycling for treatment of knee pain e.g. Tour De France and Olympics. Taping is a clinical treatment for the over-use pathology of patello-femoral pain (PFP) in elite and experienced cyclists. However, its biomechanical efficacy and clinical effectiveness have not yet been demonstrated.

Objective: To determine and evaluate biomechanical changes around the knee in elite and experienced cyclists both with and without knee pain, using established taping techniques at varying powers.

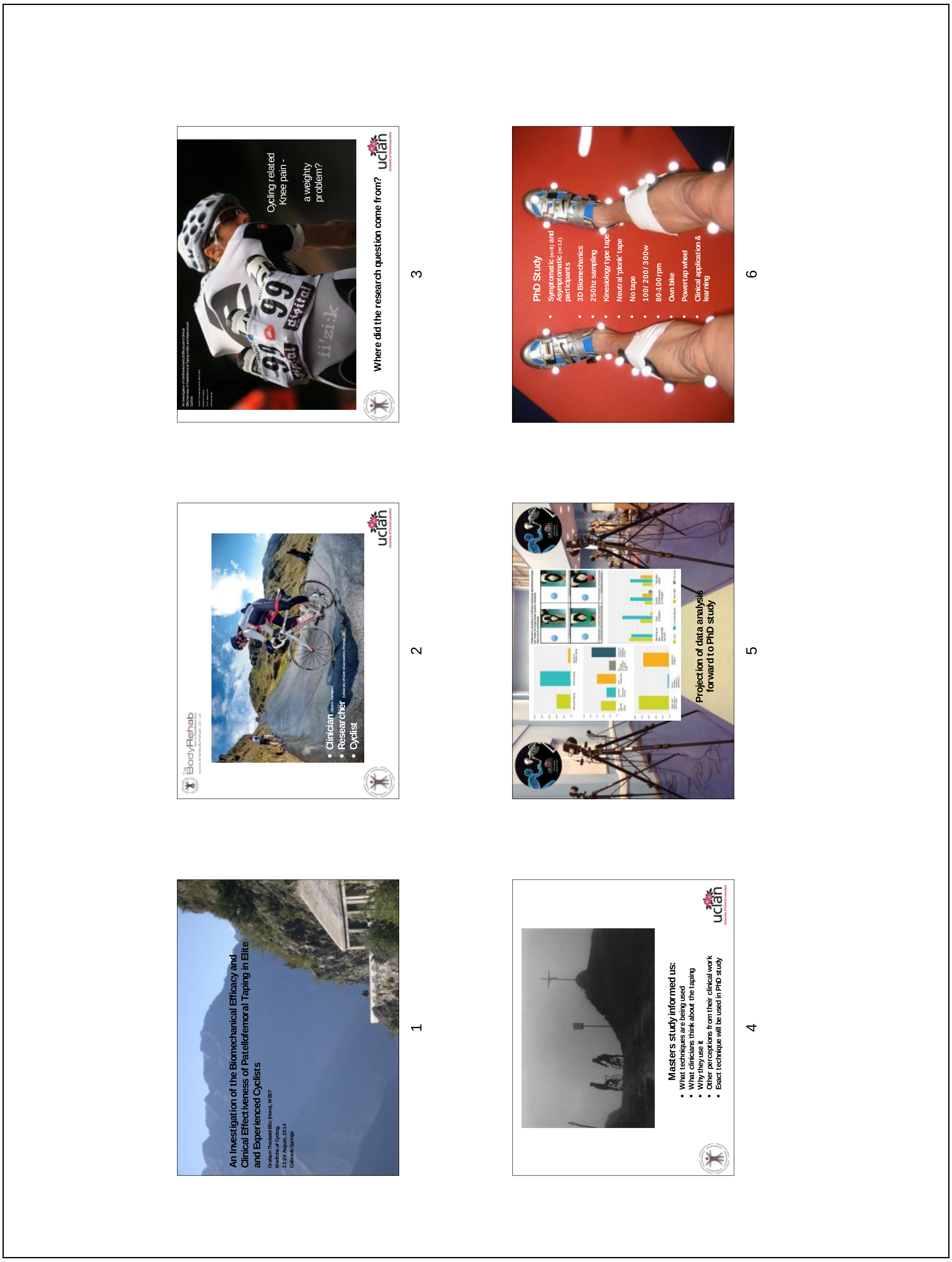
Methods: 12 asymptomatic participants and 8 symptomatic participants conducted three separate tests at three powers (100w, 200w & 300w) on a static trainer using a Powertap™ wheel and their own bike. The study was conducted under three randomised conditions a) no tape, b) neutral tape, c) KTT. Kinematic data were collected using a 10 camera Qualysis motion analysis system (fig 1). Reflective markers were placed on the foot, shank, thigh and pelvis using the CAST technique (fig 1).

Results: A repeated-measures two-way ANOVA test was performed together with posthoc Pairwise comparison with Bonferroni adjustment. Results were reported in kinematic patterns, ROM and SPSS for clinical relevance (fig 1). Alongside this, a new approach was investigated to measure the knee 'in relation to' both the hip/pelvis and ankle/foot (fig 1). Results indicate statistical significant differences in both Asymptomatic and Symptomatic cyclists. These differences were across all powers and conditions. The lower powers indicate significant instability in the target group.

Significance to cycling medicine: Both the hip/pelvis and foot indicate changes that may be relevant to clinical application of taping with cyclists, with a possible link between these movement patterns and cycling related knee pain. For clinical significance the statistics, kinematic patterns and ROM need to be considered as a whole. The work undertaken to date indicates the complexities of both human movement and the variables of a highly repetitive sport.

8 Copy of presentation slides presented during invited oral research presentation at the 2014 Medicine of Cycling Conference in Colorado Springs, USA and The Science of Cycling Symposium in Varese, Italy, July, 2014

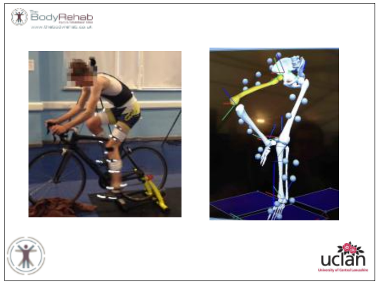
(http://www.medicineofcycling.com/conference/)
http://www.scienceofcycling.com.au/injury-prevention-course-italy/



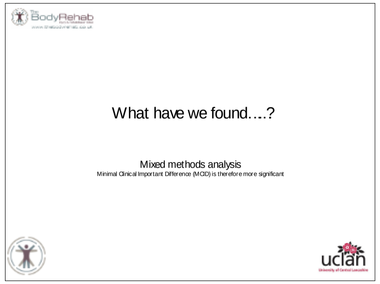

BodyRehab
Figure 1 – Lab, Marker and KTT
uclan


BodyRehab
uclan


BodyRehab
uclan

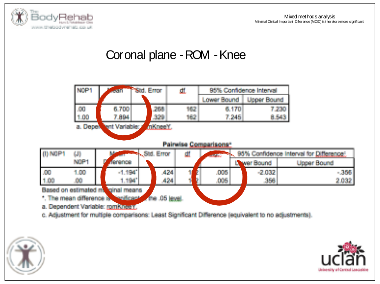

BodyRehab
uclan

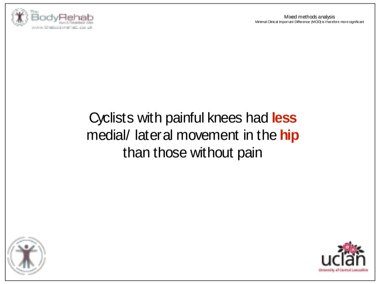

uclan

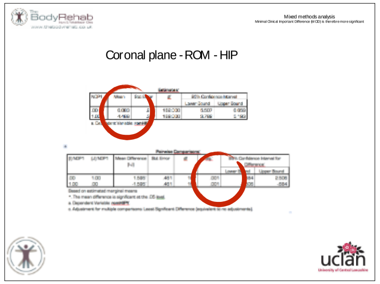

BodyRehab
What have we found….?
Mixed methods analysis
Minimal Clinical Important Difference (MCID) is therefore more significant
uclan

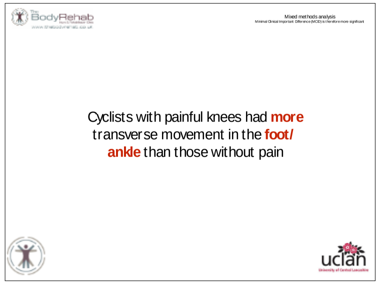

Cyclists with painful knees had more medial/ lateral movement in the knee than those without pain

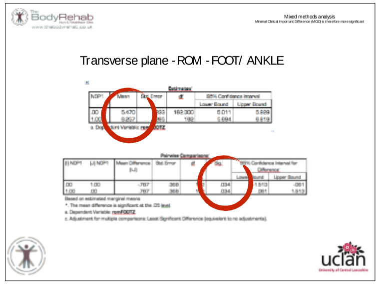
Did we know this before?

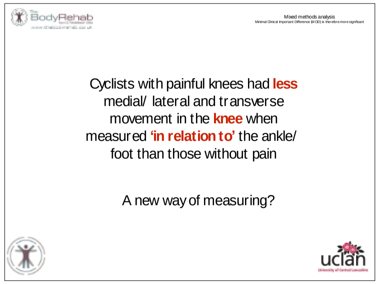

Coronal plane - ROM - Knee

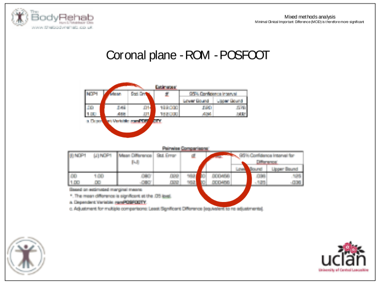

Cyclists with painful knees had less medial/ lateral movement in the hip than those without pain

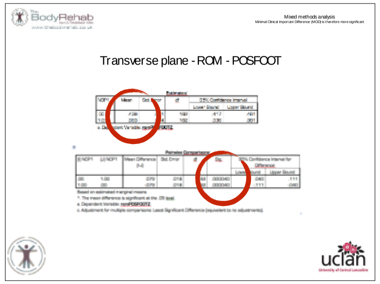

Coronal plane - ROM - HIP

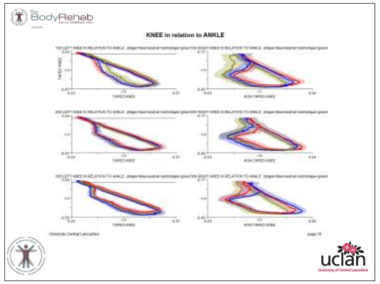

Cyclists with painful knees had more transverse movement in the foot/ ankle than those without pain

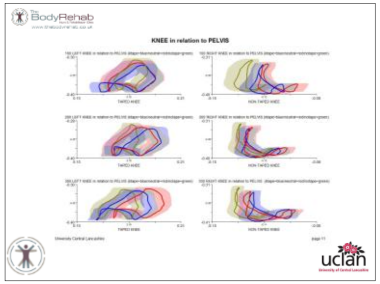

Transverse plane - ROM - FOOT/ ANKLE

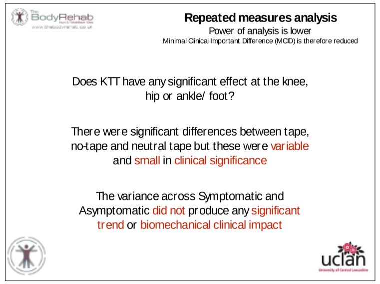

Mixed methods analysis
Cyclists with painful knees had less medial/ lateral and transverse movement in the knee when measured 'in relation to' the ankle/ foot than those without pain
A new way of measuring?
uclan

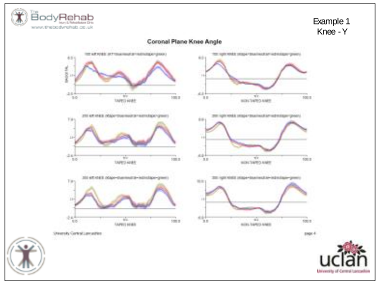

Mixed methods analysis
Coronal plane - ROM - POSFOOT
uclan

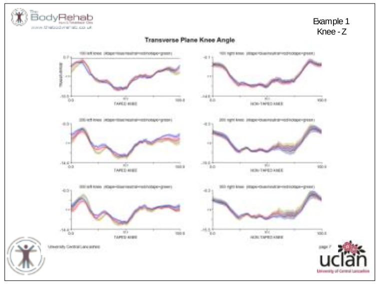

Mixed methods analysis
Transverse plane - ROM - POSFOOT
uclan


KNEE in relation to ANKLE
uclan

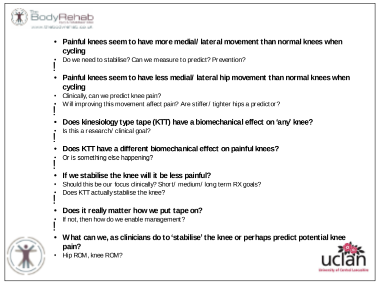

KNEE in relation to PELVIS
uclan

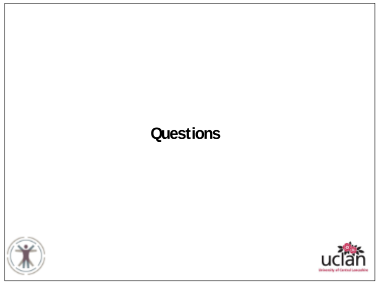

Repeated measures analysis
Power of analysis is lower
Minimal Clinical Important Difference (MCID) is therefore reduced
Does KTT have any significant effect at the knee, hip or ankle/ foot?
There were significant differences between tape, no-tape and neutral tape but these were variable and small in clinical significance
The variance across Symptomatic and Asymptomatic did not produce any significant trend or biomechanical clinical impact
uclan


BodyRehab
Example 1
Knee - Y
Coronal Plane Knee Angle
uclan


BodyRehab
Example 1
Knee - Z
Transverse Plane Knee Angle
uclan

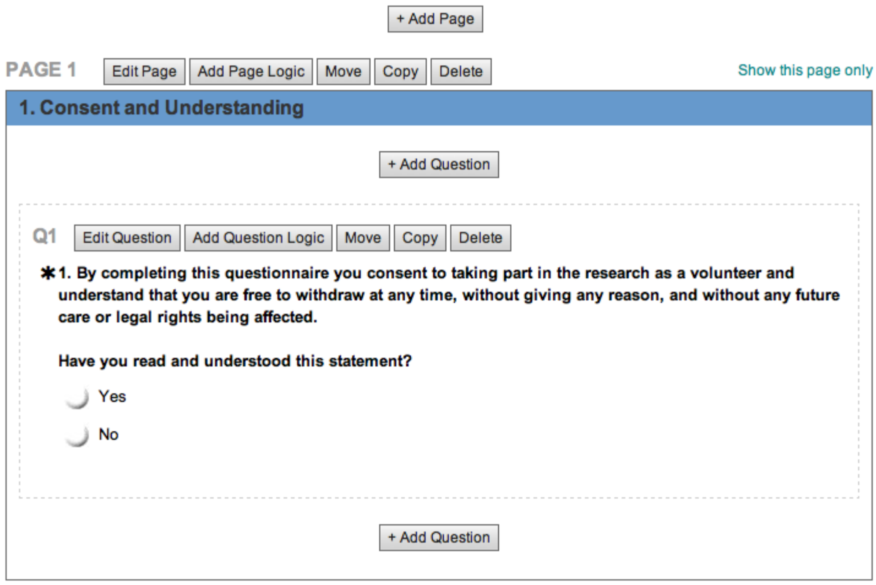

So what?
uclan


BodyRehab
Painful knees seem to have more medial/ lateral movement than normal knees when cycling
Do we need to stabilise? Can we measure to predict? Prevention?
Painful knees seem to have less medial/ lateral hip movement than normal knees when cycling
Clinically, can we predict knee pain?
Will improving this movement affect pain? Are stiffer/ tighter hips a predictor?
Does kinesiology type tape (KTT) have a biomechanical effect on 'any' knee?
Is this a research/ clinical goal?
Does KTT have a different biomechanical effect on painful knees?
Or is something else happening?
If we stabilise the knee will it be less painful?
Should this be our focus clinically? Short/ medium/ long term RX goals?
Does KTT actually stabilise the knee?
Does it really matter how we put tape on?
If not, then how do we enable management?
What can we, as clinicians do to 'stabilise' the knee or perhaps predict potential knee pain?
Hip ROM, knee ROM?
uclan


Questions
uclan

Flyer for Science of Cycling symposium where author presented an outline of this work

9 Online questionnaire – exact screen shots



+ Add Page

PAGE 1 Edit Page | Add Page Logic | Move | Copy | Delete — Show this page only

1. Consent and Understanding

+ Add Question

Q1 Edit Question | Add Question Logic | Move | Copy | Delete

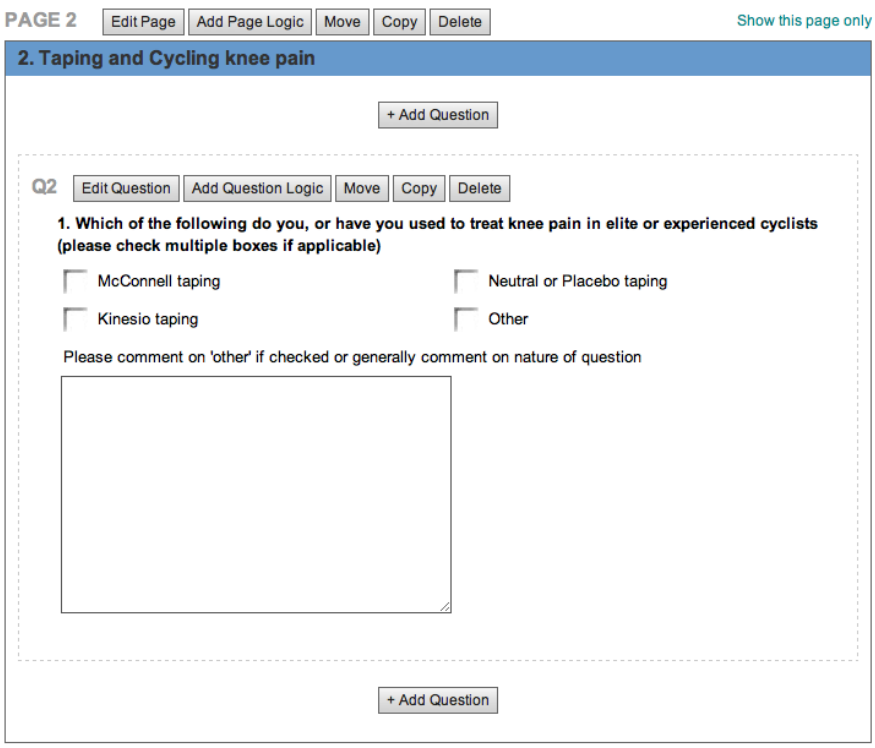
***1. By completing this questionnaire you consent to taking part in the research as a volunteer and understand that you are free to withdraw at any time, without giving any reason, and without any future care or legal rights being affected.**

Have you read and understood this statement?

Yes

No

+ Add Question



PAGE 2 Edit Page | Add Page Logic | Move | Copy | Delete — Show this page only

2. Taping and Cycling knee pain

+ Add Question

Q2 Edit Question | Add Question Logic | Move | Copy | Delete

1. Which of the following do you, or have you used to treat knee pain in elite or experienced cyclists (please check multiple boxes if applicable)

McConnell taping

Neutral or Placebo taping

Kinesio taping

Other

Please comment on 'other' if checked or generally comment on nature of question

+ Add Question

PAGE 3 Edit Page | Add Page Logic | Move | Copy | Delete Show this page only

3. Taping application

+ Add Question

Q3 Edit Question | Add Question Logic | Move | Copy | Delete

1. Normally, when you apply taping to elite or experienced cyclists with knee pain, what are you clinical outcome goals? (please check multiple boxes if applicable)

- [ ] Re-alignment of patella
- [ ] Activation of associated muscles
- [ ] Pain management
- [ ] Bio-mechanical changes in cycling action
- [ ] Can be any of above depending on clinical findings
- [ ] Other

Please comment on 'other' if checked or generally comment on nature of question

Q4 Edit Question | Add Question Logic | Move | Copy | Delete

2. When applying taping techniques to elite and/or experienced cyclists, do you.....................(please check multiple boxes if applicable)

- [ ] Adapt each application to each cyclist
- [ ] Used a standard, recognised application each time
- [ ] Apply, test, re-apply
- [ ] Other

Please comment on 'other' if checked or generally comment on nature of question

+ Add Question | Split Page Here

Q5 Edit Question | Add Question Logic | Move | Copy | Delete

3. How often would you use taping in treating cycling related knee pain?

- [ ] Every time
- [ ] Dependant on clinical findings
- [ ] Often (more than 50%)
- [ ] Not very often (less than 25%)

Please comment on nature of question and your answers

Q6 Edit Question | Add Question Logic | Move | Copy | Delete

4. When treating experienced and elite cyclists, which specific pathologies do you use taping for? (please check multiple boxes if applicable)

- [ ] Patello-femoral syndrome
- [ ] Patella maltracking
- [ ] Tight musculature
- [ ] Tight Facia
- [ ] Muscle offload
- [ ] Muscle re-eductaion (rehab)
- [ ] Pain management
- [ ] Other

Please comment on 'other' if checked or generally comment on nature of question

+ Add Question

PAGE 4 Edit Page Move Copy Delete Show this page only

3. Taping training and experiences

+ Add Question

Q7 Edit Question Add Question Logic Move Copy Delete

1. Have you been formally trained in the following taping techniques? (please tick if formally trained - leave blank if not)

- [ ] McConnell
- [ ] Kinesio
- [ ] Other

Please comment or expand on details of either formal or informal training

Q8 Edit Question Add Question Logic Move Copy Delete

2. Do you, or have you ever used taping as a neutral or placebo treatment for cycling related knee pain with experienced and elite cyclists?

- [ ] yes
- [ ] no

If yes, please expand with thoughts and comments (all comments remain strictly confidential at all times)

Q9 Edit Question | Add Question Logic | Move | Copy | Delete

3. Clinically, is your taping treatment a success with regards to cycling related knee pain in elite and experienced cyclists?

- Every time
- Sometimes
- Never
- Other

Please comment on 'other' if checked or generally comment on nature of question

Q10 Edit Question | Add Question Logic | Move | Copy | Delete

4. How do you measure the success of your taping treatment with elite and experienced cyclists with knee pain? (please check mutiple boxes if applicable)

- Functional reduction in knee pain using VAS scale
- Cessation of functional knee pain when cycling using VAS scale
- Functional reduction in knee pain (verbal)
- Cessation of functional knee pain when cycling (verbal)
- Less knee pain than before when cycling
- Altered biomechanics during cycling leading to reduction in knee pain
- Patient is happy with outcome
- Altered biomechanics during cycling leading to complete cessation in knee pain
- Improved performance
- All of the above
- Other

please comment on 'other' if checked or generally comment on nature of question

1. Efficacy and Effectiveness of taping

Taping that produces the desired results on the knee.
Clinical success of taping treatment in regards to cycling related knee pain.

+ Add Question

Q1 Edit Question Move Copy Delete

1. How Effective do you think the following applications are in treating knee pain with Elite and experienced cyclists?

	Not at all effective	Some effect	Effective	Very effective
McConnell				
Kinesio				

Please comment on 'other' if checked or generally comment on nature of question

Q2 Edit Question Move Copy Delete

2. Do you think taping affects cycling related knee pain in experienced and elite cyclists by....

	A lot	To some degree	Very little	Not at all
Working on the proprioception of the joint				
Pain inhibition				
Direct biomechanical changes				
Placebo effect				
All of the above				
Other				

Please comment on 'other' if checked or generally comment on nature of question

Q3 Edit Question Move Copy Delete

3. With regards to questions around the efficacy and effectiveness of taping with experienced and elite cyclists, please rate how important the following are to you?

	Not at all important	Quite important	Important	Very important
That it works	☐	☐	☐	☐
How it works	☐	☐	☐	☐
Why it works	☐	☐	☐	☐
That it initiates biomechanical changes around the knee	☐	☐	☐	☐
That it has a placebo affect	☐	☐	☐	☐
That it looks good to you	☐	☐	☐	☐
That it is comfortable for the cyclist	☐	☐	☐	☐
That the cyclist likes the look of it	☐	☐	☐	☐
That it is easy and quick to apply	☐	☐	☐	☐
That it is repeatable	☐	☐	☐	☐
That it is reliable	☐	☐	☐	☐
Other	☐	☐	☐	☐

Please comment on 'other' if checked or generally comment on nature of question

PAGE 2 Edit Page Add Page Logic Move Copy Delete Show this page only

2. McConnell taping (please skip if you do not use)

+ Add Question

Q4 Edit Question Add Question Logic Move Copy Delete

1. Why do you use McConnell taping with elite and/or experienced cyclists with knee pain? (skip if you do not use) - please check multiple boxes if applicable

- ☐ Effectievness
- ☐ Ease of use
- ☐ Longevity
- ☐ You are trained to use it
- ☐ You use it with other clients
- ☐ Other

Comment on other or additional comments

Q5 Edit Question | Add Question Logic | Move | Copy | Delete

2. Which McConnell technique do you, or have you used with experienced and elite cycling related knee pain? (ref:McConnell, 1996) - please check multiple boxes if applicable.

- [ ] Medial glide
- [ ] Lateral tilt (medial patella to medial femoral condyle)
- [ ] Patella rotation - External (inferior to superior/medial)
- [ ] Patella rotation - Internal (superior to inferior/medial)
- [ ] Soft tissue offload (e.g. inferior V fat pad application)
- [ ] Other

Please comment on 'other' if checked or generally comment on nature of question

PAGE 3 Edit Page | Add Page Logic | Move | Copy | Delete   Show this page only

3. Kinesio Taping (please skip if you do not use)

+ Add Question

Q6 Edit Question | Add Question Logic | Move | Copy | Delete

1. Why do you use Kinesio taping with elite and/or experienced cyclists with knee pain? (skip if you do not use) - please check multiple boxes if applicable

- [ ] Effectievness
- [ ] Ease of use
- [ ] Longevity
- [ ] You are trained to use it
- [ ] You use it with other clients
- [ ] Other

Comment on other or additional comments

Q7 Edit Question | Add Question Logic | Move | Copy | Delete

2. Which Kinesio taping technique do you, or have you used with experienced and elite cycling related knee pain? (please check multiple boxes if applicable)

- [ ] Reverse Y above patella
- [ ] Double Y above and below patella
- [ ] ( ) around patella
- [ ] Any of the above with VMO activation Y
- [ ] Other

Please comment on 'other' if checked or generally comment on nature of question

PAGE 4 Edit Page | Add Page Logic | Move | Copy | Delete   Show this page only

4. Final questions

+ Add Question

Q8 Edit Question | Move | Copy | Delete

1. Please provide any other comments, observations or relevant information with regards to your treatment of elite and/or experienced cyclists with knee pain using taping.

+ Add Question | Split Page Here

Q9 Edit Question | Add Question Logic | Move | Copy | Delete

*2. Would you be prepared to either meet or speak with the researcher for a semi-structured interview lasting no more than 60 minutes?

- Yes
- No

PAGE 5 Edit Page | Move | Copy | Delete

Show this page only

5. information about you (confidential)

+ Add Question

Q10 Edit Question | Move | Copy | Delete

*1. Please complete the contact information below. We can assure you that this information will remain confidential at all times and will not be passed on in any way.

Name:

Company:

Address 1:

Address 2:

City/Town:

State/Province:

ZIP/Postal Code:

Country:

Email Address:

Phone Number:

10 Online questionnaire - Participant questionnaire:

Information Sheet

Title of main MPhil/PhD study:

An investigation of the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists

Aim of this questionnaire:

This questionnaire aims to establish the current clinical practice of English speaking therapists in the UK, and if identified, the Union Cycliste Internationale (UCI) countries of taping techniques for the treatment of elite and experienced cyclists with patello-femoral knee pain.

Objectives of MPhil Study

1. To establish the number of therapists currently engaged the treatment of elite and experienced cyclists with PFKP.
2. To design, pilot and implement a comprehensive survey to determine current taping techniques for PFKP in elite and experienced cyclists,
3. To summarise how PFKP taping is currently used in clinical practice, which will inform the techniques to be used.

This will inform the PhD phase of the overall study and allow us to establish treatment techniques to use in the biomechanical analysis.

Who will conduct the research?

Graham Theobald BSc (Hons) will be responsible for the management of the study. Graham Theobald will also be responsible for recruitment and data collection.

What we are asking you to do:

We are asking you to complete a short online questionnaire in relation to the aim of the study. The entire questionnaire should take no longer than 30 minutes to complete. Most of the questions are in a simple format but there is space for you to expand your answers depending on your personal experience in this area. After the questionnaire you may be asked to participate in a follow up interview, either in person (through a visit) or by phone – *you are under no obligation to participate in an interview by completing the questionnaire.*

Are there any risks or benefits?

There are no foreseeable risks to you by completing the questionnaire. There will be no immediate direct benefits for you; however the results may help to develop more a better understanding of taping in elite and experienced cyclists.

Data storage:

All data will be stored in line with UCLAN regulations. Electronic data will be stored on a password protected pc, on the allied health professions pc network or another secure system. All consent forms and other documents will be stored so that no names can be associated with them in a locked filling cabinet. Electronic data and forms will be kept for 5 years following the end of the project, and then destroyed.

Who has approved this study?

This study has been approved by the Faculty of Health Ethics Committee.

Who can I contact to discuss any issues or to make a complaint?

If you have any issues with the conduct of the Postgraduate student whilst taking part in this study you can contact Professor James Selfe at the University of Central Lancashire. - JSelfe1@uclan.ac.uk

11 Online questionnaire - Consent form

Study Title: An investigation of the biomechanical efficacy and clinical effectiveness of patellofemoral taping in elite and experienced cyclists

Please read all the statements below and **initial** each box to confirm that you have read and understood each item

1. I confirm that I have read and understood the information sheet for the above study; I have had the opportunity to consider the information and ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without it affecting my legal rights.

3. I agree to:

    Taking part in an online questionnaire

    My answers and comments to be used to determine inclusion in the interview stage of the study

    Allow anonomised quotes from the questionnaire to be used in further research, in reports, publications or for teaching purposes.

-------------------------------	------------	--------------------
Name of participant	Date	Signature
-------------------------------	----------	--------------------
Name of researcher	Date	Signature

12 Online questionnaire - Covering email

University of Central Lancashire

Copy of proposed covering email, including consent by acceptance of online survey participation.

Dear…………

Your name has been brought to my attention by …………………… in regards to a MPhil/PhD study that I am currently undertaking into knee pain in Elite and Experienced Cyclists and taping.

I am looking for therapists who are, or have been, working with Elite and experienced cyclists with knee pain and subsequently treating them with taping as part of an overall treatment plan. The criteria for inclusion for the study is below, do you fit the criteria and would you be prepared to help me by completing a short online questionnaire?

- Do you treat elite and/or experienced cyclists with knee pain?
- Do you use, or have you used any form of taping as a treatment technique for cycling related knee pain?
- Are you prepared to participate in a small questionnaire aimed at this target group and treatment?

If you are happy to participate in the questionnaire could you please reply stating which email address you would like me to email the online link to. By doing so you consent to take part in the research as a volunteer and understand that you are free to withdraw at any time, without giving any reason, and without any future care or legal rights being affected.

Your consent relates to the following:

Taking part in an online questionnaire

Your answers and comments to be used to determine inclusion in any potential future interview stage of the study

Anonomised quotes from the questionnaire to be used in further research, in reports, publications or for teaching purposes.

A copy of the participant information and overall study proposal are attached here for your attention. You will have opportunity to ask any questions prior to being sent the questionnaire link.

Regards,

Graham Theobald BSc (Hons), MSST

13. Online questionnaire - Participant letter to introduce information

Dear………………..

Thank you for considering participating in this MPhil/PhD study into knee pain in Elite and Experienced Cyclists and taping.

As a therapist working with Elite and experienced cyclists with knee pain and subsequently treating them with taping as part of an overall treatment plan your experience is crucial in order to determine the PhD phase of the study and further the research in this area. The criteria for inclusion for the study is below, please take a moment to ensure you answer yes to the three points below before completing the questionnaire.

- Do you treat elite and/or experienced cyclists with knee pain?
- Do you use, or have you used any form of taping as a treatment technique for cycling related knee pain?
- Are you prepared to participate in a small questionnaire aimed at this target group and treatment?

This study will inform me of the current clinical application of our study subject and consequently from this information I expect to be able to focus a 3D biomechanical study that identifies some clear outcomes as to the effectiveness and efficacy of certain specified taping applications for knee pain and cyclists. It is possible that these results will enable you to make improved evidence based clinical decisions as to taping treatment with cyclists.

All data collected, other than for direct communication purposes to each participant from myself, will remain anonymous throughout the study. All data will be coded and only aggregated and annonymised data will be used for analysis and presented in the thesis and any other associated academic output. Coded annonymised data will be separate from any data where contact details need to be retained for communication.

Once again, thank you for considering participation in the study.

Regards,

Graham Theobald

Graham Theobald Page 1 26/01/2011

14. Online questionnaire - Summary of practical ethical issues

University of Central Lancashire

Summary of Practical Ethical Issues

After reviews the ethics checklist there are no other conditions met other than that of using humans and their resultant data.

Normally, participation in the therapist online questionnaire is accepted as informed consent, however a covering email will be sent prior to sending the direct link to the questionnaire to outline the objectives of the project and its context within the overall study.

There are no issues with lack of capacity in participation due to the nature of the questionnaire. It is designed for therapists actively involved in working with symptomatic elite and experienced cyclists and taping. This means that there should be no confusion as to whether the participant is credible as if they meet the criteria for inclusion then they are in the target group.

This simple criteria is as follows:
Do you treat elite and/or experienced cyclists with knee pain?
Do you use, or have you used any form of taping as a treatment technique for cycling related knee pain?
Are you prepared to participate in a small questionnaire aimed at this target group and treatment?

G Theobald, Feb, 2011

Graham Theobald Page 1 26/01/2011

15. Biomechanical study - Participant information sheet (4 pages)

Participant Information

Introduction:

This project is a study of biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists. As part of this study we are investigating the effects of kinesiology type taping on the biomechanical movement of the knee during 3 different cycling tests. Each test will be at a different power (watts), which will be randomised.

Before you decide if you would like to take part, it is important for you to understand why the study is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. If there is anything that is not clear or if you would like more information please contact Graham Theobald (Research student) using the contact details provided at the end of the information sheet.

Title of study:

An investigation of the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists.

Aim of study:

This study aims to investigate the biomechanical effects of knee taping in elite and experienced cyclists.

Who will conduct the research?

Graham Theobald (PhD student) will be responsible for all recruitment data collection and the day-to-day management of the project. The supervisory team are Professors Jim Richards and James Selfe and Dr Hazel Roddam

The research will take place in the Brook Building Advanced Movement Lab at the University of Central Lancashire, Preston

(http://www.uclan.ac.uk/information/services/kt/businesses/facilities/advanced_movement_lab.php)

Participant criteria

Participants will be identified using British Cycling guidelines of Elite, 1, 2, 3 and 4 category and gold/silver/bronze standard sportive cyclists. The required number of participants for the study is 30, 15 symptomatic (knee pain) and 15 Asymptomatic (NO knee pain)

Note: Symptomatic participants (those WITH cycling related knee pain), will be required to complete an further inclusion/exclusion questionnaire as well as the generic consent form that will determine the nature of their knee pain. This pain is required to be cycling related, not associated with recent acute trauma and not part of any existing and diagnosed non-cycling related knee pathology. All participants will be required to be included in line with the identified British Cycling related inclusion criteria.

Continued overleaf…….

What we will ask you to do:

Reflective markers will be placed on your lower back/pelvis, feet and legs (figure 1 below).

These will allow the movement of your legs and feet to be measured using the infra-red camera system. You will be asked to carry out three cycling tests with different taping applications on your bike attached to a turbo trainer, Figure 2, 3 & 4 (below). The three tests will be carried out at 3 separate power outputs that are measured using a powertap™ enabled rear wheel. The 3 different applications applied to your knee during each power test will be 1. predetermined kinesiology type taping technique (figure 5 overleaf), 2. neutral tape (figure 5 overleaf) and finally, 3. no taping intervention applied. The order will be randomised for every participant.

You will be given specific training and practice on a static turbo trainer (figure 2 below)) until such time as you are confident and happy to proceed. Should you feel unhappy on the static trainer then you are at liberty to withdraw at any time. If you experience any abnormal pain during the testing, the procedure will be stopped and if pain continues we will inform you of any medical advice that you should seek. Taping techniques and applications are a common treatment for knee pain in cycling and aim to relieve pain and improve control. Although they would not normally be worn by subjects without pain previous similar research has shown that they do not produce any adverse effects. All tests will not exceed either the range of movement or forces on the legs experienced in normal cycling.

If you are a participant with cycling related knee pain you will also be asked some further information regarding your pain after each test. This will be explained to you in more detail before the testing.

The testing process *should* not take longer than **90 minutes** however travel, set up and cooling down will mean that you will need to plan for a half day at the university in Preston. Each test (9 in total) will take approximately 5 minutes including data collection. All data will be coded and no names will be able to be associated with any data recorded.

Figure 1: Lower limb reflective markers

Figure 2: Turbo Trainer

Figure 3: Camera & Bike set up

Figure 4 : Camera & Bike set up

Continued overleaf…….

	
*Simple two strips ( ) (knee circumference) around the patella with additional **U** (knee circumference) below the patella tendon and towards femoral epicondyles*	*Neutral tape (50% knee circumference)*

Figure 5: Taping applications

Are there any risks or benefits?

The only foreseeable risk is associated with exercise. Any exercise can cause injury, taking part in this study will not increase your risk of injury. There is very little risk of injury when cycling on a turbo trainer.

All equipment has been risk assessed by a member of staff. There will be no direct benefits for you; however the results may help to develop more a better understanding of taping in elite and experienced cyclists. Should you feel it beneficial we can provide the video data of your cycling action in 3D MP4 format for your personal use. This information will be discussed with you during your participation and should you wish to receive any video data this will be agreed at the time of participation and this data will be provided directly to you via the research student by email within 30 days of the participation.

There will be a first aid trained person present at all times during the testing. Heart rate and exertion will be monitored during the testing.

Data storage:

All data will be stored in line with UClan regulations. Electronic data will be stored on a password protected computer, on the UClan network and also on a password protected system at The Body Rehab Injury and Rehabilitation Clinic. All consent forms and other documents will be stored so that no names can be associated with them in a locked filling cabinet. Electronic data and forms will be kept for 5 years following the end of the project, and then destroyed.

Who has approved this study?

This study has been approved by the UClan Built, Sport and Health Ethics Committee (BuSH) University Research Ethics Committee.

Participants are asked to refrain from any physical activity and the consumption of alcohol for 24 hours prior to the tests.

Continued overleaf…….

Participants may retire from the investigation at any point should they wish to do so and without prejudice. Any collected data from participant who withdraw will be deleted and not used in analysis. You may withdraw up to 2 weeks after completion of your data collection participation. Once final analysis has been completed however, your data cannot be withdrawn but will remain anonymous.

All the data produced will be treated confidentially and individually. However the anonymous results may be used in possible future publications. If participants wish, a summary of the results produced will be made available to them.

WHAT TO DO IF YOU WOULD LIKE TO PARTICIPATE IN THIS STUDY?

If you feel you fall into one of the outlined categories, in the first instance please email the researcher (Graham Theobald) at the email given below. He will then determine whether you require the further inclusion form for knee pain as well as the generic consent form. All information with regards to the study will be sent to you once your status and inclusion has been confirmed. Times and dates will be negotiated directly with you by the researcher.

Alternatively you can read further information on the study and download the appropriate consent and information documents from the following link:

http://www.thebodyrehab.co.uk/research/phd-study-/

You are advised that should the number of participants exceed the intended number required for the study you may not be required to take part but will be contacted and communicated with appropriately. Thank you in advance for considering participation.

Research student contact details:

Graham Theobald

Phone: 01539 822746
Mobile: 07866 576411
Email: graham@thebodyrehab.co.uk

Who can I contact to discuss any issues or to make a complaint?

If you have any issues with the conduct of the staff or post-graduate PhD student whilst taking part in this study you can contact Professor Jim Richards

Professor Jim Richards

Professor in Biomechanics
School of Sport, Tourism and The Outdoors
Brook Building, Room 118
University of Central Lancashire
Preston
PR1 2HE

Email: jrichards@uclan.ac.uk
Tel: +44 (0) 1772 894575

16. Biomechanical study - Participant consent form

Study Title: An investigation of the biomechanical efficacy and clinical effectiveness of patello-femoral taping in elite and experienced cyclists.

Principal investigator: Graham Theobald BSc (Hons)

Please read all the statements below and ensure that you have read and understood each item. Tick box to indicate this. Also please mark **either** box 1 or 2 to indicate whether you are currently experiencing cycling related knee pain.

I, …………………………………………consent to the following statements:

I have read and understood the information sheet (date …………….) and I have had the opportunity to ask questions – Email or in person	
I understand that I can withdraw from the study at any time without giving a reason	
I understand that it will not be possible to withdraw my data from the study after final analysis has been undertaken	
I understand that my participation will be anonymous and any details that might identify me will not be included in reports, presentations	
I agree to my anonymised data being used within reports, presentations or other publications produced from the study	
I agree to take part in this study	
I am an Elite or Experienced cyclist and am used to regular cycling (British Cycling guidelines of Elite, 1, 2, 3 and 4 category and gold/silver/bronze standard sportive cyclists)	
I have no known or diagnosed medical conditions other than cycling related knee pain that that may affect participation in this study (e.g. Chondromalacia, meniscal tear, etc)	
I understand that if I have any known or unknown medical conditions, other than cycling related knee pain, which result in injury, the research team will not be held responsible.	
All the data produced will be treated confidentially and individually. However the anonymous results may be used in possible future publications. If I wish, the results produced will be made available to me.	

Please also mark one of the following statements:

1	I HAVE cycling related knee pain NOTE: If this box is initialled you will be required to complete an additional screening form to determine your knee pain inclusion criteria	
2	I DO NOT have cycling related knee pain	

Name of Participant: ___________________________ Date:_________

Signature: ____________________________

Name of Researcher: Graham Theobald Date: _________

Signature: ____________________________

G. Theobald Page 1 20/03/2013

17. Biomechanical study - Cycling related knee pain inclusion/exclusion form

uclan
University of Central Lancashire

Knee pain Inclusion / Exclusion form

Name: Date:

Are you an experienced or elite cyclist designated one or more of the following categories: http://www.britishcycling.org.uk/road/article/roadst_Road-Categories_Classifications		
	Yes	No
British Cycling Elite		
British Cycling Cat 1		
British Cycling Cat 2		
British Cycling Cat 3		
British Cycling Cat 4		
Gold standard sportive cyclist (within 10% of fastest finisher)		
Silver standard sportive cyclist (within 30% of fastest finisher)		
Bronze standard sportive cyclist (within 60% of fastest finisher)		
	Yes	No
Do you currently have cycling related knee pain		
(if YES continue below – if NO, do not answer following questions)		
Knee pain related questions		
	Yes	No
Prior to considering this study, have you had a professionally/medically diagnosed knee problem other than cycling related knee pain? *For example: Chondromalacia, Meniscal tear, ACL deficiency, MCL tear*		
If answered yes please give further details:		
Is your pain in both knees, or just one? (please indicate)	Both	One
Please indicate in box opposite how many months your cycling related knee pain has been present in its current form.		
	Yes	No
Have you been diagnosed by your doctor to have Osteo-Arthritis of the knee?		
Have you had a knee pathology confirmed by an x-ray or MRI scan taken in the last 12 months?		
Have you had an intra-articular corticosteroid injection applied to your knee joint in the past 3-6 months?		

18. Biomechanical study - Copy of advert for participant recruitment

Cyclists wanted !!

Are you an Experienced or Elite cyclist?

What do we mean by Experienced or Elite?
You will need to be in one of the following categories:

British Cycling Elite	British Cycling Cat 1
British Cycling Cat 2	British Cycling Cat 3
British Cycling Cat 4	Gold standard sportive cyclist (within 10% of fastest finisher)
Silver standard sportive cyclist (within 30% of fastest finisher)	Bronze standard sportive cyclist (within 60% of fastest finisher)
http://www.britishcycling.org.uk/road/article/roadst_Road-Categories_Classifications	

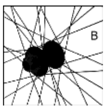
I am doing some PhD research into the biomechanical effects of different treatments of knee pain in cyclists and are looking for cyclists to give an hour or so of their time to assist the process.

Can you help?

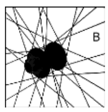
90 minutes of your time in the movement lab in Brook building

ITS INTERESTING, INNOVATIVE AND YOU GET REFLECTIVE SILVER BALLS STUCK ALL OVER YOU WHILST GETTING A WORKOUT !!!!

Either tear off a contact form below and contact Graham by phone or text on 07866 576411 or by email on graham@thebodyrehab.co.uk



Cyclists wanted !!



Contact details: please tear off from bottom and contact by email or phone

Contact Graham on 07866 576411 or graham@thebodyrehab.co.uk
Contact Graham on 07866 576411 or graham@thebodyrehab.co.uk
Contact Graham on 07866 576411 or graham@thebodyrehab.co.uk
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Contact Graham on 07866 576411 or graham@thebodyrehab.co.uk

19. Biomechanical study - Copy of risk assessment form

RISK ASSESSMENT FORM

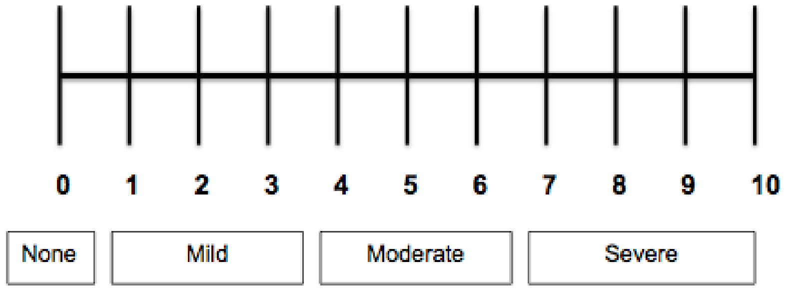
Risk Assessment For	Assessment Undertaken By	Assessment Reviewed
Service / Faculty / Dept: School of Sport, Tourism and The Outdoors	**Name:** Graham Theobald	**Name:**
Location of Activity: Brook Movement Lab	**Date: 11/07/2012**	**Date:**
Activity: Cycling on static turbo trainer alongside use of 3D cameras. Undertaking study into 3D biomechanics of cycling in Elite and Experienced cyclists using taping	**Signed by Head of Dept / equivalent**	
REF: Professor Jim Richards	**Date**	

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, med or low
Injury whist undertaking static cycling	Participants	One to one training prior to use of bike. Detailed set up of bike relative to body size, leg length etc. Continuous observation of technique and condition.	N/a	Low
Tripping on camera wires or camera tripods	Participants and staff	Orientation and explanation given to all participants and staff entering the lab environment during testing or set up. Emphasis given to safety and position of cameras and wiring. System in place of entry and exit from testing area via a cable free route. No other passage allowed and this is monitored by training staff. Vigilant control is encouraged at all times, especially during times when participants has to change set up or in between testing.	N/a	Low
Entry into area by non related staff or students	Staff and students	All doors will be monitored for security whist set up, testing and de-rig are carried out.	N/a	Low
Combined use of movement lab by other therapists	Staff and students	No individual unrelated to thee testing procedure will be allowed in the movement lab during testing, set up and de-rig without permission. Timetables and room booked through the School of Sport, Tourism and The Outdoors.	N/a	Low

20. Biomechanical study - Adapted numeric pain scale

Cycling Specific Numeric Pain Rating Scale

0 - 10



Instructions:

1. The cyclist is asked the following questions:

   - What number would you give your pain **before** the specific test?
   - What number on the 0 to 10 scale above would you give your pain **during** the specific test?
   - What number on the 0 to 10 scale above would you give your pain **after** the specific test?

2. When the explanation suggested in #1 above is not sufficient for the cyclist, it is sometimes helpful to further explain or conceptualize the Numeric Rating Scale in the following manner:

0 = No Pain 1-3 = Mild Pain (nagging, annoying) 4–6 = Moderate Pain (interferes significantly with function/performance) 7-10 = Severe Pain (disabling; unable to pedal, function, perform)

Reference:

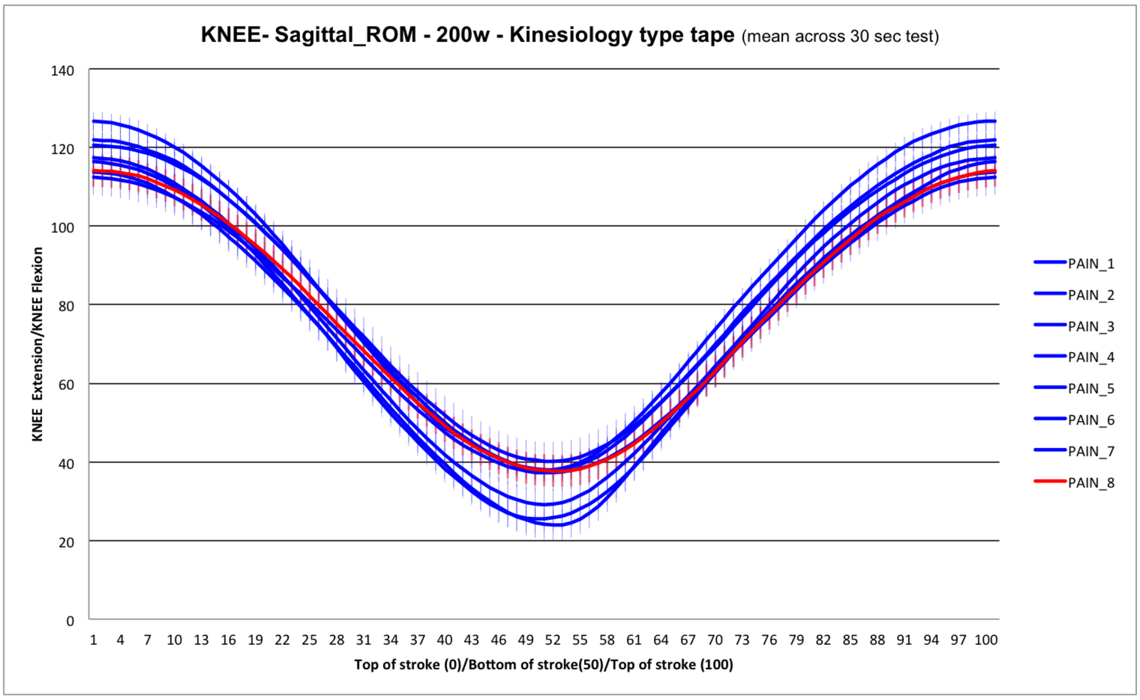
McCaffery, M., & Beebe, A. (1993). Pain: Clinical Manual for Nursing Practice. Baltimore: V.V. Mosby Company.

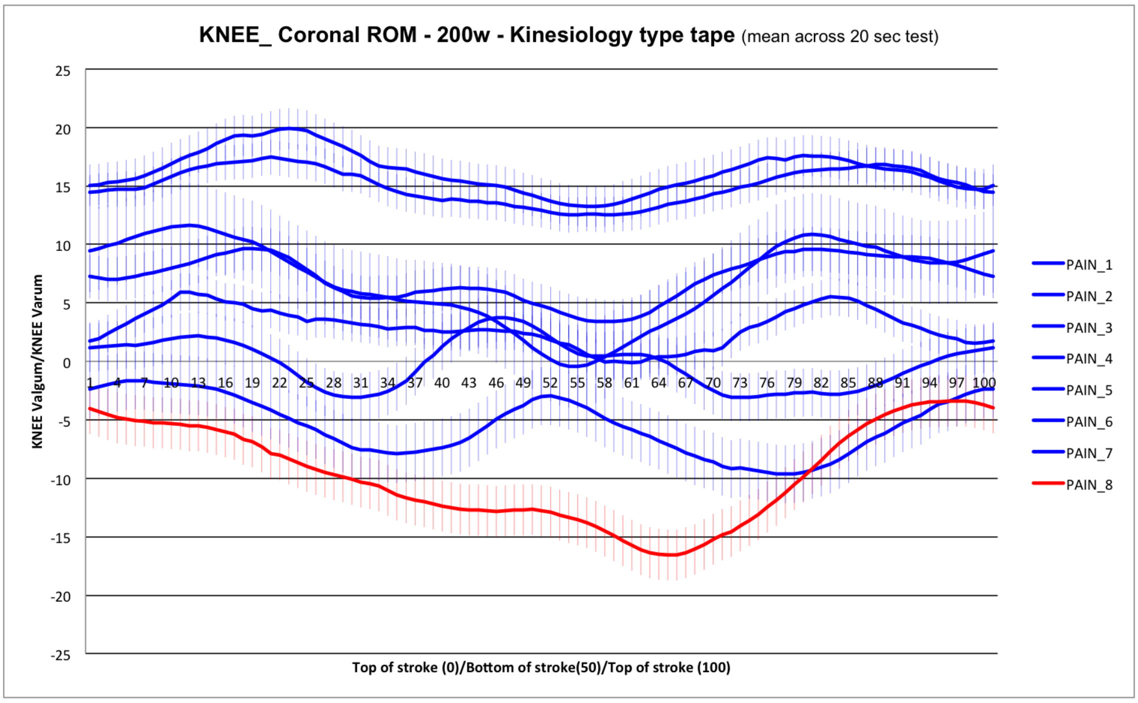
Test	Cycling Specific Numeric Pain Rating Scale			Notes
	Before	During	After	
1 Power: Condition:				
2 Power: Condition:				
3 Power: Condition:				
4 Power: Condition:				
5 Power: Condition:				
6 Power: Condition:				
7 Power: Condition:				
8 Power: Condition:				
9 Power: Condition:				

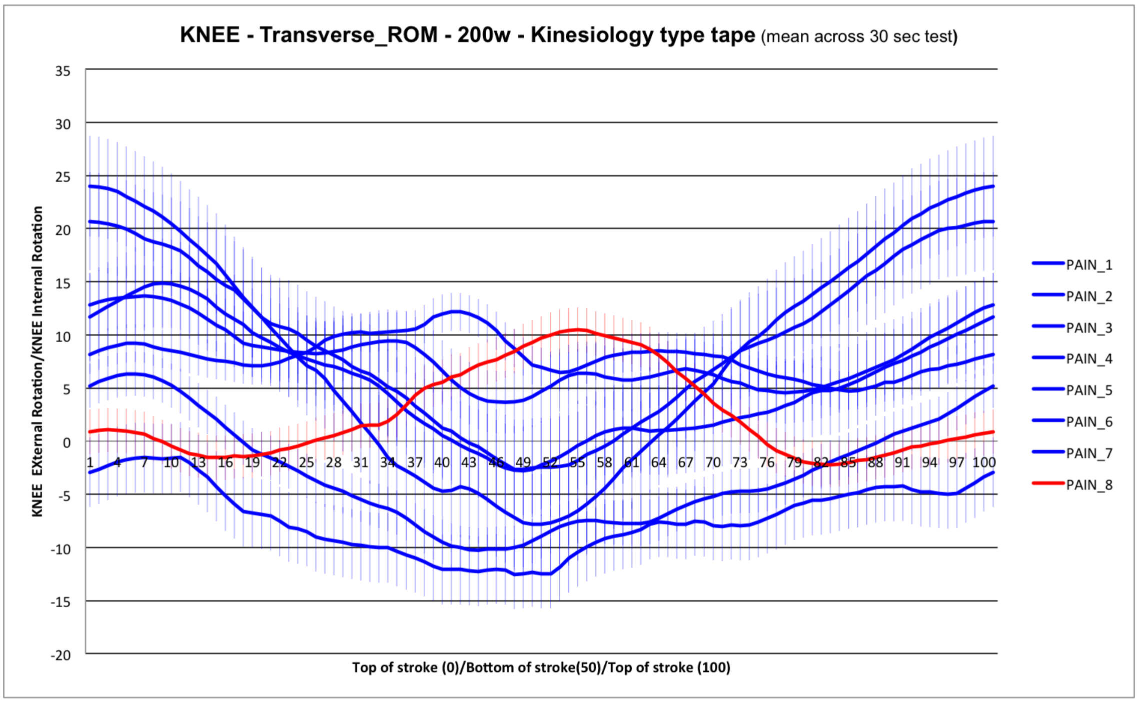
Condition key: NT = No tape, KT = Kinesiology tape, PT = Plonk tape

21. Biomechanical study - Results with outlier removed

21.1 Kinematic patterns overlaid to illustrate outlier







KNEE - Transverse_ROM - 200w - Kinesiology type tape (mean across 30 sec test)
35
30
25
20
15
10
5
0
-5
-10
-15
-20
KNEE EXternal Rotation/KNEE Internal Rotation
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100
Top of stroke (0)/Bottom of stroke(50)/Top of stroke (100)
PAIN_1
PAIN_2
PAIN_3
PAIN_4
PAIN_5
PAIN_6
PAIN_7
PAIN_8

Appendix 21.2:

Analysis of variance (ANOVA) : **Outlier removed**

SAGITTAL – comparison with and without outlier

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between conditions (KTT/Neutral tape/NO tape)									
Sagittal plane – ROM – KNEE (degrees)									
Condition		Mean Difference	Sig	<0.05 yes/no	Condition		Mean Difference	Sig	<0.05 yes/no
KTT	Neutral tape	-.286	.776	no	KTT	Neutral tape	-.334	no	no
	NO tape	-.715	.476	no		NO tape	-.795	no	no
Neutral tape	KTT	.286	.776	no	Neutral tape	KTT	.334	no	no
	NO tape	-.429	.669	no		NO tape	-.461	no	no
NO tape	KTT	.715	.476	no	NO tape	KTT	.795	no	no
	Neutral tape	.429	.669	no		Neutral tape	.461	no	N0

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between Asymptomatic and Symptomatic participants									
Sagittal plane – ROM – KNEE (degrees)									
	Mean ROM	Mean Diff	Sig	<0.05 yes/no		Mean ROM	Mean Diff	Sig	<0.05 yes/no
Asymptomatic	84.350	.576	.497	no	Asymptomatic	84.350	-.385	.655	no
Symptomatic	83.774	-.576	.497	no	Symptomatic	84.736	.385	.655	no

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between powers (100w/200w/300w)									
Sagittal plane – ROM – KNEE (degrees)									
Power		Mean Difference	Sig	<0.05 yes/no	Power		Mean Difference	Sig	<0.05 yes/no
100w	200w	-.854	.395	no	100w	200w	-.842	.425	no
	300w	-1.811	.072	no		300w	-1.659	.117	no
200w	100w	.854	.395	no	200w	100w	.842	.425	no
	300w	-.957	.340	no		300w	-.817	.439	no
300w	100w	1.811	.072	no	300w	100w	1.659	.117	no
	200w	.957	.340	no		200w	.817	.439	no

CORONAL – comparison with and without outlier

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between conditions (KTT/Neutral tape/NO tape)									
Coronal plane – ROM – KNEE (degrees)									
Condition		Mean Difference	Sig	<0.05 yes/no	Condition		Mean Difference	Sig	<0.05 yes/no
KTT	Neutral tape	-.127	.783	no	KTT	Neutral tape	-.156	.764	no
	NO tape	-.464	.314	no		NO tape	-.218	.675	no
Neutral tape	KTT	.127	.783	no	Neutral tape	KTT	.156	.764	no
	NO tape	-.337	.464	no		NO tape	-.062	.905	no
NO tape	KTT	.464	.314	no	NO tape	KTT	.218	.675	no
	Neutral tape	.337	.464	no		Neutral tape	.062	.905	no

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between Asymptomatic and Symptomatic participants									
Coronal plane – ROM – KNEE (degrees)									
	Mean ROM	Mean Diff	Sig	<0.05 yes/no		Mean ROM	Mean Diff	Sig	<0.05 yes/no
Asymptomatic	6.700	-.504	.197	no	Asymptomatic	6.700	-1.194*	**.005**	yes
Symptomatic	7.204	.504	.197	no	Symptomatic	7.894	1.194*	**.005**	yes

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between powers (100w/200w/300w)									
Coronal plane – ROM – KNEE (degrees)									
Power		Mean Difference	Sig	<0.05 yes/no	Power		Mean Difference	Sig	<0.05 yes/no
100w	200w	.079	.864	no	100w	200w	.142	.785	no
	300w	-.063	.891	no		300w	-.088	.866	no
200w	100w	-.079	.864	no	200w	100w	-.142	.785	no
	300w	-.142	.758	no		300w	-.230	.659	no
300w	100w	.063	.891	no	300w	100w	.088	.866	no
	200w	.142	.758	no		200w	.230	.659	no

TRANSVERSE – comparison with and without outlier

WITHOUT OUTLIER – n=19					**WITH** OUTLIER – n=20				
Between conditions (KTT/Neutral tape/NO tape)									
Transverse plane – ROM – KNEE (degrees)									
Condition		Mean Difference	Sig	<0.05 yes/no	Condition		Mean Difference	Sig	<0.05 yes/no
KTT	Neutral tape	-.093	.947	no	KTT	Neutral tape	.033	.981	no
	NO tape	-.330	.812	no		NO tape	-.163	.908	no
Neutral tape	KTT	.093	.947	no	Neutral tape	KTT	-.033	.981	no
	NO tape	-.237	.865	no		NO tape	-.195	.889	no
NO tape	KTT	.330	.812	no	NO tape	KTT	.163	.908	no
	Neutral tape	.237	.865	no		Neutral tape	.195	.889	no

WITHOUT OUTLIER – n=19					WITH OUTLIER – n=20				
Between Asymptomatic and Symptomatic participants (degrees)									
	Mean ROM	Mean Diff	Sig	<0.05 yes/no		Mean ROM	Mean Diff	Sig	<0.05 yes/no
Asymptomatic	14.004	-2.066	.081	no	Asymptomatic	14.004	-1.676	.146	no
Symptomatic	16.070	2.066	.081	no	Symptomatic	15.680	1.676	.146	no

WITHOUT OUTLIER – n=19					WITH OUTLIER – n=20				
Between powers (100w/200w/300w)									
Transverse plane – ROM – KNEE (degrees)									
Power		Mean Difference	Sig	<0.05 yes/no	Power		Mean Difference	Sig	<0.05 yes/no
100w	200w	.528	.704	no	100w	200w	.289	.837	no
	300w	1.053	.450	no		300w	.812	.564	no
200w	100w	-.528	.704	no	200w	100w	-.289	.837	no
	300w	.525	.706	no		300w	.524	.710	no
300w	100w	-1.053	.450	no	300w	100w	-.812	.564	no
	200w	-.525	.706	no		200w	-.524	.710	no

22. Biomechanical study: Results not presented in section 4 or referred to in results section

Statistical Analysis of variance (ANOVA) across all participants- n=20
Sagittal plane – ROM - KNEE
Between conditions (KTT/Neutral tape/No tape)

Table 22.1 - Knee/sagittal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.334	.751	no
	NO tape	-.795	.451	no
Neutral tape	KTT	.334	.751	no
	NO tape	-.461	.662	no
NO tape	KTT	.795	.451	no
	Neutral tape	.461	.662	no

Between Asymptomatic and Symptomatic participants

Table 22.2 - Knee/sagittal between Asymptomatic & Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	84.350	-.385	.655	no
Symptomatic	84.736	.385	.655	no

Between powers (100W/200W/300W)

Table 22.3 - Knee/sagittal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.842	.425	no
	300W	-1.659	.117	no
200W	100W	.842	.425	no
	300W	-.817	.439	no
300W	100W	1.659	.117	no
	200W	.817	.439	no

Coronal plane – ROM - KNEE

Between conditions (KTT/Neutral tape/No tape)

Table 22.4 - Knee/coronal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.156	.764	no
	NO tape	-.218	.675	no
Neutral tape	KTT	.156	.764	no
	NO tape	-.062	.905	no
NO tape	KTT	.218	.675	no
	Neutral tape	.062	.905	no

Between Asymptomatic and Symptomatic participants

Table 22.5 - Knee/coronal between Asymptomatic & Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	6.700	-1.194*	**.005**	yes
Symptomatic	7.894	1.194*	**.005**	yes

Between powers (100W/200W/300W)

Table 22.6 - Knee/coronal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	.142	.785	no
	300W	-.088	.866	no
200W	100W	-.142	.785	no
	300W	-.230	.659	no
300W	100W	.088	.866	no
	200W	.230	.659	no

Transverse plane – ROM - KNEE

Between conditions (KTT/Neutral tape/No tape)

Table 22.7 - Knee/transverse between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	.033	.981	no
	NO tape	-.163	.908	no
Neutral tape	KTT	-.033	.981	no
	NO tape	-.195	.889	no
NO tape	KTT	.163	.908	no
	Neutral tape	.195	.889	no

Between Asymptomatic and Symptomatic participants

Table 22.8 - Knee/transverse between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	14.004	-1.676	.146	no
Symptomatic	15.680	1.676	.146	no

Between powers (100W/200W/300W)

Table 22.9 - Knee/transverse between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	.289	.837	no
	300W	.812	.564	no
200W	100W	-.289	.837	no
	300W	.524	.710	no
300W	100W	-.812	.564	no
	200W	-.524	.710	no

Statistical Post hoc analysis: Comparison of significant differences across planes – ASYMPTOMATIC – KNEE

Table 22.10 - Significant differences Asymptomatic knee - Between conditions, within powers

WITHIN POWER			**SAGITTAL** KTT	Neutral	No tape		**CORONAL** KTT	Neutral	No tape		**TRANSVERSE** KTT	Neutral	No tape	
KNEE kinematics **Asymptomatic** (n=12)	**100W**	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape	0.023			NO tape				
	200W	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape	0.002	0.011		NO tape				NO tape				
	300W	KTT				KTT				KTT				**300W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape	0.005	0.041		NO tape				NO tape		0.033		

Table 22.11 - Transverse plane - Significant differences asymptomatic knee - Between powers, within conditions

WITHIN CONDITION			**SAGITTAL** 100W	200W	300W		**CORONAL** 100W	200W	300W		**TRANSVERSE** 100W	200W	300W	
KNEE kinematics **Asymptomatic** (n=12)	**KTT**	100W				100W				100W				**KTT**
		200W				200W				200W				
		300W				300W				300W				
	Neutral tape	100W				100W				100W				**Neutral tape**
		200W				200W				200W				
		300W		0.002		300W				300W		0.042		
	NO tape	100W				100W				100W				**NO tape**
		200W				200W				200W				
		300W	0.005	0.002		300W				300W				

Comparison of significant differences across planes - SYMPTOMATIC – KNEE

Table 22.12 - Significant differences Symptomatic knee - Between conditions, within powers

WITHIN POWER			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			KTT	Neutral	No tape		KTT	Neutral	No tape		KTT	Neutral	No tape	
KNEE kinematics **Symptomatic** (n=8)	**100W**	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				
	200W	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				
	300W	KTT				KTT				KTT				**300W**
		Neutral tape	**0.014**			Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				

Table 22.13 - Significant differences Symptomatic knee - Between powers, within conditions

WITHIN CONDITION			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			100W	200W	300W		100W	200W	300W		100W	200W	300W	
KNEE kinematics **Symptomatic** (n=8)	**KTT**	100W				100W				100W				**KTT**
		200W				200W				200W				
		300W				300W		**0.029**		300W				
	Neutral tape	100W				100W				100W				**Neutral tape**
		200W				200W				200W				
		300W	**0.026**			300W				300W				
	NO tape	100W				100W				100W				**NO tape**
		200W	**0.016**			200W	**0.028**			200W				
		300W	**0.002**			300W				300W		**0.017**		

Statistical Analysis of variance (ANOVA) across all participants- n=20

Sagittal plane – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

Table 22.14 - Hip/sagittal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.378	.679	no
	NO tape	-.572	.531	no
Neutral tape	KTT	.378	.679	no
	NO tape	-.194	.832	no
NO tape	KTT	.572	.531	no
	Neutral tape	.194	.832	no

Between Asymptomatic and Symptomatic participants

Table 22.15 - Hip/sagittal between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	52.108	1.410	.060	no
Symptomatic	50.698	-1.410	.060	no

Between powers (100W/200W/300W)

Table 22.16 - Hip/sagittal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.349	.702	no
	300W	-.991	.278	no
200W	100W	.349	.702	no
	300W	-.642	.482	no
300W	100W	.991	.278	no
	200W	.642	.482	no

Coronal plane – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

Table 22.17 - Hip/coronal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.763	.179	no
	NO tape	-.420	.458	no
Neutral tape	KTT	.763	.179	no
	NO tape	.342	.545	no
NO tape	KTT	.420	.458	no
	Neutral tape	-.342	.545	no

Between Asymptomatic and Symptomatic participants

Table 22.18 - Hip/coronal between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	6.083	1.595*	**.001**	yes
Symptomatic	4.488	-1.595*	**.001**	yes

Between powers (100W/200W/300W)

Table 22.19 - Hip/coronal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.613	.279	no
	300W	-1.199*	**.035**	yes
200W	100W	.613	.279	no
	300W	-.586	.301	no
300W	100W	1.199*	**.035**	yes
	200W	.586	.301	no

Transverse plane – ROM - HIP

Between conditions (KTT/Neutral tape/No tape)

Table 22.20 - Hip/transverse between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.078	.866	no
	NO tape	-.236	.609	no
Neutral tape	KTT	.078	.866	no
	NO tape	-.158	.732	no
NO tape	KTT	.236	.609	no
	Neutral tape	.158	.732	no

Between Asymptomatic and Symptomatic participants

Table 22.21 - Hip/transverse between Asymptomatic and Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	10.459	-.273	.469	no
Symptomatic	10.732	.273	.469	no

Between powers (100W/200W/300W)

Table 22.22 - Hip/transverse between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.947*	**.041**	yes
	300W	-1.642*	**.000**	yes
200W	100W	.947*	**.041**	yes
	300W	-.695	.133	no
300W	100W	1.642*	**.000**	yes
	200W	.695	.133	no

Comparison of significant differences across planes - ASYMPTOMATIC – HIP

Table 22.23 - Significant differences Asymptomatic hip - Between conditions, within powers

WITHIN POWER			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			KTT	Neutral	No tape		KTT	Neutral	No tape		KTT	Neutral	No tape	
	100W	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape		0.051		NO tape				
HIP kinematics **Asymptomatic** (n=12)	**200W**	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape	0.021			Neutral tape				
		NO tape	0.040			NO tape				NO tape				
	300W	KTT				KTT				KTT				**300W**
		Neutral tape				Neutral tape	0.044			Neutral tape				
		NO tape	0.018	0.026		NO tape				NO tape	0.045			

Table 22.24 - Significant differences Asymptomatic hip - Between powers, within conditions

WITHIN CONDITION			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			100W	200W	300W		100W	200W	300W		100W	200W	300W	
	KTT	100W				100W				100W				**KTT**
		200W				200W	0.018			200W				
		300W				300W	0.015			300W				
HIP kinematics **Asymptomatic** (n=12)	**Neutral tape**	100W				100W				100W				**Neutral tape**
		200W				200W	0.016			200W				
		300W	0.041	0.006		300W				300W				
	NO tape	100W				100W				100W				**NO tape**
		200W	0.037			200W	0.017			200W				
		300W	0.025			300W	0.004	0.008		300W				

Comparison of significant differences across planes - SYMPTOMATIC – HIP

Table 22.25 - Significant differences Symptomatic hip - Between conditions, within powers

WITHIN POWER			**SAGITTAL** KTT	Neutral	No tape	**CORONAL**	KTT	Neutral	No tape	**TRANSVERSE**	KTT	Neutral	No tape	
HIP kinematics **Symptomatic** (n=8)	**100W**	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				
	200W	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				
	300W	KTT				KTT				KTT				**300W**
		Neutral tape	**0.016**			Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				

Table 22.26 - Significant differences Symptomatic hip - Between powers, within conditions

WITHIN CONDITION			**SAGITTAL** 100W	200W	300W	**CORONAL**	100W	200W	300W	**TRANSVERSE**	100W	200W	300W	
HIP kinematics **Symptomatic** (n=8)	**KTT**	100W				100W				100W				**KTT**
		200W				200W				200W	**0.000**			
		300W				300W				300W	**0.004**			
	Neutral tape	100W				100W				100W				**Neutral tape**
		200W				200W				200W				
		300W		**0.023**		300W		**0.039**		300W	**0.009**	**0.009**		
	NO tape	100W				100W				100W				**NO tape**
		200W				200W				200W	**0.001**			
		300W				300W		**0.042**		300W	**0.001**			

Statistical Analysis of variance (ANOVA) across all participants- n=20

Sagittal plane – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

Table 22.27 - Ankle/sagittal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.081	.956	no
	NO tape	.132	.929	no
Neutral tape	KTT	.081	.956	no
	NO tape	.213	.885	no
NO tape	KTT	-.132	.929	no
	Neutral tape	-.213	.885	no

Between Asymptomatic and Symptomatic participants

Table 22.28 - Ankle/sagittal between Asymptomatic & Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	26.129	-1.353	.264	no
Symptomatic	27.482	1.353	.264	no

Between powers (100W/200W/300W)

Table 22.29 - Ankle/sagittal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.155	.917	no
	300W	-.134	.928	no
200W	100W	.155	.917	no
	300W	.021	.989	no
300W	100W	.134	.928	no
	200W	-.021	.989	no

Coronal plane – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

Table 22.30 - Ankle/coronal between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	.134	.711	no
	NO tape	.116	.748	no
Neutral tape	KTT	-.134	.711	no
	NO tape	-.018	.960	no
NO tape	KTT	-.116	.748	no
	Neutral tape	.018	.960	no

Between Asymptomatic and Symptomatic participants

Table 22.31 - Ankle/coronal between Asymptomatic & Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	5.779	.289	.327	no
Symptomatic	5.490	-.289	.327	no

Between powers (100W/200W/300W)

Table 22.32 - Ankle/coronal between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	-.393	.277	no
	300W	-.714*	**.049**	yes
200W	100W	.393	.277	no
	300W	-.321	.373	no
300W	100W	.714*	**.049**	yes
	200W	.321	.373	no

Transverse plane – ROM - ANKLE

Between conditions (KTT/Neutral tape/No tape)

Table 22.33 - Ankle/ transverse between conditions (KTT/Neutral tape/NO tape)

Condition		Mean Difference (º)	Sig	<0.05 yes/no
KTT	Neutral tape	-.276	.540	no
	NO tape	-.487	.281	no
Neutral tape	KTT	.276	.540	no
	NO tape	-.210	.641	no
NO tape	KTT	.487	.281	no
	Neutral tape	.210	.641	no

Between Asymptomatic and Symptomatic participants

Table 22.34 - Ankle/ transverse between Asymptomatic & Symptomatic participants

	Mean ROM (º)	Mean Diff (º)	Sig	<0.05 yes/no
Asymptomatic	5.470	-.787*	**.034**	yes
Symptomatic	6.257	.787*	**.034**	yes

Between powers (100W/200W/300W)

Table 22.35 - Ankle/transverse between powers (100W/200W/300W)

Power (W)		Mean Difference (º)	Sig	<0.05 yes/no
100W	200W	.036	.936	no
	300W	-.022	.961	no
200W	100W	-.036	.936	no
	300W	-.058	.897	no
300W	100W	.022	.961	no
	200W	.058	.897	no

Comparison of significant differences across planes – ASYMPTOMATIC – ANKLE

Table 22.36 - Significant differences Asymptomatic ankle - Between conditions, within powers

WITHIN POWER			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			KTT	Neutral	No tape		KTT	Neutral	No tape		KTT	Neutral	No tape	
ANKLE kinematics **Asymptomatic** (n=12)	**100W**	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape	**0.004**			
		NO tape				NO tape				NO tape	**0.001**			
	200W	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape	**0.008**			NO tape	**0.044**			
	300W	KTT				KTT				KTT				**300W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape	**0.010**			

Table 22.37 - Significant differences Asymptomatic ankle - Between powers, within conditions

WITHIN CONDITION			**SAGITTAL**				**CORONAL**				**TRANSVERSE**			
			100W	200W	300W		100W	200W	300W		100W	200W	300W	
ANKLE kinematics **Asymptomatic** (n=12)	**KTT**	100W				100W				100W				**KTT**
		200W				200W				200W				
		300W				300W				300W				
	Neutral tape	100W				100W				100W				**Neutral tape**
		200W				200W				200W				
		300W				300W	**0.033**	**0.030**		300W				
	NO tape	100W				100W				100W				**NO tape**
		200W				200W	**0.006**			200W				
		300W				300W	**0.031**			300W				

Comparison of significant differences across planes – SYMPTOMATIC – ANKLE

Table 22.38 - Significant differences Symptomatic ankle- Between conditions, within powers

WITHIN POWER			SAGITTAL				CORONAL				TRANSVERSE			
			KTT	Neutral	No tape		KTT	Neutral	No tape		KTT	Neutral	No tape	
ANKLE kinematics **Symptomatic** (n=8)	**100W**	KTT				KTT				KTT				**100W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape		**0.035**		NO tape				
	200W	KTT				KTT				KTT				**200W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				
	300W	KTT				KTT				KTT				**300W**
		Neutral tape				Neutral tape				Neutral tape				
		NO tape				NO tape				NO tape				

Table 22.39 - Significant differences Symptomatic ankle - Between powers, within conditions

WITHIN CONDITION			SAGITTAL				CORONAL				TRANSVERSE			
			100W	200W	300W		100W	200W	300W		100W	200W	300W	
ANKLE kinematics **Symptomatic** (n=8)	**KTT**	100W				100W				100W				**KTT**
		200W				200W				200W				
		300W				300W				300W				
	Neutral tape	100W				100W				100W				**Neutral tape**
		200W				200W	**0.039**			200W				
		300W				300W	**0.040**			300W				
	NO tape	100W				100W				100W				**NO tape**
		200W				200W				200W				
		300W				300W				300W				

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