Asymmetry in Hip, Knee and Ankle Kinematics in cyclists with chronic unilateral Patellofemoral pain.

Erika G. Brand

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STUDY LEADERS:
Prof. Q. Louw (B.Sc. Physio, MASP, PhD)
Ms. L. Crous (B.Sc. Physio, M.Sc. Physio)

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained herein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights, and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2016

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2. All the cyclists who took part in the research study and who went to lengthy efforts to visit the laboratory for testing on the appointed days and times.
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Abstract

Background: Cycling has grown in popularity over the last number of years and the nature of the sport has led to a high incidence of overuse injuries such as patellofemoral pain (PFP). With patellofemoral pain being multifactorial numerous aspects have been investigated. In an attempt to further investigate contributing factors, asymmetry of joint kinematics in the lower limb has been investigated. Kinematics of the hip, knee and ankle joints in the sagittal, coronal and transverse plane were evaluated.

Aim: The aim of this study was to investigate whether asymmetry of hip, knee and ankle kinematics in cyclists could contribute to patellofemoral pain when compared with cyclist without knee pain.

Study Design: Descriptive study design was incorporated.

Study Setting: This study was conducted at the FNB -3D motion analysis laboratory at the University of Stellenbosch, South Africa.

Method: Road *cyclists* were recruited in South Africa and Namibia. The study sample comprised of seven road cyclists (4 with PFP and 3 without pain) who were evaluated at the FNB Motion Analysis Laboratory at Stellenbosch University. The Vicon Motion Systems (Ltd) (Oxford, UK) was used to capture three-dimensional joint kinematics. Collected data was utilised to draw graphs for visual comparison.

Results: In the sagittal plane no asymmetry was noted in the hip and knee movement, but asymmetry was present in the ankle joint. However the asymmetry was present for both asymptomatic and symptomatic groups. In the coronal and transverse plane asymmetry was present in all joints; both the asymptomatic and symptomatic group presented some level of asymmetry.

Conclusion: Asymmetry was apparent in the hip, knee and ankle joints in the coronal and the transverse plane, however it is present in the symptomatic as well as in the asymptomatic group and could therefore not be identified as a contributing factor for the development of patellofemoral pain**.** These findings highlight the fact that PFP is multifactorial and that all possible contributing factors should be kept in mind when evaluating and treating cyclists with PFP.

Keywords: *cycling, leg dominance, asymmetry, patellofemoral pain, anterior knee pain, incidence and prevalence.*

Opsomming

Agtergrond: Fietsry het oor die afgelope paar jaar in populariteit gegroei, en die aard van die sport het gelei tot 'n groot hoeveelheid oorgebruik beserings, soos patellofemorale pyn (PFP). Aangesien patellofemorale pyn menigvuldige bydraende faktore het, is verskeie aspekte reeds ondersoek. In 'n poging tot verdere ondersoek rakende bydraende faktore, was asimmetrie kinematika van die heup, knie en enkel bewegings in die sagitale, koronale en transverse vlakke geevalueer.

***Doelstelling*s:** Die doel van die studie was om te bepaal of asimmetrie van die heup, knie en enkel kinemetika in fietsryes 'n bydraende factor kan wees tot die ontwikkeling van patellofemorale pyn wanneer hulle vergelyk word met fietsryers sonder knie pyn.

Studie: Beskrywende studie.

Metode: Padfietsryers is in Suid-Afrika en Namibia gewerf. 'n Totaal van sewe padfietsryers (4 met patellofemorale pyn en 3 sonder pyn) was by die FNB Bewegings Analise Laboratorium by Stellenbosch Universiteit geevalueer. Die Vicon Motion Systems (Ltd) (Oxford, UK) was gebruik om driedimensionele beweging van die gewrigte vas te vang. Die versamelde data was verwerk om grafieke te teken en sodoende visuele vergelykings te tref.

Hoof Bevindinge en Interpretasie: Asimmetrie was duidelik in die koronale en transvers vlakke, maar is teenwoordig in beide die simptomatiese asook die asimptomatiese groepe en kon daarom nie geidentifiseer word as enigste bydraende faktor nie. Dit benadruk dat PFP menigvuldige bydraende faktore het en dat alle moontlike aspekte geevalueer en behandel moet word by fietsryers met PFP.

Sleutelwoorde: fietsry, been dominansie, asimmetrie, patellofemorale pyn, anterior knie pyn, voorkoms en gemeenskaplikheid

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Glossary

ACRONYMS

BDC	:	Bottom Dead Centre
BW	:	Body Weight
MRI	:	Magnetic Resonance Imaging
MU	:	Motor Unit
PFP	:	Patellofemoral Pain
ROM	:	Range of Motion
RPM	:	Rates per Minute
SASP	:	South African Society of Physiotherapy
TDC	:	Top Dead Centre

DEFINITIONS

Asymmetry	:	Asymmetry is the variation of moment around the zero mean (Al-Eisa et al. 2004)
Abduction	:	Movement of a limb or other part away from the midline of the body
Adduction	:	Movement of a limb or other part towards the midline of the body
Bottom Dead Centre	:	180° radial position in the crank cycle
Bicycle Fit / Bicycle Configuration	:	Bicycle fit is a process of changing body position by adjusting different bicycle parts to achieve an optimal interaction between a number of variables as to minimise resistive forces and maximise bicycle velocity while at the same time reducing the risk of injury occurrence
Biomechanics	:	The study of the action of external and internal forces on the living body, especially on the skeletal system
Crank Cycle	:	One 360° that the crank follows during one pedal cycle
Coronal Plane	:	A vertical plane that passes through the body dividing it into anterior and posterior portions
Extension	:	The action of straightening of a joint. This action will increase the angle between the bones forming the joint

Flexion	:	The action of bending a joint. This action will cause a decrease in the angle between the bones forming the joint
Kinematics	:	Mechanics that study the motion of a body or a system of bodies without consideration given to its mass or the forces acting on it
Patellofemoral Pain	:	Anterior knee pain, in the absence of intra-articular pathology, which may include the patella and/or the surrounding retinaculum but not involving the tibial-femoral structures. Pain is exacerbated by activities demanding knee flexion (Nijs et al. 2006, Cook et al. 2012, Nunes et al. 2013)
Power Phase	:	0° – 180° of the crank cycle
Rates Per Minute	:	Number of crank cycles completed in a minute
Recovery Phase	:	180° - 360° of the crank cycle
Rotation	:	The action of rotating around an axis or centre
Sagittal Plane	:	A plane along the long axis of the body. It divides the body into a right and a left side.
Top Dead Centre	:	0° radial position in the crank cycle
Transverse Plane	:	Plane passing through the body at right angles to the median and the coronal planes. A horizontal plane divides the body into superior and inferior parts

Chapter 1

1. STUDY BACKGROUND AND SIGNIFICANCE

1.1 BACKGROUND

Patellofemoral pain (PFP) is a common injury among physically active people and is regarded as the most common overuse injury or condition in the lower limb (Powers 2010). Pain location is on the anterior-medial aspect of the knee and is in the absence of intra-articular pathology. However, the affected area may include the patella and/or the surrounding retinaculum and pain is exacerbated by activities that demand knee flexion (Nijs et al. 2006, Cook et al. 2012, Nunes et al. 2013).

While there is a lot of research regarding PFP, most of the available studies have been performed during walking or running gait or during descending stairs (Souza and Powers 2009). The information from these studies can be useful because both walking and cycling has a weight bearing component and is alternating in nature, however, cycling patterns could be different due to the fact that the upper body and the pelvis are supported during movement and the body is forced to comply with a bicycle that is symmetric in design (Holmes et al. 1994).

Cycling is considered a low impact sport but repetitive strain predisposes cyclists to various injuries of the lower limbs (Callaghan 2005) causing a third of cyclists to complain about knee pain (Hannaford et al. 1986). While all individuals with PFP share the experience of knee pain, the intensity and nature of the symptoms may vary greatly between them (Thomee et al. 1999). Research reported that about 27% of cyclists miss training due to knee pain (Clarsen et al. 2010).

When viewed from the front, knee movement during cycling does not always follow a straight up and down pattern but rather a clockwise circular motion with the knee adducted when pushing down and abducted when returning to the top causing higher intersegment knee loads (Callaghan, 2005). Weakness in hip abduction, extension and external rotation could lead to dynamic malalignment with femoral adduction and internal rotation, valgus collapse at the knee, tibial internal rotation and foot pronation. Thus muscle weakness around the hip and poor neuromuscular control of proximal structures contributes to poor control of coronal and transverse plane movements (Earl et al., 2011).

Conservative management of PFP was statistically insignificant in 60% of reported results (Selfe et al. 2013). This indicates that either the true nature of the problem is not fully understood or that not all possible causes for injury have been investigated and explored and therefore not successfully addressed or incorporated within the treatment programme. Currently five possible risk factors have been indicated in research namely; malalignment of the lower extremity, muscle imbalances, biomechanical abnormalities, over activity and extrinsic factors. Therefore the aetiology of PFP appears to be multifactorial (Callaghan 2005).

Addressing PFP from a multifactorial perspective, the presence of asymmetry and the possibility of it contributing to PFP development in cyclists has been questioned (Callaghan 2005). Further investigation regarding lower limb kinematics in the sagittal, coronal and transverse plane during cycling is needed to determine possible differences in asymmetry when comparing symptomatic and asymptomatic cyclists with each other.

1.2 SIGNIFICANCE

While research on asymmetry in cycling is prolific it mainly focuses on leg preference (Carpes et al. 2010(a), Carpes et al. 2010(b), Smak 1999, Carpes et al. 2007), muscle activation patterns (Carpes et al. 2010, Carpes et al. 2011) and power production (Sanderson 1991, Carpes et al. 2010). Research regarding asymmetry in joint kinematics during cycling is limited and mainly focuses on joint kinematics in the sagittal plane (Bini et al. 2011). However, joint kinematics is three dimensional therefore this study endeavours to investigate asymmetry in the sagittal, coronal and transverse plane, and the possible relationship between the presence of asymmetry and the development of PFP. The objectives were to determine hip, knee and ankle joint range of motion (ROM) in the three planes and to compare the values between the symptomatic and asymptomatic subjects.

Should asymmetry be an indicator for the development of PFP, it could be addressed and corrected before pain develops and therefore limit the prevalence of PFP or improve the prognosis of symptomatic cyclists.

Chapter 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

Increased popularity of cycling over the last couple of years has led to a high incidence of overuse injuries (Bini et al. 2011). Cycling is a low impact sport but due to the prolonged postural adaptations and repetitive nature of the sport, cyclists are prone to develop various injuries of the lower limbs (Callaghan 2005).

This study endeavours to explore concepts related to PFP and will give an overview of the biomechanics and kinematics of the hip, knee and ankle joints of healthy as well as symptomatic cyclists. Furthermore intrinsic factors related to overuse injuries in these structures will be discussed. Since not every cyclist develops PFP it can be assumed that there must be a second insult to the structures that makes it more susceptible to overuse injuries. The presence of increased asymmetry in hip, knee and ankle kinematics in symptomatic cyclists will be investigated as such a possibility. Although research on asymmetry is prolific regarding power production, leg preference and muscle activation patterns (Bini et al., 2011), there is limited information regarding asymmetry in hip, knee and ankle kinematics in the coronal plane.

Research information was gathered using various databases namely PubMed, CHINAL, Sports Discuss, Scopus and Science Direct. The literature search was conducted between March 2013 and August 2014. Articles pertaining to the following were excluded: neurological cases, traumatic injuries, animals, children, amputations, osteoarthritis, diabetics and artificial limbs. The following words were used during the search: cycling, leg dominance, asymmetry, patellofemoral pain, PFP, incidence and prevalence. Words were used on their own and in various combinations.

2.2 PATELLOFEMORAL PAIN

Patellofemoral pain (PFP) is a common injury among physically active people and possible causes have been researched extensively. In the orthopaedic setting it is regarded as the most common overuse injury or condition (Powers 2010) experienced in the peripatellar area with symptoms exacerbated by sport activities (Earl et al. 2011).

2.2.1 Prevalence of Patellofemoral Pain

Knee problems are most prevalent in physically active people and account for 23% – 31% (Thomee et al. 1999). PFP is the most common of all knee problems (Thomee et al. 1999) and females have a 2.2 times higher incidence rate compared to their male counterparts (Powers 2010). More alarming is the time of dysfunction and limitation since the condition has been diagnosed. While 91% - 96% of patients still suffered with pain and dysfunction 4 years after diagnosis; 94% were still symptomatic 16 years after being diagnosed (Selfe et al. 2013).

Cycling is considered a low impact sport but prolonged postural adaptations and repetitive strain predispose cyclists to various injuries of the lower limbs (Callaghan 2005). About a third of cyclists complain of knee pain (Hannaford et al. 1986) and although prevalence for lower back pain (58%) is higher than knee pain (36%), more cyclists miss training (27%) and competition (9%) due to knee pain (Clarsen et al. 2010). Although lateral knee pain is common, PFP with anterior knee joint (PFJ) involvement is most common (Callaghan 2005). While all subjects share the experience of pain, the intensity and nature of other related symptoms may vary greatly between subjects (Thomee et al. 1999). It has been described as PFP, in the absence of intra-articular pathology, which may include the patella and/or the surrounding retinaculum but not involving the tibial-femoral structures. Pain is exacerbated by activities that demand knee flexion such as climbing and descending stairs, sustained sitting, squatting and kneeling (Nijs et al. 2006, Cook et al. 2012, Nunes et al. 2013).

The term “chondromalacia patellae” has been used wrongly as a synonym for PFP though many studies confirmed poor correlation between cartilage damage and retro-patellar pain (Thomee et al. 1999). Many cyclists have been wrongly diagnosed with “chondromalacia patellae” and several cycling texts fail to distinguish (Callaghan 2005) between the pathological and clinical condition of PFP (Callaghan 2005). Chondromalacia patellae describes a specific macroscopic pathological abnormality indicating softening and fissuring on the ventral surface of the patella, while PFP indicates a clinical syndrome where pain originates form patellofemoral joint structures. This syndrome is caused by biomechanical abnormality of the patellofemoral complex (Van Zyl et al. 2001). However in spite of PFP being present without pathological abnormalities, conservative management of PFP was statistically insignificant in 60% of reported results. To promote targeted intervention modalities, a classification system for subjects with PFP has been proposed (Selfe et al. 2013). Although literature does not link the proposed subgroups to cycling it can be a helpful guide to direct evaluation, treatment and further research concerning PFP in cyclists. See *Figure 2.1*.

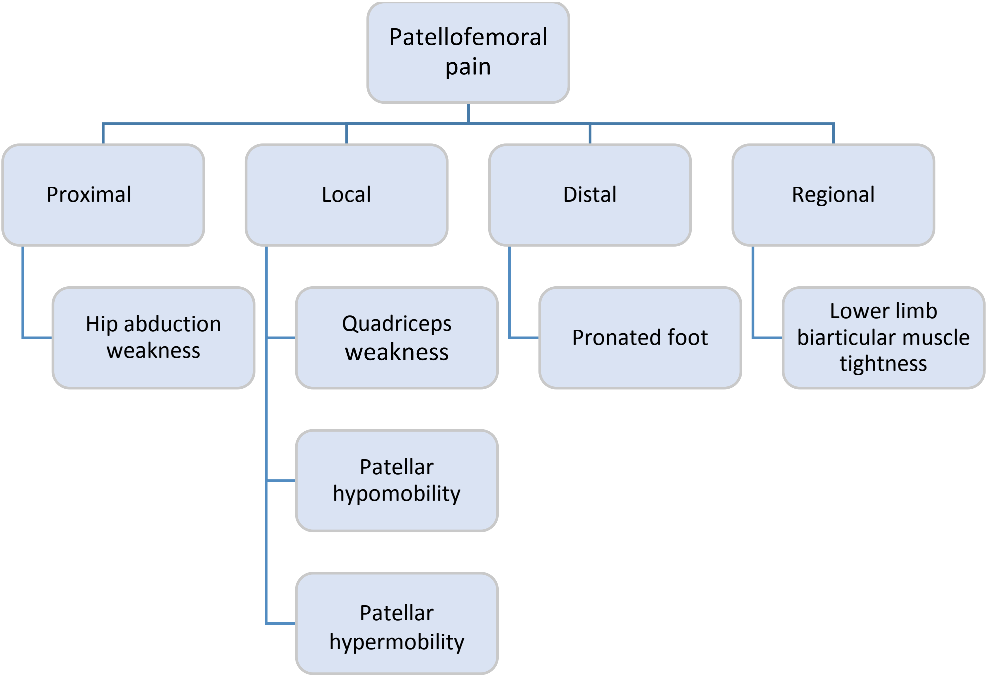


Figure 2.1: Clinical subgroups for patellofemoral pain (Selfe et al. 2013)

2.2.2 Aetiology: Contributing Risk Factors

The aetiology of PFP appears to be multifactorial (Meira and Brumitt 2011) with anatomical abnormalities being indicative for developing overuse injuries (Bailey et al. 2003). Overuse injuries involve micro-trauma of tissue structures which can be caused either by extrinsic or intrinsic factors. Extrinsic factors refer to bicycle configuration and training methods whereas intrinsic factors refer to anatomical or biomechanical abnormalities such as leg length discrepancy or abnormal foot posture (Callaghan 2005). Intrinsic factors will inevitably be affected and magnified by the extrinsic factors due to a symmetric bicycle design that has to be matched with asymmetric variations of the human body (Holmes et al. 1994). Incorrect bicycle configuration, training methods making use of increased distances and excessive use of low gears, predispose cyclists to overuse injuries (Callaghan 2005) and may reduce performance (Bini et al. 2011).

Taking all extrinsic factors into consideration, saddle height and the connection to the pedals are normally related to development of PFP (Callaghan 2005). A too far forward saddle position predisposes cyclists to PFP whereas a too low saddle increases the risk for PFP (Callaghan 2005) by causing knee flexion angles greater than 25° - 30° (Bini et al. 2011). While most saddle fitment is performed in a static setting it is important to note that static knee angles are not a representation of actual dynamic angles during cycling activities (Ferrer-Roca et al. 2012). The interphase for energy transfer between cyclist and bicycle is at the pedals, therefore, malalignment between cyclist and pedals can contribute to knee injuries (Callaghan 2005). In an attempt to limit overuse the “floating” clipless cleat system has been introduced to decrease or limit pedal torque which is highest during power phase (Callaghan 2005).

Intrinsic factors signify muscle and joint function. The Q-angle indicates the line of pull of the quadriceps on the patellar tendon. An angle larger than 15° – 20° is regarded a possible risk factor for development of PFP by causing excessive strain on the medial retinaculum and creating a shear force on the patellar tendon (Bailey et al. 2003). “Compressive force at the patellofemoral joint depends on the magnitude of the quadriceps force and the quadriceps tendon angle on the patellar tendon in relation to the longitudinal axis of the patella” (Bini et al. 2013). Therefore, the magnitude and direction of bilateral imbalance may predispose a subject to PFP (Livingston et al. 1999). Cycling with the knee in an adducted position (close to the body midline) may cause excessive Q-angles which may disrupt the extensor mechanism during the drive phase (0° - 180°). The Q-angle may be affected by knee and foot position, contractile quality of the quadriceps muscle group as well as the subjects’ body posture (Livingston et al. 1999).

Despite numerous predictions and explanations why certain intrinsic and extrinsic factors could indicate or contribute to the development of PFP, literature is inconclusive. While some authors argue in favour of certain proposed risk factors, others oppose the notion of their correlations with PFP. While not all proposed risk factors are directly related to cycling a summary of the suggested possibilities may be helpful to generate an overview. See *Figure 2.2*.

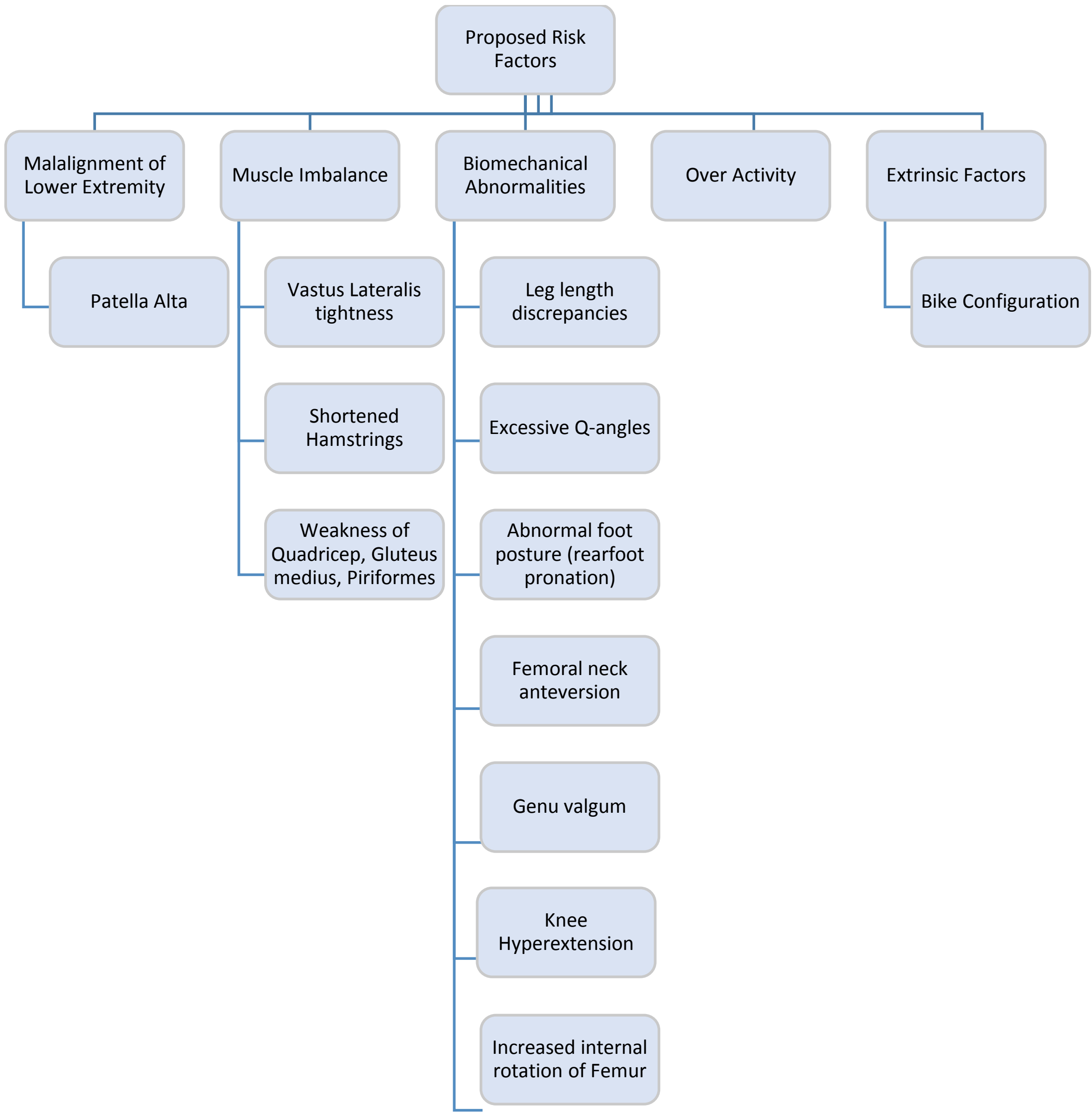


Figure 2.2: Proposed risk factors for the development of patellofemoral pain

2.3 BIOMECHANICS

2.3.1 Definition

Biomechanics pertain to a variety of elements that exert influence on numerous structures and function of structures (Kreighbaum and Barthels Katharine 1996). Knowledge regarding biomechanics may prove useful in various disciplines of sport to describe motion at different body segments as well as forces acting thereupon. When combining knowledge of force and motion with functional human anatomy, possible relationships between tissue injury and external events can be explored. While it is not the scope of this research paper to cover all areas, joint kinematics of the hip, knee and ankle joints as well as related muscle function during cycling, will be discussed. Furthermore, the sagittal and coronal planes will be investigated simultaneously to establish the degree of the flexion/extension angle at which coronal plane changes occur during cycling (Bailey et al. 2003).

For the purpose of clear description, a full cycling rotation is divided into two phases namely; a power phase and a recovery phase. Viewed from the side, the crank position is referred to as 0° (top dead centre), 90°, 180° (bottom dead centre) and 270°. The power phase covers the 0° - 180° while the recovery phase runs from the 180° back to the 0° mark (Wozniak Timmer 1991). See *Figure* 2.3.

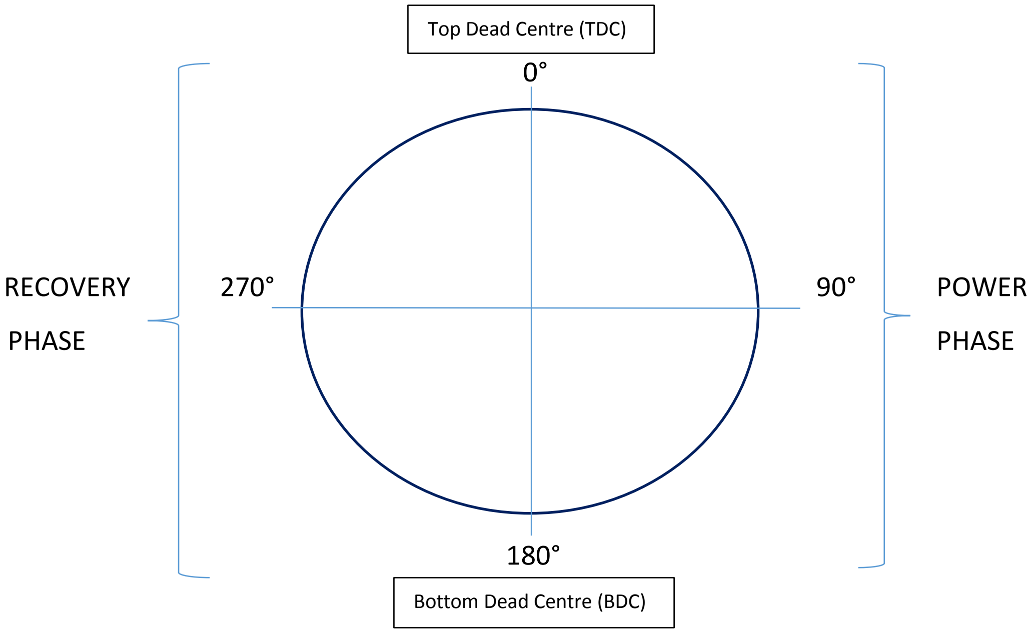


Figure 2.3: Graphic presentation and description of a crank cycle

2.3.2 Biomechanics in the Sagittal Plane

In the sagittal plane, hip activity during cycling only occurs "*in the flexion part of the range of motion*" (Wozniak Timmer 1991). When flexion in the hip exceeds 90°, as in cycling, the hip starts to adduct and rotate internally. Simultaneously pelvic instability is accentuated by the small support base, the saddle, and the relative extended position of the contralateral side (Wozniak Timmer 1991). While joint moments at the hip were low at top dead centre, considerable extending movement is already present at the knee. Through the course of the down stroke (0° – 180° crank cycle) knee moments decrease while hip moments increase. This phenomenon can largely be explained by the change in direction of the force through the foot on the pedal. The direction of force varies from in front of the knee, during the last part of the down stroke, to a point just in front of the hip joint (Van Ingen Schenau et al. 1992).

Knee extension occurs together with hip extension, but never reaches full extension (Wozniak Timmer 1991). At 45° of the power phase, where extreme values for knee extension moments are reached, various knee moments and internal axial moments also develop (Ruby et al. 1992). On average the power phase starts with a valgus moment which turns to a varus moment at about 70° of the power phase. This varus moment decreases to zero Newton at the end of the power phase and a valgus moment starts to develop during the recovery phase, reaching its main value at 250° of the crank cycle (Gregersen and Hull 2003). Equally an internal axial moment accompanies the power phase reaching its peak at 25° while the external axial moment is present at the start of the recovery phase (Gregersen and Hull 2003). These internal and varus knee moments increase the patellar contact area as well as the force, but no significant increase in mean contact pressure has been noted. Furthermore, the contact area seems to be affected more significantly by the internal moment than by the varus moment (Wolchok et al. 1998).

Ankle movement covers a total range of 50° with a maximum dorsiflexion of 13° at 90° crank position and maximum plantarflexion of 37° at 285° crank position. Dorsiflexion in the ankle occurs simultaneously with knee and hip flexion while plantar flexion correlates with knee and hip extension (Wozniak Timmer 1991).

2.3.3 Biomechanics in the Coronal and Transverse Plane

In the coronal plane, when viewed from the front, knee movement during cycling does not always follow a straight up and down pattern, but rather a clockwise circular motion with the knee adducted (shifted medially) when pushing down (power phase) and abducted (shifted laterally) when returning to the top (recovery phase) indicating hip rotations and causing high intersegmental knee loads (Callaghan 2005, Ruby et al. 1992). Furthermore tibial rotation during the power phase has been indicated as a risk factor for developing PFP (Sayers et al. 2012). While some authors ascribe this phenomenon to the possibility of pronation of the subtalar joint causing internal rotation of the tibia, others conclude that this cannot be the cause of injury as a net varus knee moment has been reported for all cyclists, including those without PFP (Ruby et al. 1992). However, varus and valgus knee moments may influence patellar tracking and can indicate infrapatellar pain due to medial or lateral tracking of the patella in relation to the intercondylar notch. Lateral knee pain is related to varus knee moments while medial knee pain is related to valgus knee moments. The axial rotation of the tibia does not affect patellar tracking alone, but also causes tension to medial and lateral knee structures (Ruby et al. 1992)

2.3.4 Muscle Function

Joint movement is accomplished through muscle function and there is co-activation between mono and bi-articular muscles. The power phase mainly entails hip and knee extension performed by the hamstrings (biarticular) and the gluteus maximus (monoarticular). To achieve hip extension gluteus maximus briefly acts alone between 0° - 45°. The hamstring muscle supports the gluteus maximus between 45° - 125° after which it acts on its own to finish off the extension movement up to 180° (Wozniak Timmer 1991). Knee extension is supported by the vastii group and the rectus femoris muscle from 295° to 115°. During extension, external rotation of the tibia is performed by the biceps femoris muscle and internal rotation is achieved through the pes anserinus and the semi-membranosis muscles. Contraction of the vastus medialis causes a medial pull of the patella while the vastus lateralis causes a lateral pull. The vastus intermedius and the rectus femoris are responsible for a lateral and proximal pull on the patella (Thomee et al. 1999). During the recovery phase hip and knee flexor muscles are responsible for leg movement and include the rectus femoris, sartorius, tensor fascia latae and gracilis (Thomee et al. 1999).

According to Van Ingen Schenau et al. (1992) force transmission at the ankle differs from the hip and knee. Forces generated by the gastrocnemius and soleus must be transmitted via the tarsal bindings to the forefoot. Gastrocnemius and soleus activation starts after hip and knee activation has occurred. The soleus is active between 27° - 145° and the gastrocnemius between 35° - 260°. Gastrocnemius contracts for the longest period of all muscles and tibialis anterior is mainly active during the recovery phase and contracts at 270° and relaxes at 88°. See *Figure 2.4*.

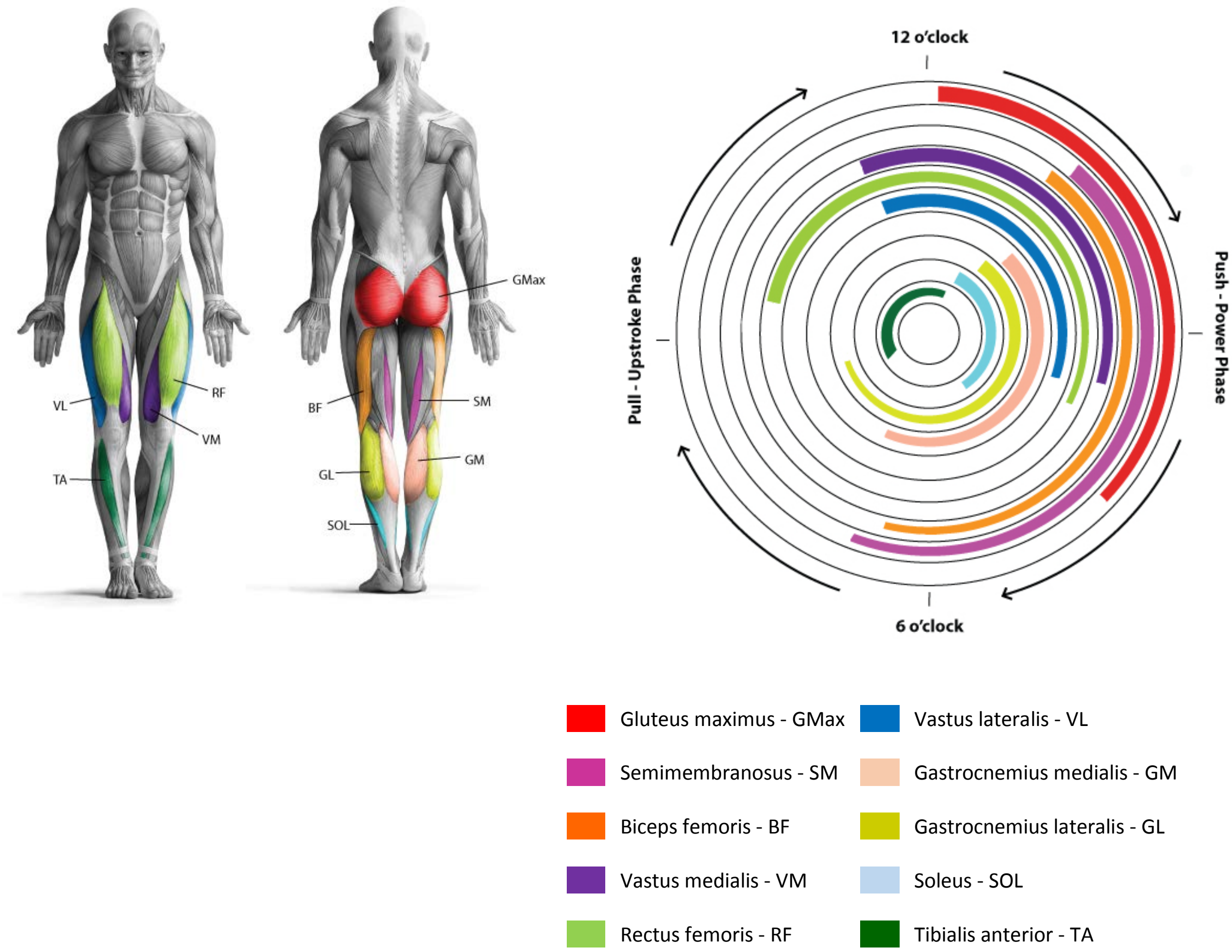


Figure 2.4: Muscle Activity During a Cycle

Source: (Highland Training http://home.trainingpeaks.com/blog/article/the-primary-muscles-used-for-cycling-and-how-to-train-them)

2.4 ASYMMETRY

2.4.1 Definition

Asymmetry is the variation of movement around the zero mean, and the degree of asymmetry is influenced by the subjects' level of fitness and health (Al-Eisa et al. 2004). Many variables can influence symmetry during cycling. Research regarding asymmetry in cycling mainly focused on the effect of leg preference (Carpes et al. 2010(a), Carpes et al. 2010 (b), Smak et al. 1999, Carpes et al. 2007), muscle activation patterns (Carpes et al. 2010, Carpes et al. 2011), force (Carpes et al. 2010, Sanderson 1991, Carpes et al. 2011, Cavanagh et al. 1974), crank torque (Carpes et al. 2007) and joint kinematics (Smak et al. 1999), where joint kinematics were mostly observed in the sagittal plane (Bini et al. 2011). Agreement exists that asymmetry decreases when pedalling rate or external workload increases. This phenomenon is not influenced by leg preference (Liu and Jensen 2012, Smak et al. 1999), but it is subject specific (Smak et al. 1999). Furthermore, a decrease in asymmetry showed an increase in performance (Liu and Jensen 2012).

2.4.2 Force Asymmetry (crank torque, work, power)

The presence of asymmetry in cyclists has been investigated extensively with regards to force production (Carpes et al. 2010, Carpes et al. 2011, Sanderson 1991, Cavanagh et al. 1974), torque output (Carpes et al. 2007, Smak et al. 1999) and work (Sauer et al. 2007, Carpes et al. 2010). Force has been described as “that which causes or tends to cause change in a body’s motion or shape”, while work describes force multiplied by the distance through which that specific force was applied (Kreighbaum and Barthels Katharine 1996). Torque indicates a rotary force and is the “product of a force and the perpendicular distance from the line of action of the force to the axis of rotation” (Kreighbaum and Barthels Katharine 1996). For these variables asymmetry, when present, appears to be influenced by pedalling cadence (Sauer et al. 2007, Carpes et al. 2010, Smak et al. 1999) and external workload (Sanderson 1991, Smak et al. 1999, Carpes et al. 2010). While the presence of asymmetry seems to be highly variable between subjects (Carpes et al. 2010) an increase in exercise intensity and cadence reduced the presence of asymmetry (Carpes et al. 2007).

The influence of leg dominance on above mentioned variables has been investigated and the outcome of the different studies is contradictive (Smak et al. 1999, Carpes et al. 2014, Carpes et al. 2011). While some authors argue that the dominant leg contributes 18% more force to the knee moment and that the hip and knee patterns differ substantially (Smak et al. 1999); on the contrary it has been stated saying that asymmetry in this regard does not exist (Carpes et al. 2010, Carpes et al. 2011).

2.4.3 Joint Kinematic Asymmetry

PFP is considered an overuse injury experienced in the peripatellar area with symptoms exacerbated by sport activities (Earl and Hoch 2011). While all cyclists are subjected to bilateral repetitive strain and overuse, not every cyclist develops knee pain and those who do develop knee pain do not always develop bilateral symptoms. This may indicate the existence of a cause other than repetitive strain only. An alternative possibility may be the presence of asymmetry in joint kinematics.

Generic literature regarding PFP reported weakness in hip abduction, extension and external rotation which could lead to dynamic malalignment with femoral adduction (Meira and Brumitt 2011) and internal rotation (Salsich and Perman 2013), valgus collapse at the knee, tibial internal rotation (Meira and Brumitt 2011) and foot pronation (Powers 2010). Furthermore, patellofemoral joint mechanics is affected by abnormal movement of the tibia and the femur in the transverse and coronal plane where increased internal rotation of the femur or external rotation of the tibia will increase the contact pressure at the patellofemoral joint (Powers 2003). Magnetic Resonance Imaging (MRI) images linked PFP with poor hip strength and coordination by demonstrating an increased internal rotation of the femur and lateral patellar tracking during movement (Meira and Brumitt 2011). Therefore, muscle weakness around the hip and poor neuromuscular control of proximal structures, especially inhibited eccentric strength (Meira and Brumitt 2011), contributes to poor control of coronal and transverse plane movements (Earl and Hoch 2011), and these variables seem to be worsened by fatigue (Meira and Brumitt 2011). Whether above mentioned variables are present during cycling and asymmetric in their presentation between the right and the left leg calls for further research.

Research regarding asymmetry in joint kinematics during cycling is limited (Smak et al. 1999, Edeline 2004); even more so articles related to lower limb kinematics in the coronal plane (Edeline 2004). Authors agree that asymmetry is present, but the degree of asymmetry regarded as significant has not been established. There have been attempts to establish a correlation between kinematic asymmetry in the coronal plane and the risk of injury in cyclists; however, the degree of asymmetry between the right and the left leg of a cyclist with knee pain has not been compared to the degree of asymmetry between the right and the left leg of an asymptomatic cyclist. In order to link increased asymmetry to an increased risk for PFP, the presence of significant asymmetry between symptomatic and asymptomatic cyclists, in the coronal plane, needs to be established.

In the sagittal plane asymmetry was present in the hip and knee joints (Smak et al.1999), however, it does not relate to PFP (Hunt et al. 2003). On the contrary, cyclists with PFP displaying greater internal rotation and adduction of the hip (the knee more medial relative to the ankle) on the symptomatic side (Bailey et al. 2003).

2.4.4 Muscle Activation Asymmetry

Despite the fact that numerous studies indicated the presence of asymmetry in numerous variables, muscle activation patterns are symmetric and there seems to be no difference between the dominant and non-dominant leg concerning the magnitude of muscle activation. As exercise intensity increases a significant increase in muscle activation is present and it has been suggested that the effect of fatigue can contribute to symmetrical muscle activation patterns (Carpes et al.

2010, Carpes et al. 2011). These findings do not support the findings of asymmetry in force and torque. Furthermore, it seems that cycling experience does not have an influence on muscle activation patterns and the presence of symmetry in muscle activation levels was present in cyclists and non-cyclists. There were also no differences between different muscle groups, and interlimb muscle excitation was symmetrical between the two legs; indicating that lateral preference cannot be associated with improved muscle efficiency and therefore cannot be a probable explanation for asymmetries recorded in work and torque values (Carpes et al. 2010).

Chapter 3

3. METHODOLOGY

3.1 INTRODUCTION

The purpose of this study was to investigate the presence of asymmetry in joint kinematics in the hip, knee and ankle joints in all three planes (sagittal, transvers and coronal), as well as the possible influence thereof on patellofemoral knee pain in road cyclists. A descriptive study design was used to direct the study.

Chapter 3 provides a detailed description of the methodology, data collection and data analysis used to conduct the study. The study ran over a period of 2 days and road cyclists who cycled a minimum of 5 hours a week and who were competitive were recruited from Namibia and South Africa. Data of the joint kinematics of the hip, knee and ankle joints were collected from cyclists with anterio-medial pain, also known as patellofemoral pain (PFP) as well as cyclists without PFP.

3.2 RESEARCH QUESTION

Is there a difference in asymmetry of the hip, knee and ankle kinematics when comparing cyclists with chronic unilateral patellofemoral pain to cyclists without patellofemoral pain?

3.3 AIM OF THE STUDY

The aim of the study was to investigate whether asymmetry of hip, knee and ankle kinematics in cyclists could contribute to patellofemoral pain when compared to cyclists without knee pain.

3.4 OBJECTIVES

The objectives of the study were to determine the following during a crank cycle:

- The degree of asymmetry in maximum and minimum hip flexion and extension within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum hip abduction and adduction within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum hip internal and external rotation within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum knee flexion and extension within the PFP group, pain free group and between groups

- The degree of asymmetry in maximum and minimum knee abduction and adduction within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum knee internal and external rotation within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum dorsiflexion and plantar flexion in the ankle within the PFP group, pain free group and between groups
- The degree of asymmetry in maximum and minimum internal and external rotation of the ankle within the PFP group, pain free group and between groups

3.5 STUDY DESIGN

A cross-sectional descriptive study design was used to investigate the degree of asymmetry of the kinematics of the hip, knee and ankle joints during cycling.

3.6 STUDY DURATION

The study started in January 2013. The proposal was submitted beginning of February 2014. Ethics approval followed two months later and was reapplied for after a year. Data collection took place on the 9th and 10th of March 2015.

3.7 RESEARCH SETTING

The research study was conducted through the Faculty of Medicine and Health Sciences at the University of Stellenbosch. Data collection materialised at the FNB-3D Motion Analysis Laboratory at the Tygerberg Medical Campus at the Faculty of Health Sciences.

3.8 CYCLISTS

3.8.1 Sampling Description

Two groups of road cyclists, aged between 23 and 45, were recruited. Cyclists had to be active in cycling for at least one year without interruption and had to cycle a minimum of five hours per week on their road bicycles. Furthermore, active participation in competitive events was required. Cyclists in the asymptomatic group must have been pain free for at least one year and there should have been no complaints of pain in the hip, knee or ankle structures in the last 12 months.

3.8.2 Sample Size

The original aim was to recruit 16 cyclists, eight with PFP and eight without pain. Due to a very strict and limiting inclusion and exclusion criteria, recruitment yielded only seven cyclists. The test group with PFP consisted of four cyclists while the control group consisted of three cyclists without PFP. While recruitment was directed to male and female cyclists, only male cyclists showed interest; thus the study pertained to male cyclists only.

3.9 RECRUITMENT

Recruitment was done in South Africa and in Namibia. Both countries were included in an attempt to increase recruitment numbers. The population of the two countries were deemed similar due to the nature of cycling. Recruitment was directed to cycling clubs, physiotherapy practices and individuals.

3.9.1 Cycling Clubs

Chairpersons of 10 cycling clubs in the Cape Metropole and 2 cycling clubs in Namibia were contacted telephonically and via e-mail (*APPENDIX 1*) to discuss the research in short and to ask for their permission and support by e-mailing a research invitation to all their club members. A letter describing the research, the purpose of the research and the possible risk factors accompanied the e-mail (*APPENDIX 2*) to ensure that possible research cyclists would be well informed. The letter clearly stated the inclusion and exclusion criteria for participation in the research and interested cyclists were asked to contact the researcher by e-mail or by telephone. Cyclists responding to the invitation had to complete a PFP questionnaire (*APPENDIX 3*) and return it to the researcher via e-mail. The name and contact details of the primary researcher were clearly stated on all correspondence documents.

3.9.2 Physiotherapy Practices

The Western Cape branch of the South African Society of Physiotherapy (SASP) was contacted via e-mail to inform them about the research and to seek permission to notify all members about the study in the Cape Metropole. They were supplied with an e-mail (*APPENDIX 4*) to forward to the physiotherapists requesting assistance with recruitment of cyclists either symptomatic or asymptomatic. Furthermore, individual physiotherapists working at Sport Clinics, or those directly involved with competitive events were contacted directly for assistance in recruitment of cyclists.

3.9.3 Individuals

Individuals were recruited through social networks using advertising avenues at the Stellenbosch Tygerberg University Campus and the number one cycling network in South Africa, “thehub”.

3.10 CYCLISTS’ EXCLUSION CRITERIA

To exclude internal variables that could affect asymmetry, a minimum age of 23 was indicated to ensure that cyclists had completed normal growth. Individuals above the age of 45 were excluded to limit possible influence of degenerative joint disease. Furthermore, cyclists were excluded from the study if they suffered from any systemic diseases namely osteoarthritis, diabetes or any neurological diseases. No amputees with artificial limbs were included and cyclists who indicated traumatic knee injuries, meniscal or intra-articular injuries, reconstruction of the lower limbs or any surgery to the PF joint, cruciate or collateral ligaments were also excluded. Other conditions for exclusion were:

- Known articular cartilage damage confirmed by imaging
- Cruciate or collateral ligament laxity
- Tenderness of iliotibial band or pes anserines
- Presence of effusion
- Referred pain from hip or lumbar area
- Use of non-steroidal anti-inflammatory drugs or corticosteroids for long periods

3.11 CYCLISTS’ INCLUSION CRITERIA

Patellofemoral pain (PFP) has multifactorial pathology and a lack of sensitive tests to rule out PFP when negative suggests PFP is best diagnosed by ruling out contending diagnoses (Cook et al. 2012). There is agreement that PFP is present during activities involving knee flexion such as climbing stairs, sitting with knees in a flexed position and squatting (Nunes et al. 2013, Earl et al. 2011) therefore, these factors need to be accounted for in the inclusion criteria for the symptomatic group. The extra criteria are as follows:

- Insidious onset of unilateral PFP (either left or right) that has been present for at least four weeks (Earl and Hoch 2011)
- Pain must be to such an extent that it limits performance, hampers the training regime or caused the cyclist to seek medical advice (Earl and Hoch 2011)
- PFP during at least three of the following activities: stair climbing, squatting, cycling, prolonged sitting, during or after activity (Earl and Hoch 2011, Nijs et al. 2006)
- Positive vastus medialis coordination test (Nijs et al. 2006)
- Positive patellar apprehension test (Nijs et al. 2006)

- Positive eccentric step test (Nijs et al. 2006)

3.12 SCREENING MEASURES AND EVALUATION PRIOR TO ENTERING THE STUDY

Two screening questionnaires were used. The PFP questionnaire (*APPENDIX 3*) was to identify eligible cyclists and to indicate the group; either symptomatic or asymptomatic. Final Screening form for cyclists with PFP (*APPENDIX 7*) was designed to confirm or negate PFP in eligible cyclists through a physical examination. The physical examination was performed by the same physiotherapist, and all the tests were done according to a written protocol (*APPENDIX 8*).

3.12.1 PFP Questionnaire *(APPENDIX 3)*

This PFP questionnaire was completed by the cyclists without any intervention or help from the researcher. **Section A** of this questionnaire dealt with the minimum inclusion criteria to establish eligibility of each cyclist, while **Section B** was designed to indicate the group, either symptomatic or asymptomatic. Apart from **Section A** questioning gender, age, cycling hours and cycling years; this PFP questionnaire (*APPENDIX 3*) was used as an initial screening tool and consisted out of a number of open ended questions allowing only a “yes” or a “no” answer. To be included in the study both the symptomatic and the asymptomatic group had to indicate a “no” answer in the **history** section to ensure exclusion of traumatic injuries. In the **symptoms** section the symptomatic group had to indicate a “yes” while the asymptomatic group had to indicate a “no” to the questions. This section also included everyday life activities involving knee flexion. Activities in question were pain during prolonged sitting, stair climbing or when squatting or kneeling. At least one of these activities should cause pain or noticeable discomfort in the PFP group while the control group should be cleared on all.

3.12.2 Final Screening form for cyclists with PFP (APPENDIX 7)

Final screening of all cyclists was conducted prior to actual data collection by means of the “Final screening form for cyclists with PFP” (*APPENDIX 7*). The presence of PFP had to be confirmed or negated to confirm eligibility for the study. The evaluation tests used were the patellar apprehension test, patellar tilt test, patellar compression test, vastus medialis coordination test and the eccentric step test. Palpation was performed on the patellar tendon, iliotibial band and the pes anserines. The physical evaluation was performed by the main researcher and was done according to the described protocol (*APPENDIX 8*). Cyclists in the PFP group had to test positive on at least one of these tests while test results of the pain free group should have been negative on all the tests. Palpation of the patellar tendon and pes anserines had to be painful in the test group and pain free in the control group.

3.13 INFORMED CONSENT

Each cyclist had to sign an informed consent form (*APPENDIX* 6) stating that he has been informed about the procedures, possible risks involved in the data collection process and that all questions have been answered satisfactorily. They also agreed and signed consent that information gathered may be used for research purposes and that, although identity will be confidential, score results and the outcome of the study may be published.

Consent forms were e-mailed in advance so that each cyclist had the time to read through the form before the testing day. Forms had to be signed before final screening and testing commenced. Nobody refused to sign consent, however, should a cyclist have indicated reluctance to sign; he would have been withdrawn from the research.

3.14 OUTCOME MEASURES AND MEASUREMENT TOOLS

Cyclists were tested on their own bicycle wearing normal cycling gear and cleats (cycling helmets were not required). Bicycle configurations were left unchanged, but saddle height was measured from the top of the saddle to the pedal surface, with the crank in line with the seat tube (Bini et al. 2011). Each bicycle was fitted with a power tap wheel and fixated on a resistance controlled trainer (CycleOps PowerBeam Pro, PowerSync – ANT+ version). Virtual Training software (version1.11.1) for iPad3 was used to remotely set and control the resistance on the resistance controlled trainer. An ANT+ sensor was connected to the iPad for communication between the iPad and the resistance controlled trainer. A cadence meter was fitted to the handlebar.

Reflective markers were used to indicate specific body landmarks as well as landmarks on the bicycle; they were attached by means of double sided tape. All reflective areas on shoes and clothing were covered with masking tape. To maintain intra-measurer reliability and ensure standardisation, all markers were placed by the same laboratory physiotherapist. A total of 22 markers were placed on the body and the bicycle. Placements on the bicycle included one marker positioned on the top tube and one marker on the centre of rotation of the pedal, bilaterally. Placements on the body were bilaterally on the Anterior Superior Iliac Spine (ASIS), Posterior Superior Iliac Spine (PSIS), greater trochanter, superior fibular head, lateral malleoli, medial malleoli, tibial tuberosity, heel of the shoe and over the big toe. A single extra marker was positioned over the centre of the sacrum. *Figure 3.1*

Figure 3.1: Presentation of setup with reflective markers

An eight camera Vicon T-series motion analysis system (Vicon Motion Systems (Ltd) (Oxford, UK), was used to capture three dimensional joint kinematics of the hip, knee and ankle during cycling. The T-10 system has a unique combination of high speed accuracy and resolution. The system has a resolution of 1 mega pixels, captures 10-bit grey scale images using 1120 x 896 pixels and a capture speed of up to 2,000 frames per second (Windolf et al. 2008). Vicon Integrated Software, Nexus 1.4 116 software and giganet were used to interpret measurements. The Vicon has an overall accuracy of 63 ±5µm (precision 15µm) (Windolf et al. 2008).

3.15 DATA COLLECTION PROCEDURES

Cyclists were booked for testing at the FNB 3D Motion Analysis Laboratory at Stellenbosch Tygerberg Campus. About a week prior to the scheduled appointment each cyclist received and e-mail confirming the appointment date and time; a map providing directions to the campus as well as to the FNB 3D Motion Analysis Laboratory and a short reminder about what they needed to bring along for the data collection, namely their road bicycle and cycling gear.

Upon arrival they were met by the primary researcher who gave an individual and elaborate explanation regarding the data collection procedures. Cyclists were given the opportunity to ask questions and all questions were answered. Before screening commenced each cyclist had to sign an informed consent form (*APPENDIX 6*) stating that he/she has been informed about the procedures, possible risks involved in the data collection process and that all questions have been answered satisfactorily. They also agreed and signed consent that information gathered may be used for research purposes and that, although identity will be kept confidential, score results and the outcome of the study may be published.

Once the informed consent form was signed they were allowed to change into their cycling gear (cycling shorts and shirt) in privacy before they were screened by the primary researcher. All screening was done by the primary researcher. To prevent bias, the screening entailed a physical evaluation that was done according to a set protocol (*APPENDIX 8*). The outcome only allowed for a yes or a no answer, not leaving room for personal interpretations. This was to prevent bias, ensure compliancy with the criteria and to group them either under the PFP group or the pain free group (Chapter 3.12). The physical evaluation was performed in a private room furnished with a treatment plinth.

Once a cyclist's eligibility was confirmed they were introduced to the laboratory engineer and the laboratory physiotherapist who were both involved with the data collection. First the bicycle set-up was performed by the primary researcher. To ensure normal training posture each cyclist used his own training bicycle, which was fitted with a power tap wheel on the rear, before it was mounted on a trainer with a power meter. To standardise the gear ratio as far as possible a front cog of either 50 or 53 teeth were used, depending on what each individual's bicycle was fitted with, in combination with a rear cog of 13 teeth. This higher gear ratio was chosen to ensure a greater force at a lower cadence. Depending on the front cog size of each bicycle, a gear ratio between 3.8" and 4.04" was used. A cadence meter was fitted to the handlebar to allow cyclists to control the cadence. No alterations were done to the existing bicycle configurations, but the saddle height was measured and noted down. Saddle height was measured from the top of the saddle to the pedal surface with the crank in line with the seat tube (Bini et al. 2011) and the measurement from the greater trochanter to the floor was measured to enable calculation of correct saddle height. Both measurements were performed by the primary researcher.

Some standardised general measurements were taken by the laboratory physiotherapist. These measurements included the height, weight, leg length (right and left) and age of each cyclist. Each cyclist's weight was used to calculate two different resistance (wattage) settings. The first setting was two times body weight and the second setting was three times body weight. These settings were noted down below the general measurements.

The laboratory physiotherapist prepared the reflective markers and placed them on the predefined body marks (Chapter 3.14) to enable 3D-movement analysis and data recording. Calibration of the Vicon was performed by the laboratory engineer before testing started and the resistance controlled trainer was calibrated by the primary researcher for each cyclist before testing started.

Cyclists were then asked to mount the bicycle and cycle at a moderate cadence of own choice. A few minutes were used to check that all reflective markers stayed in place while cycling and that all markers were picked up by the motion cameras and clearly displayed on the computer screen. Once confirmed that all markers were visible, cyclists were warned that the first increase in resistance was about to follow. Resistance was calculated on a power-to-mass ratio and measured in Watts per kilogram of body weight. The power-to-weight ratios used were two and three times body weight which is considered as low and medium outputs respectively (Gracia-Lopez et al. 2009). The resistance was increased to the first calculated wattage (two times body weight) and once the resistance was at the desired setting, cyclists had to reach and maintain a cadence of 90RPM by controlling the count on the cadence meter attached to the handlebar. They were asked to indicate when they had reached 90RPM upon which that data recording was started. Data was collected for one minute after which cyclists were warned that the second increase in resistance would follow. Resistance was increased to the second calculated wattage (three times body weight) and cyclists again had to achieve and maintain a cadence of 90RPM. Once they indicated that they had reached the desired cadence, the second set of data was collected for one minute. After completion, resistance was released completely and cyclists had the opportunity to slow down and to cool down at their own pace. Data was checked by the laboratory engineer to ensure that data collection was successful and then cyclists were allowed to finish their cooling down before the reflective markers were removed from their bodies and their bicycles. The original rear wheel of each bicycle was fitted and cyclists were allowed to change back into their normal clothes if they wished to.

3.16 ETHICAL CONSIDERATION

The outline of the proposed study was reviewed by the Health Research Ethics Committee at Stellenbosch University and it was conducted according to internationally accepted ethical standards and guidelines of the Declaration of Helsinki, the South African Guidelines for Good Clinical Practice and the Medical Research Council Ethical Guidelines for research. Ethical acceptance was first received on the 16th of April 2014 with protocol number S14/02/034. Due to delay in recruiting eligible cyclists the initial ethical acceptance expired. Application for renewal was handed in and confirmation of renewal was received on the 30th of April 2015 with protocol number S14/02/034.

3.16.1 Fair Selection of Cyclists

An open invitation was extended to cycling clubs in the Cape Metropole in South Africa and in Namibia. The same invitation was extended to physiotherapy practices in the Cape Metropole. These procedures have been chosen because it was believed to provide the most possible contact with eligible cyclists. However, any cyclist who fitted the inclusion criteria and who would be available for data collection at the motion analysis laboratory were considered.

3.16.2 Favourable Risk-benefit Ratio

No risk factors were identified due to the absence of medical interventions during testing. However, cyclists were warned that they could experience muscle stiffness and discomfort of the lower limbs due to the cycling intensity and duration. There would be no reason for concern and the symptoms would ease off within 24 - 48 hours.

3.16.3 Informed Consent (*APPENDIX 6*)

Cyclists received an information consent form prior to the start of data collection. Data collection procedures were explained and cyclists had the opportunity to ask questions before they were asked to sign the informed consent form. In case a cyclist refrained from signing the consent form, they were not included in the research.

3.16.4 Respect of Cyclists and Study Communities

Every cyclist was informed that he could withdraw from the study at any given moment and that they could do so without providing reason.

3.16.5 Confidentiality and Anonymity

Confidentiality was respected at all times. A numerical value was assigned to each cyclist. All documentation as well as data collected were linked to the code and no personal names or surnames that could identify the cyclist were used. Personal information was not shared.

All data collected was stored on the researcher's external hard drive and backups were kept up to date. In both instances files were protected by means of a password, known only by the researcher.

Data collection was conducted in privacy with only the research team present.

3.17 DATA ANALYSIS

3.17.1 Data Processing

Gap filling was performed using the standard Woltering filter supplied by Vicon. The events of interest were calculated automatically using Matlab. Joint kinematics were calculated using the Plug-In Gait (PIG) model; it was filtered with a 4^{th}-order Butterworth filter at a 10Hz cut-off frequency. Data was exported to Matlab to extract all the parameters listed in the objectives.

3.17.2 Data Management

All hard copies were handled as strictly confidential and were kept in a safe location. Each participant received a research number. Hard copies were scanned and electronically protected by means of a password which only the primary researcher had knowledge of.

Kinematic data were captured and processed using the Vicon Nexus software. The Butterworth filter algorithm provided in the Vicon Nexus software (4^{th} order filter with cut-off frequency of 6Hz) was used to filter model outputs and biomechanical data processing was by means of Nexus Version 1.7. Gaps in collected data were filled using the pattern fill option of the Vicon Nexus 1.7 software.

3.17.3 Outcomes and Statistical Analysis

Data of only ten cycles of each cyclist for each resistance respectively was exported into an Excel spread sheet. Separate sheets for every joint (hip, knee and ankle) in a specific axis (X, Y or Z axis) for a specific side (right or left) were created. The cycles constituted the separate columns and the radial positions constituted the separate rows. Radial positions were calculated as follows: hundred and one radial positions or points were evenly plotted throughout the 360° so that 0 and 101 were the same point, 25 was equal to 90°, 51 was equal to 180°, 76 was equal to 270° and 101 was equal to 360°. The 0 radial position was referred to as the top dead centre (TDC) and the bottom dead centre (BDC) referred to radial position 50.

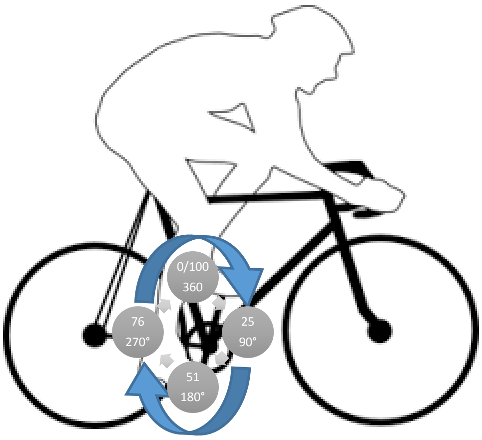


Figure 3.2: Radial positions in 360°

The average was calculated and used to draw the graphs for each cyclist comparing right and left sides for the hip, knee and ankle joints in different planes and at two different resistance levels respectively. Movement planes evaluated were the sagittal plane (flexion/extension movement), the coronal plane (abduction/adduction movement) and the transverse plane (internal/external rotation). Knee movement in the coronal plane and ankle movement in the coronal and transverse plane were excluded because they are not seen as functional movements.

All angles were defined according to the Plug-In-Gait model. Positive and negative values had the same anatomical meaning for right and left legs. For the X axis positive values implied flexion and negative values extension. In the Y axis positive values indicated adduction while negative values indicated abduction and for values on the Z axis, positive values implied internal rotation while negative values indicated external rotation. Kinematic measurements were taken for the hip, knee and ankle joints in the X axis (flexion/extension) in the Y axis (abduction/adduction) and in the Z axis (internal/external rotation).

Averages were calculated for each of the seven cyclists, for each cycle, each joint and each side for two different resistance levels. The averages were used to draw line graphs of all the kinematic movement measured. Graphs of the same joints were grouped together in the same table to allow for comparison between the cases and the controls.

Chapter 4

4. RESULTS

4.1 SAMPLE DEMOGRAPHICS

Before testing general information was gathered from each cyclist by means of the two questionnaires (*APPENDIX 3 and 7*) described in the method. The information has been summarized in *Table 4.1* below.

Table 4.1: Subject Information

Ref. No.	Gender	Age	Weight kg	Height cm	Dominant leg	R Leg length cm	L Leg length cm	Trochanteric length R in cm	Trochanteric length L in cm	Knee Pain	Average cycling h/w	Saddle height cm
(1)	Male	38	71.4	1674	R	93	92	85	84	R	8	88.5
(2)	Male	43	94.4	1812	R	101	100	93	95	L	14	96
(3)	Male	36	76.2	1736	R	92	92.5	82.5	82.5	R	6	88.5
(4)	Male	41	104.3	1849	R	101	100	92.5	92	L	5.75	96
1	Male	35	87.3	1823	R	94.5	95	82.5	83	None	7	94.5
2	Male	39	67.7	1781	R	98	96	90	91	None	7	91.2
3	Male	37	60.6	1639	R	87	89	84	84	None	5	78

4.2 SAGITTAL PLANE

Movement of the hip, knee and ankle joints were measured, bilaterally, in the sagittal plane (X- axis). This was done to establish the range of flexion and extension movement in each joint and to compare each cyclist's right and left side with one another. Furthermore, comparison regarding the amount of asymmetry present between controls and cases was evaluated.

4.2.1 Hip

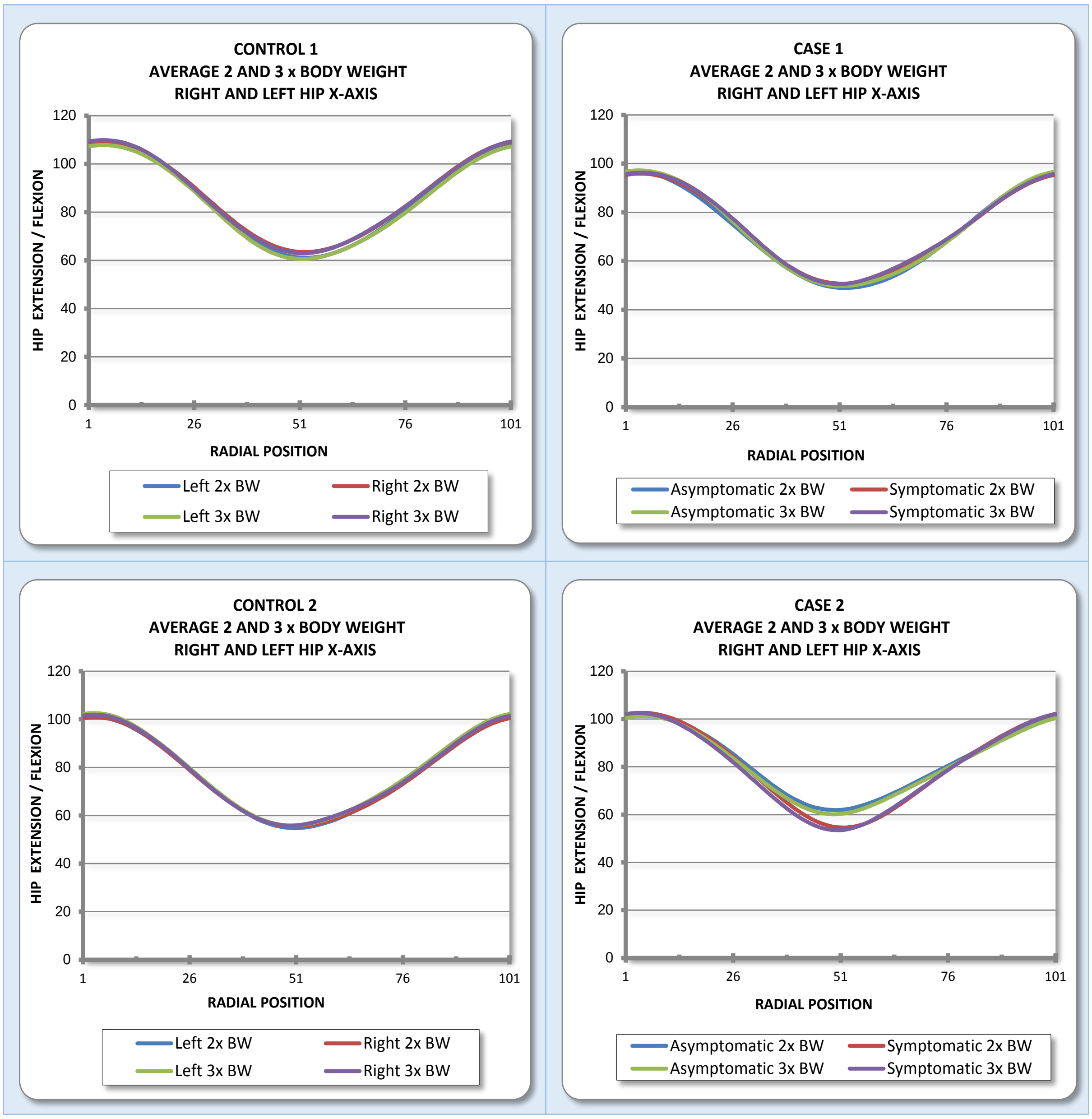
Graphs depicting the flexion (+ values) and extension (- values) movement of the hip joint are shown in *Table 4.2*. Controls are depicted in the left column of the table and cases in the right column. Each graph contains the measurements for a cyclist's right and left hip for both resistance levels (two times BW and three times BW) respectively.

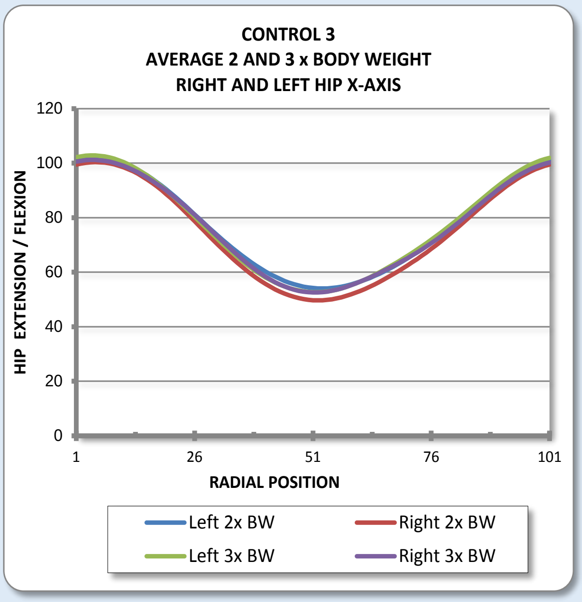
The flexion and extension range of the hip follows the same curve for both controls and cases (*Table 4.2*). Maximum flexion occurs at top dead centre (radial position 1) and decreases until the foot reaches bottom dead centre (radial position 51). For all cyclists hip extension occurred in the first half of the cycle while hip flexion occurred in the second half. The hip never reached full flexion or full extension and movement is in the same range for controls and cases. It is important to notice that although the hip performed an extension movement, the joint was never really in an extended position anatomically. Graphically no asymmetry is depicted. Even between the two different resistance levels very little difference was indicated.

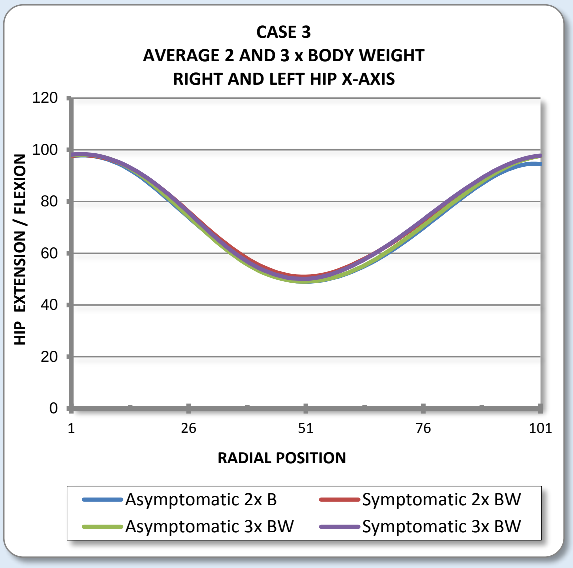
For further evaluation data pertaining to maximum and minimum values and total ROM was summarised in *Table 4.3* and *Table 4.4*. Each table contains readings for the two resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicated the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

Supporting the graphs, readings for the right and left side as well the ROM for each side do not show great differences for maximum, minimum or ROM values.

Table 4.2: Sagittal Plane, Hip, Controls vs Cases




CONTROL 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP X-AXIS
HIP EXTENSION / FLEXION
0
20
40
60
80
100
120
1
26
51
76
101
RADIAL POSITION
Left 2x BW
Right 2x BW
Left 3x BW
Right 3x BW


CASE 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP X-AXIS
HIP EXTENSION / FLEXION
0
20
40
60
80
100
120
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x B
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

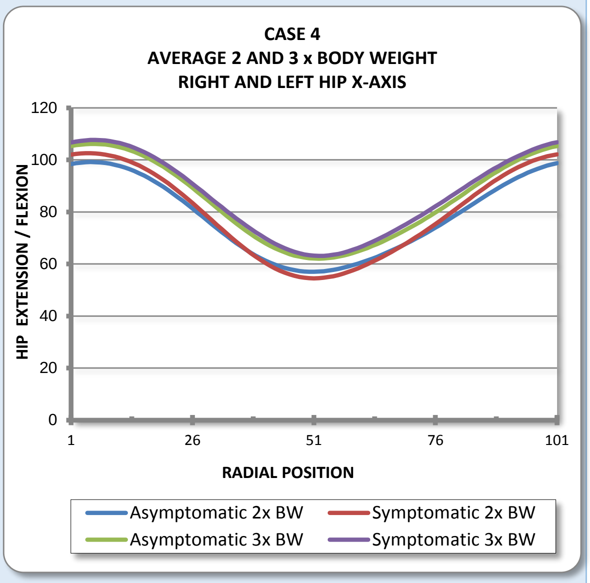

CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP X-AXIS
HIP EXTENSION / FLEXION
0
20
40
60
80
100
120
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.3: Summary of Hip Range in the Sagittal Plane; 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 2X BW	MAX RIGHT (SYMOTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 2X BW	MIN RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 2X BW	RANGE RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	96.9	(95.9)	1	48.9	(50.7)	1.8	48.0	(45.2)	2.8
(2)	(102.6)	101.7	0.9	(54.6)	61.9	7.3	(48.0)	39.8	8.2
(3)	97.9	(97.9)	4.1	49.0	(51.0)	2	48.8	(47.0)	1.8
(4)	(102.6)	99.2	3.4	(54.5)	57.0	2.5	(48.1)	42.2	5.9
1	107.8	109.2	1.4	61.0	63.4	2.4	46.8	45.8	1
2	100.9	101.1	0.2	54.7	55.4	0.7	46.2	45.6	0.6
3	102	100.4	1.6	54	49.7	4.3	48	50.7	2.7

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.4: Summary of Hip Range in the Sagittal Plane; 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	97.2	(96.3)	0.9	49.7	(50.5)	0.8	47.5	(45.8)	1.7
(2)	(102.5)	101.3	1.2	(53.5)	60.2	6.7	(49.0)	41.2	7.8
(3)	98.1	(98.3)	0.2	49.1	(50.1)	1	49.0	(48.2)	0.8
(4)	(107.7)	106.2	1.5	(63.1)	62.1	1	(44.6)	44.1	0.5
1	107.8	109.9	2.1	60.6	63	2.4	47.3	46.9	0.4
2	102.6	102	0.6	55.8	55.8	0	46.8	46.2	0.6
3	102.8	101.1	1.7	52.7	52.6	0.1	50.1	48.6	1.5

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

4.2.2 Knee

Knee flexion (+ values) and extension (- values) movement are shown in Table 4.5. Controls are depicted in the left column of the table and cases in the right column. Each graph contains measurements for a cyclist's right and left knee for both resistance levels (two times BW and three times BW) respectively.

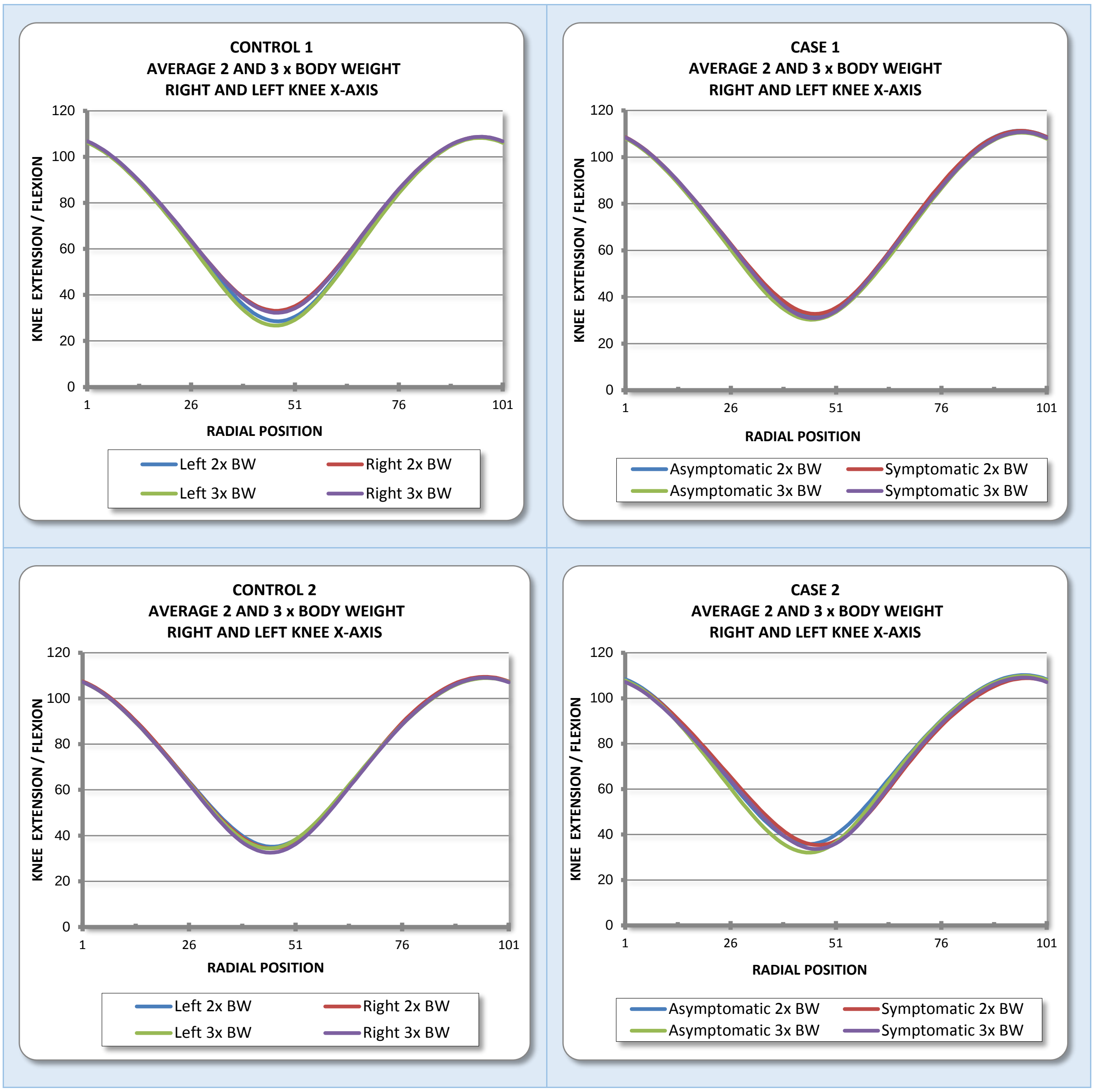
The flexion and extension range of the knee follows the same curve for both controls and cases, (Table 4.5). Maximum flexion occurs just before top dead centre (radial position 95 - 97) and decreases until just before the foot reaches bottom dead centre (radial position 45 - 47).

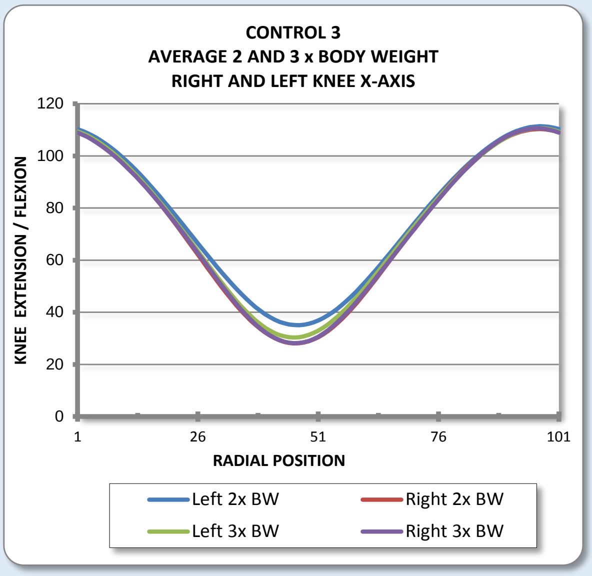
Knee extension occurred in the first half of the cycle while knee flexion occurred in the second half for all cyclists. The knee never reached full flexion or full extension and movement is in the same range for controls and cases. Although the knee performed an extension movement it is important to notice that, as the hip, the knee joint was never really in an extended position anatomically. No asymmetry was depicted within cyclists' (right and left) or between cyclists' (controls and cases). Visually, there was also no asymmetry noted at the different resistance levels.

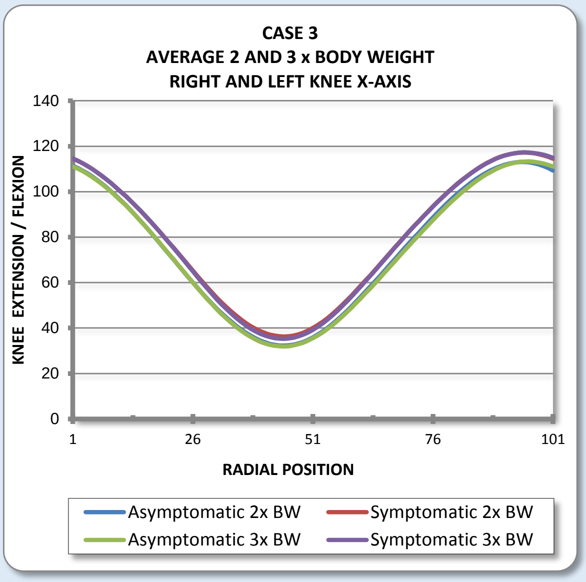
For further evaluation data pertaining to maximum and minimum values and total ROM of the knee was summarised in Table 4.6 and Table 4.7. Each table contains readings for resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicate the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

Supporting the graphs, maximum, minimum and ROM readings for the right and left sides do not show great differences in the controls or the cases.

Table 4.5: Sagittal Plane, Knee, Controls vs Cases




CONTROL 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT KNEE X-AXIS
KNEE EXTENSION / FLEXION
120
100
80
60
40
20
0
1
26
51
76
101
RADIAL POSITION
Left 2x BW
Right 2x BW
Left 3x BW
Right 3x BW


CASE 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT KNEE X-AXIS
KNEE EXTENSION / FLEXION
140
120
100
80
60
40
20
0
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

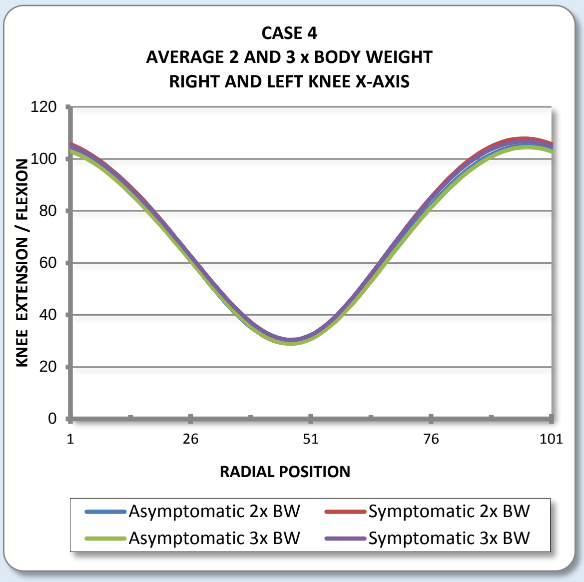

CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT KNEE X-AXIS
KNEE EXTENSION / FLEXION
120
100
80
60
40
20
0
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.6: Summary of Knee Range in the Sagittal Plane; 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE KNEE									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 2X BW	MAX RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 2X BW	MIN RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 2X BW	RANGE RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	111.3	(111.3)	0	31.7	(32.7)	1	79.6	(78.5)	1.1
(2)	(108.9)	110.2	1.3	(35.4)	35.9	0.5	(73.5)	74.4	0.9
(3)	113.1	(117.2)	4.1	32.3	(36.3)	4	80.8	(81)	0.2
(4)	(107.8)	105.2	2.6	(29)	29.5	0.5	(78.8)	75.7	3.1
1	108.5	108.7	0.2	28.6	33.1	0.9	80	75.5	4.5
2	109	109.4	0.4	35.2	34.4	0.8	73.9	75.0	1.1
3	111.4	110.3	1.1	35.1	28.1	7	76.3	82.2	5.9

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.7: Summary of Knee Range in the Sagittal Plane; 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE KNEE									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	110.5	(110.8)	0.3	30.2	(30.9)	0.4	80.2	(79.9)	0.3
(2)	(109.1)	109.8	0.7	(33.7)	32.1	1.6	(75.4)	77.7	2.3
(3)	113.3	(117.3)	4	31.9	(35.3)	3.4	81.4	(82)	0.6
(4)	(106.8)	104.6	2.2	(30.4)	28.9	1.5	(76.3)	75.6	0.7
1	108.2	108.7	0.5	26.7	32.3	5.6	81.5	76.5	5.9
2	108.9	109.1	0.2	34.4	32.5	1.9	74.5	76.6	2.1
3	110.6	110.6	0	30.3	28.1	2.2	80.3	82.4	2.1

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

4.2.3 Ankle

Graphs depicting the dorsiflexion (+ values) and plantarflexion (- values) movement of the ankle joint are shown in Table 4.8 below. Controls are depicted in the left column of the table and cases in the right column. Each graph contains the measurements for a cyclist's right and left ankle for both resistance levels (two times BW and three times BW) respectively.

Contrary to the hip and knee, ankle movement between cyclists does not follow the same movement pattern. There are notable inter-cyclist variations. Although the patterns differ greatly between cyclists, intra-cyclist variation is minimal as depicted visually.

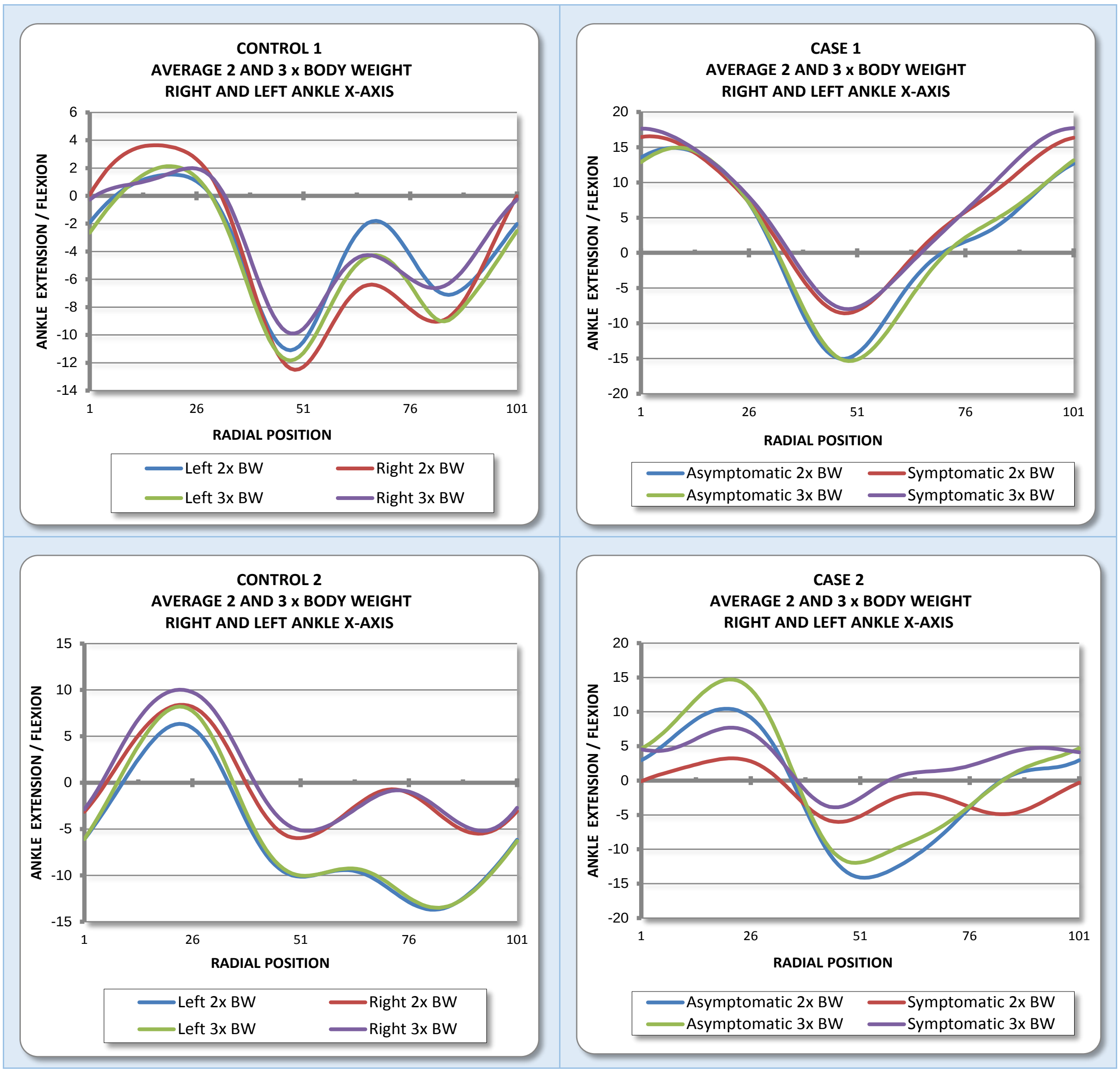
Case 1 (Table 4.8) and Case 4 (Table 4.8) start in a flexion position at top dead centre (radial position 0) and goes into extension, reaching maximum extension at bottom dead centre (radial position 50). All the other cyclists, Control 1, 2 and 3 and Case 2 and 3 (Table 4.8) does not have maximum flexion at top dead centre (radial position 0) but only reach it at the 25th radial position. They do however, reach maximum extension at bottom dead centre (radial position 50). From bottom dead centre to the top dead centre, although following a flexion movement, these cyclists make a small extension movement before reaching top dead centre.

The total range of motion (ROM) between maximum flexion and maximum extension shows very little difference between cyclists. For Case 1, 2 and 3 (Table 4.8) the asymptomatic side showed more ankle extension range at bottom dead centre than the symptomatic side. In Control 2 (Table 4.8) there is also a difference in the ankle extension range with the left ankle displaying more range at bottom dead centre than the right ankle. Very limited asymmetry was depicted visually in the graphs.

For further evaluation data pertaining to maximum and minimum values and total ROM for the ankle was summarised in Table 4.9 and Table 4.10. Each table contains readings for both resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicated the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

More obvious differences are indicated for maximum, minimum and ROM values for the ankle than for the hip and the knee. These differences are across the whole study group and cases do not display more asymmetry than controls.

Table 4.8: Sagittal Plane, Ankle, Controls vs Cases



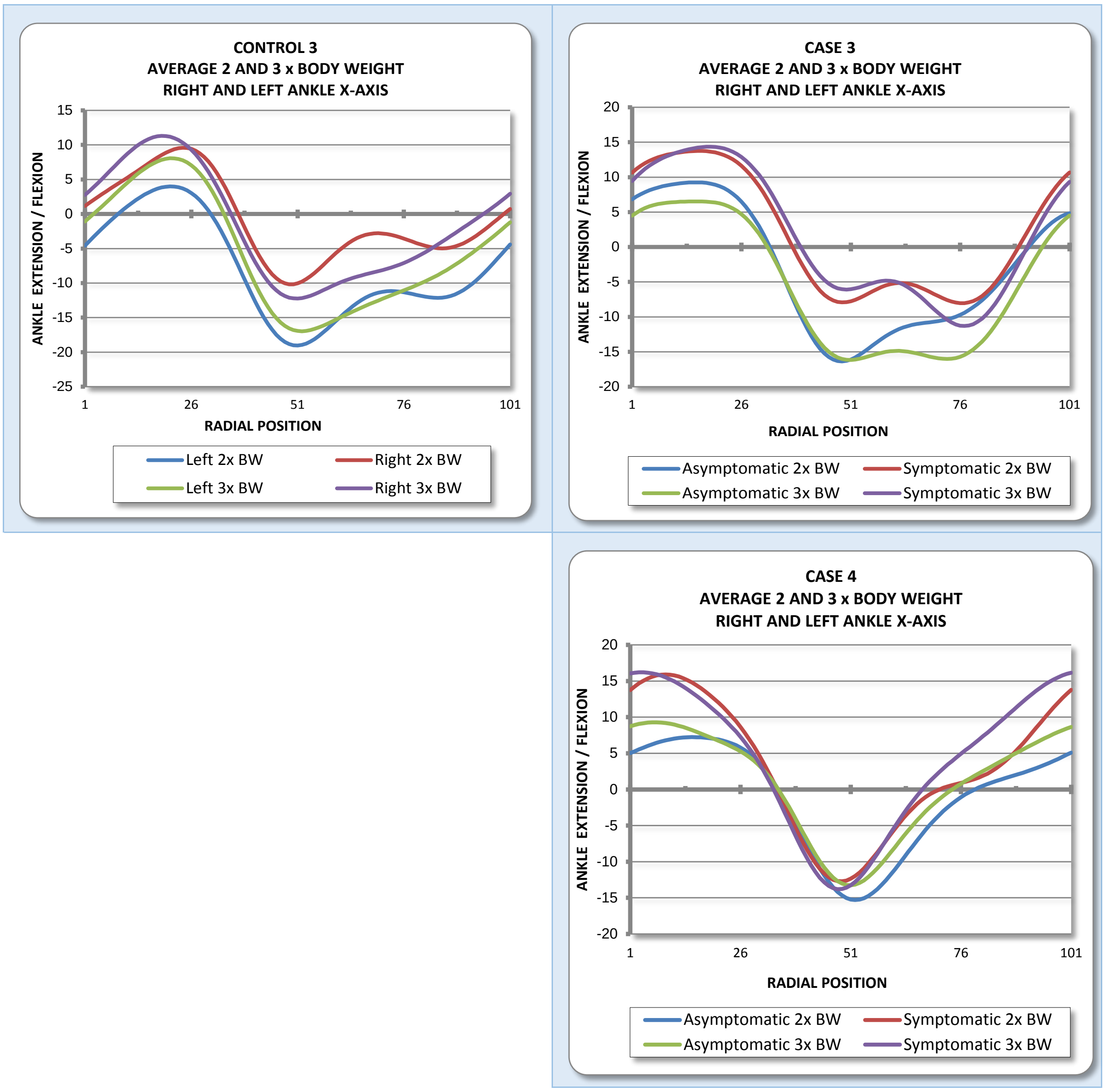

CONTROL 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT ANKLE X-AXIS
ANKLE EXTENSION / FLEXION
15
10
5
0
-5
-10
-15
-20
-25
1
26
51
76
101
RADIAL POSITION
Left 2x BW
Right 2x BW
Left 3x BW
Right 3x BW
CASE 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT ANKLE X-AXIS
ANKLE EXTENSION / FLEXION
20
15
10
5
0
-5
-10
-15
-20
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW
CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT ANKLE X-AXIS
ANKLE EXTENSION / FLEXION
20
15
10
5
0
-5
-10
-15
-20
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.9: Summary of Ankle Range in the Sagittal Plane; 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE ANKLE									
CONTROL (CASES)	**MAX LEFT (SYMPTOM) 2X BW**	**MAX RIGHT (SYMPTOM) 2X BW**	**DIFFERENCE BETWEEN LEFT AND RIGHT**	**MIN LEFT (SYMPTOM) 2X BW**	**MIN RIGHT (SYMPTOM) 2X BW**	**DIFFERENCE BETWEEN LEFT AND RIGHT**	**RANGE LEFT (SYMPTOM) 2X BW**	**RANGE RIGHT (SYMPTOM) 2X BW**	**DIFFERENCE BETWEEN LEFT AND RIGHT**
(1)	14.9	(16.6)	1.7	-15.1	(-8.6)	6.5	30	(25.1)	4.9
(2)	(3.2)	10.5	7.3	(-6)	-14.2	8.2	(9.3)	24.6	15.3
(3)	9.3	(13.7)	7.4	-16.4	(-8)	8.4	25.6	(21.8)	3.8
(4)	(15.9)	7.2	8.7	(-12.7)	-15.3	2.6	(28.6)	22.5	6.1
1	1.5	3.6	2.1	-11.1	-12.5	1.4	12.6	16.1	3.5
2	6.3	8.4	2.1	-13.7	-6	7.7	20.1	14.4	5.7
3	4	9.6	5.6	-19	-10.2	8.8	23	19.8	3.2

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.10: Summary of Ankle Range in the Sagittal Plane; 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
SAGITTAL PLANE ANKLE									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	14.9	(17.7)	2.8	-15.4	(-8)	7.4	30.3	(25.7)	4.6
(2)	(7.7)	14.7	7	(-3.9)	-12	8.1	(11.6)	26.7	15.1
(3)	6.5	(14.3)	7.8	-16.2	(-11.3)	4.9	22.7	(25.7)	3
(4)	(16.2)	9.3	6.9	(-13.8)	-13.3	0.5	(30)	22.6	7.4
1	2.1	2	0.1	-11.8	-9.9	1.9	14	11.9	2.1
2	8.2	10	1.8	-13.5	-5.2	8.3	21.7	15.2	6.5
3	8.1	11.3	3.2	-17	-12.2	4.8	25	23.5	1.5

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

4.3 CORONAL PLANE

Movement of the hip joint was measured, bilaterally, in the coronal plane (Y- axis). This was done to establish the range of abduction and adduction movement in each joint and to compare each cyclists' right and left side with one another. Furthermore, comparison regarding the amount of asymmetry present between controls and cases was evaluated.

4.3.1 Hip

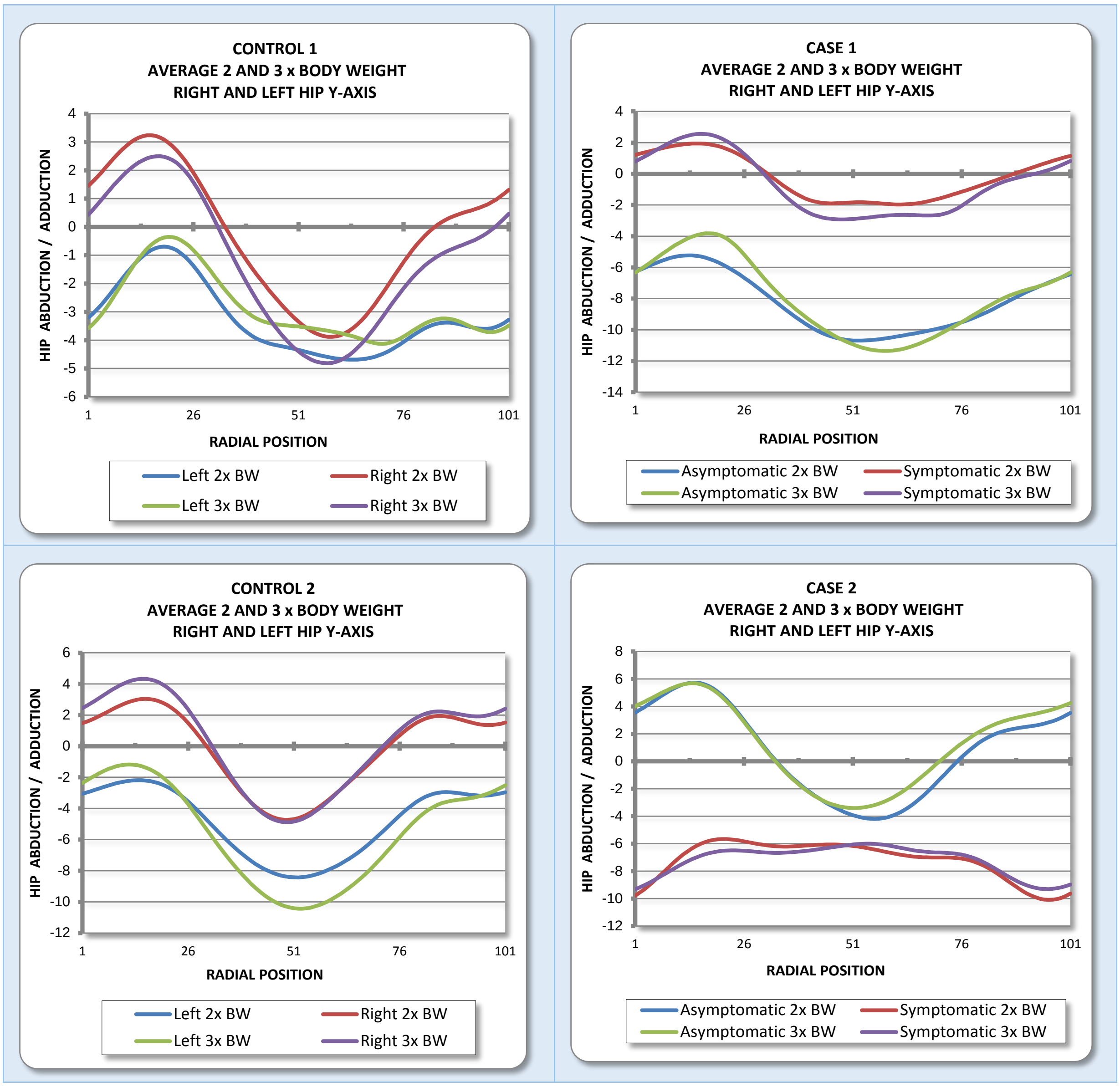
Graphs depicting the adduction (+ values) and abduction (- values) movement of the hip joint are shown in Table 4.10. Controls are depicted on the left side of the table and cases on the right side. Each graph contains the measurements for a cyclists' right and left hip for both resistance levels (two times BW and three times BW) respectively.

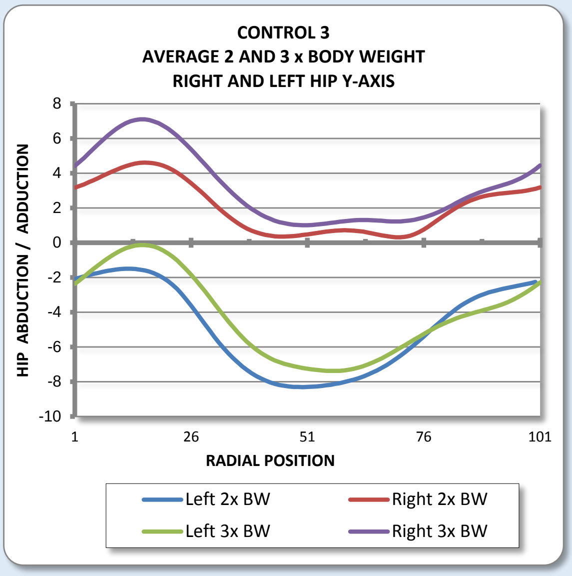
The abduction and adduction movement of the hip is unique for each individual cyclist and for each side of the body. All cyclists start the cycle with an adduction movement which increases in ROM to reach maximum adduction at the 25th radial position. The amount of adduction differs greatly between cyclists and between a cyclists' right and left side. One side stays in an abducted position; even though there is deviation towards adduction, the joint never reaches real anatomical adduction. The other side follows a true anatomical adduction - abduction - adduction pattern. This phenomenon is present for both controls and cases. Although obvious asymmetry is present regarding the ROM of adduction and abduction, this is present in all cyclists.

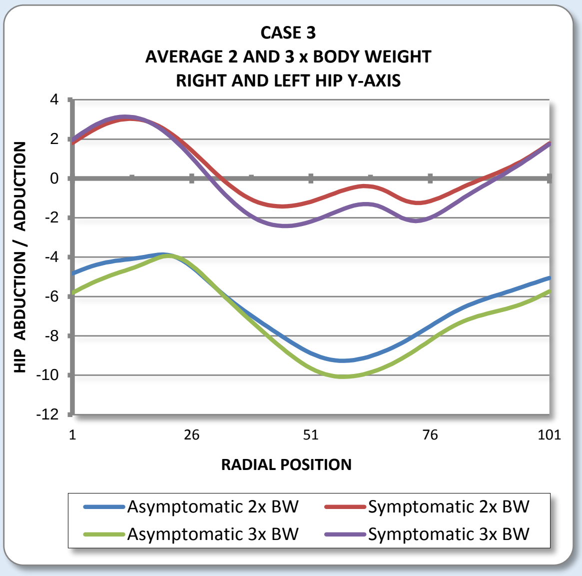
For further evaluation data pertaining to maximum and minimum values and total ROM for the hip was summarised in Table 4.12 and Table 4.13. Each table contains readings for the resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicated the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

According to the Table 4.12 all cyclists except, Case 4, had negative maximum left values indicating abduction and positive maximum right values indicating adduction. Minimum left and right values were negative indicated abduction except for Control 3. Therefore, the hip alternates between abduction and adduction movements even though the left side stays in abduction. Comparing range between right and left sides shows asymmetry, but the asymmetry is present across the whole group.

Table 4.11: Coronal Plane, Hip, Controls vs Cases




CONTROL 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP Y-AXIS
HIP ABDUCTION / ADDUCTION
8
6
4
2
0
-2
-4
-6
-8
-10
1
26
51
76
101
RADIAL POSITION
Left 2x BW
Right 2x BW
Left 3x BW
Right 3x BW


CASE 3
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP Y-AXIS
HIP ABDUCTION / ADDUCTION
4
2
0
-2
-4
-6
-8
-10
-12
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

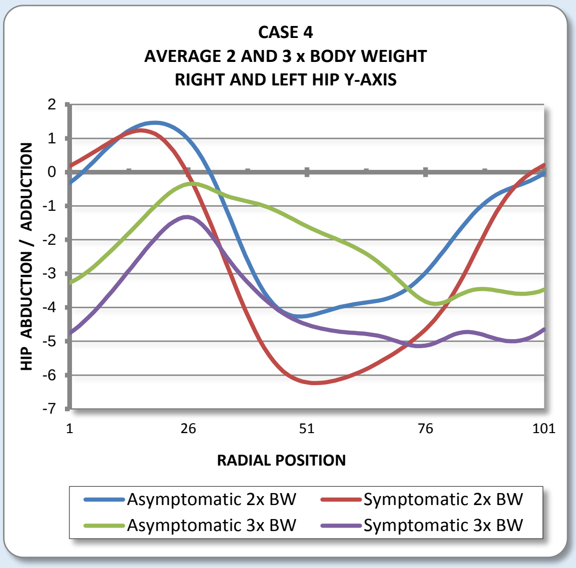

CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP Y-AXIS
HIP ABDUCTION / ADDUCTION
2
1
0
-1
-2
-3
-4
-5
-6
-7
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.12: Summary of Hip Range in the Coronal Plane; 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
CORONAL PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 2X BW	MAX RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 2X BW	MIN RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 2X BW	RANGE RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	-5.2	(1.9)	3.3	-10.7	(-2)	8.7	5.5	(3.9)	1.6
(2)	(-5.7)	5.7	0	(-10.1)	-4.2	5.9	(4.4)	9.9	5.5
(3)	-3.9	(3)	0.9	-9.3	(-1.4)	7.9	5.4	(4.5)	0.9
(4)	(1.2)	1.5	0.3	(-6.2)	-4.3	1.9	(7.5)	5.7	1.8
1	-0.7	3.2	2.5	-4.7	-3.9	0.8	4	7.1	3.1
2	-2.2	3	0.8	-8.4	-4.7	3.7	6.2	7.8	1.6
3	-1.5	4.6	3.1	-8.3	0.3	8	6.8	4.3	2.5

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.13: Summary of Hip Range in the Coronal Plane; 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
CORONAL PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM)3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	-3.8	(2.6)	1.2	-11.4	(-2.9)	8.5	7.5	(5.50)	2
(2)	(-6)	5.7	0.3	(-9.3)	-3.4	5.9	(3.3)	9.1	5.8
(3)	-3.9	(3.1)	0.8	-10.1	(-2.4)	7.7	6.1	(5.6)	0.5
(4)	(-1.3)	-0.3	1	(-5.1)	-3.9	1.2	(3.8)	3.6	0.2
1	-0.4	2.5	2.1	-4.1	-4.8	0.7	3.8	7.3	3.5
2	-1.2	4.3	3.1	-10.4	-4.9	5.5	9.3	9.2	0.1
3	-0.1	7.1	7	-7.4	1	6.4	7.2	6.1	1.1

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

4.4 TRANSVERSE PLANE

Movement of the hip joint was measured, bilaterally, in the transverse plane (Z- axis). This was done to establish the range of internal and external rotation movement in each joint and to compare each cyclist's right and left side with one another. Furthermore, comparison regarding the amount of asymmetry present between controls and cases was evaluated.

4.4.1 Hip

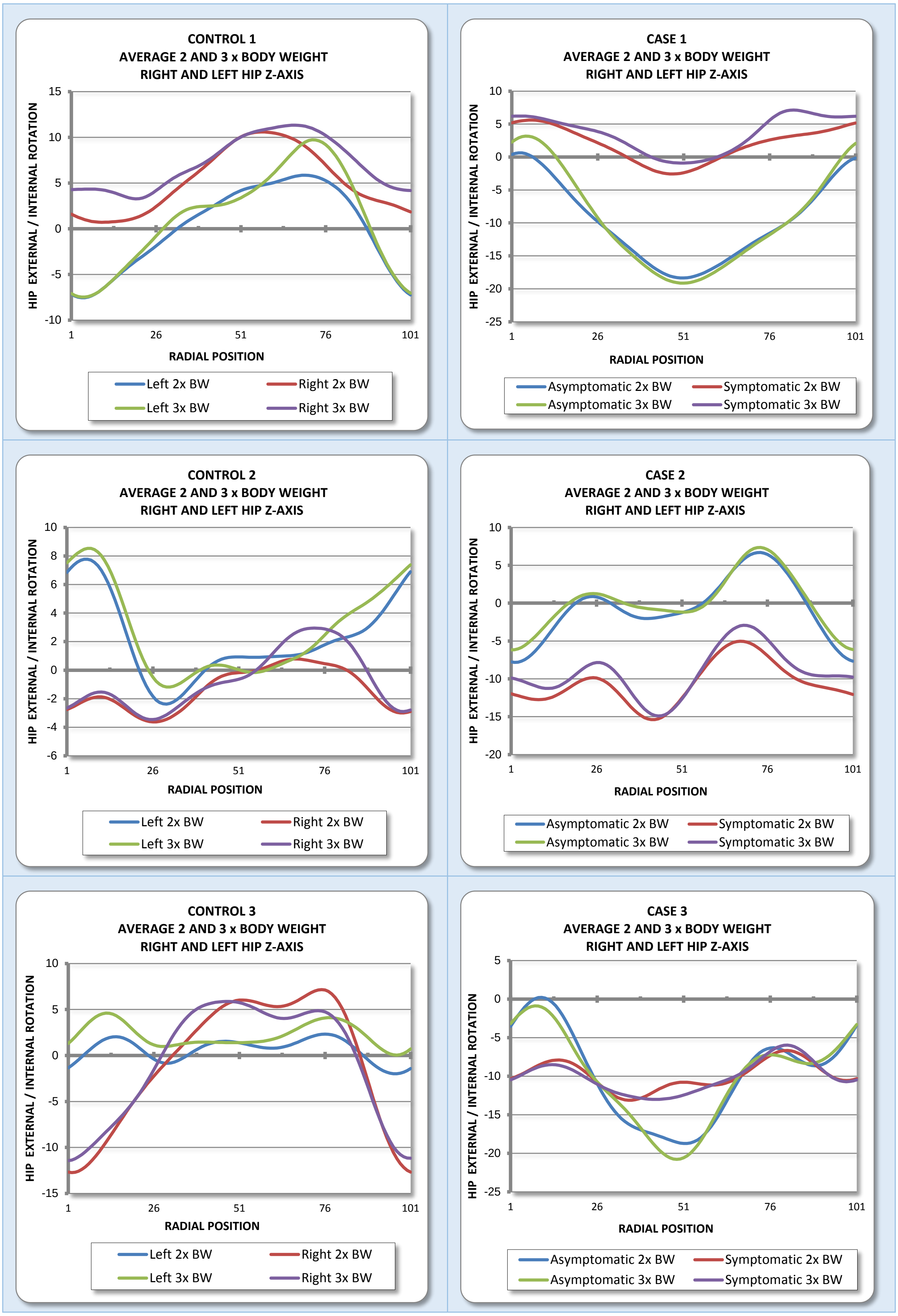
Graphs depicting the internal rotation (+ values) and external rotation (- values) movement of the hip joint are shown in Table 4.14*.* Controls are depicted on the left side of the table and cases on the right side. Each graph contains the measurements for a cyclist's right and left hip for both resistance levels (two times BW and three times BW) respectively.

There is no consistency depicted regarding hip internal and external rotation patterns. In all cyclists the hip rotates internally and externally during a cycle, however, the ROM of the movement varies greatly between cyclists. At top dead centre (radial position 0) great differences are clearly visible between cyclists, with some (Case 1) starting the cycle in an internal rotation (Table 4.14) and others (Case 2, 3 and 4) starting in an external rotation (Table 4.14). This difference is also seen between the right and the left hip in some cyclists (Control 1, 2 and 3) (Table 4.14).

For further evaluation data pertaining to maximum and minimum values and total ROM for the hip was summarised in Table 4.15 and Table 4.16. Each table contains readings for both resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicated the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

Table 4.15 and Table 4.16 indicates great variances in maximum and minimum values for both sides. ROM also varies greatly within cyclist and between cyclists. The ROM values indicates definite asymmetry in the rotational component but this is present in cases and controls.

Table 4.14: Transverse Plane, Hip, Controls vs Cases



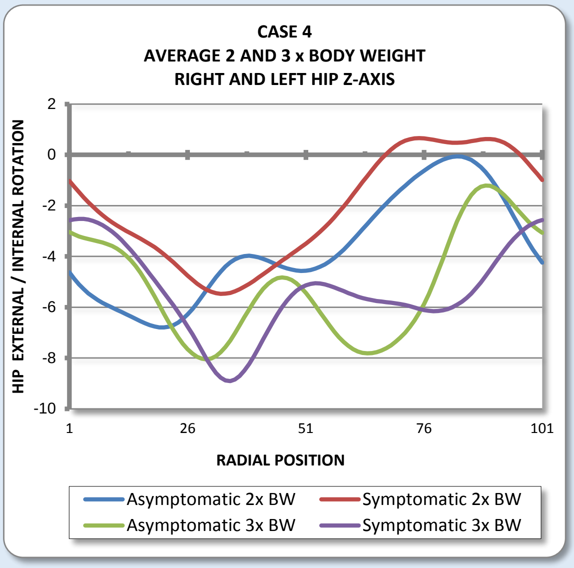

CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT HIP Z-AXIS
HIP EXTERNAL / INTERNAL ROTATION
2
0
-2
-4
-6
-8
-10
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.15: Summary of Hip Range in the Transverse Plane 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
TRANSVERSE PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 2X BW	MAX RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 2X BW	MIN RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 2X BW	RANGE RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	0.6	(5.6)	5	-18.4	(-2.6)	15.8	19	(8.2)	10.8
(2)	(-5)	6.7	1.7	(-15.4)	-7.8	7.6	(10.4)	14.5	4.1
(3)	0.2	(-6.7)	6.5	-18.7	(-13.1)	5.6	19	(6.5)	12.5
(4)	(0.7)	-0.1	0.6	(-5.5)	-6.8	1.3	(6.1)	6.7	0.6
1	5.9	10.6	4.7	-7.5	0.7		13.4	9.9	3.5
2	7.8	0.8	7	-2.4	-3.6	1.2	10.2	4.4	5.8
3	2.3	7.2	4.9	-2	-12.7	10.7	4.3	19.9	15.6

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.16: Summary of Hip Range in the Transverse Plane 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
TRANSVERSE PLANE HIP									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	3.2	(7.1)	3.9	-19.1	(-0.9)	19.01	22.3	(8)	14.3
(2)	(-2.9)	7.4	4.8	(-14.9)	-6.2	8.7	(12)	13.5	1.5
(3)	-0.9	(-6)	5.1	-20.8	(-13)	7.8	19.9	(7)	12.9
(4)	(-2.5)	-1.2	1.3	(-8.9)	-8.1	0.8	(6.4)	6.8	0.4
1	9.7	11.3	1.9	-7.5	3.3	4.2	17.2	8.1	9.1
2	8.5	2.9	5.6	-1.2	-3.5	2.3	9.7	6.4	3.3
3	4.6	5.9	1.3	0	-11.4	11.4	4.6	17.3	12.7

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

4.4.2 Knee

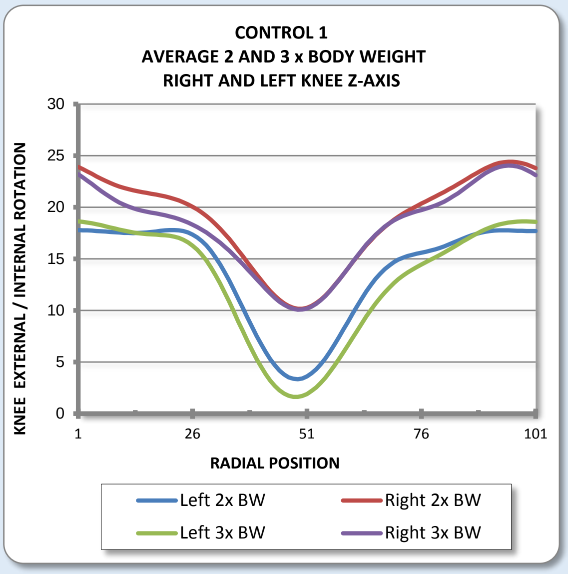
Graphs depicting the internal rotation (+ values) and external rotation (- values) movement of the knee joint are shown in *Table 4.7*. Controls are depicted on the left side of the table and cases on the right side. Each graph contains the measurements for a cyclist's right and left knee for both resistance levels (two times BW and three times BW) respectively.

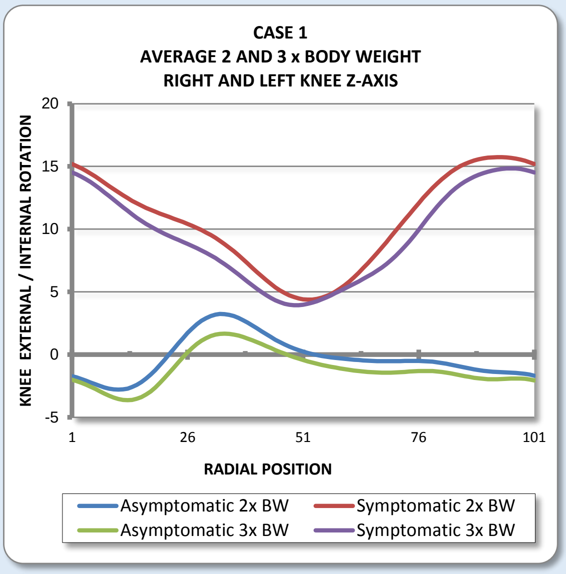
All cyclists display a general interchange between external and internal rotation during a cycle. In all cyclists, except one (Table 4.9), the right and left knee followed the same rotation pattern. Case 1 (Table 4.9) is different in that the right and the left knee follow opposite patterns, meaning that one knee is deviating towards internal rotation while the other knee deviates towards external rotation. Most cyclists (Table 4.9) started with an internal rotation of the knee at the 0 radial position, which deviates to external rotation, reaching maximum deviation at the 50th radial position, returning to the starting position. In Case 3 (Table 4.9) the subject started in external rotation at the 0 radial position, deviating towards internal rotation towards bottom dead centre. Case 1 (Table 4.9) is the only cyclist who started with one knee in internal rotation while the other knee started in external rotation at the top dead centre. No obvious increase in asymmetry is noticeable in the test group.

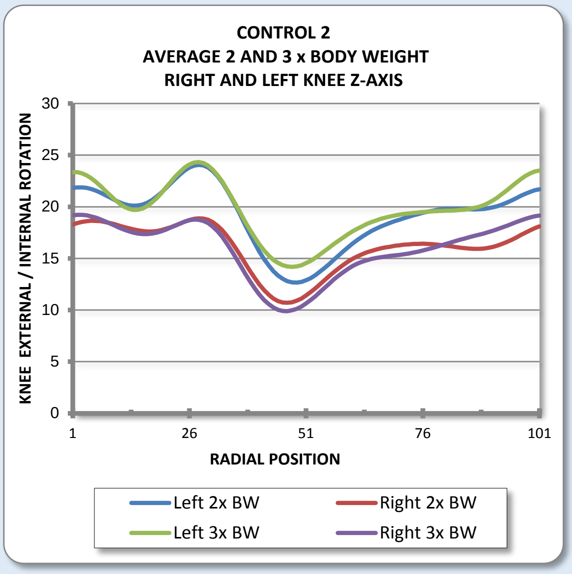
For further evaluation data pertaining to maximum and minimum values and total ROM for the knee was summarised in Table 4.13. Each table contains readings for both resistance levels (two times BW and three times BW) respectively. Controls and cases are depicted in the same table and brackets () were used to indicated the cases and therefore the values of the symptomatic side. For easy comparison maximum and minimum values, as well as ROM of the right and left leg, were recorded in adjacent columns.

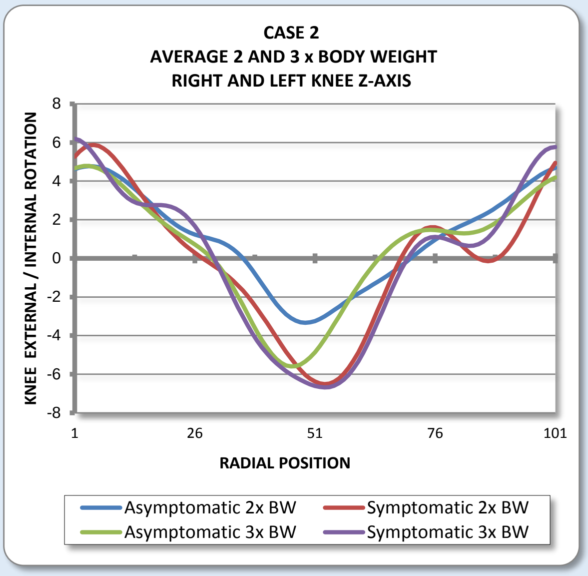
According to the Table 4.13 great variances were present for the maximum and minimum values as well as for the values depicting total range. These great variances were present for the right and the left sides indicating asymmetry in rotation at the knee joint.

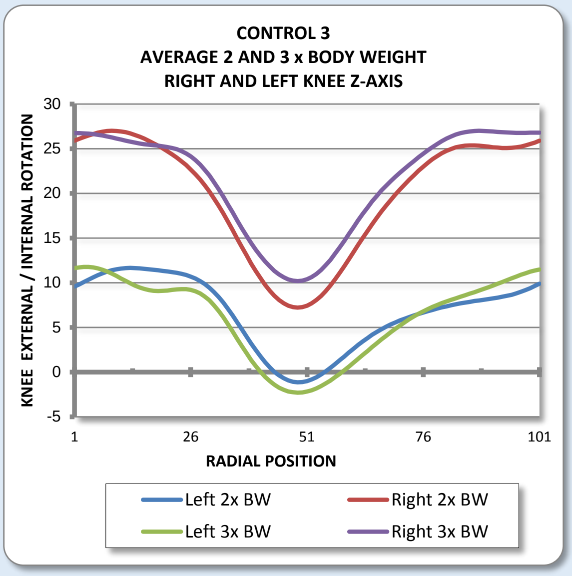
Table 4.17: Transverse Plane, Knee, Controls vs Cases

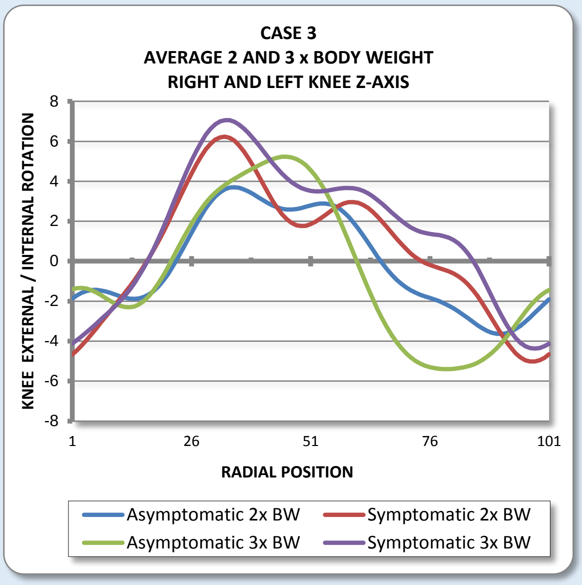












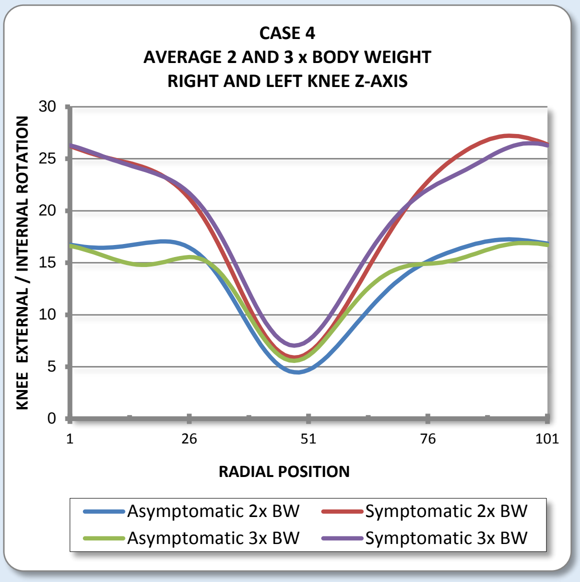

CASE 4
AVERAGE 2 AND 3 x BODY WEIGHT
RIGHT AND LEFT KNEE Z-AXIS
KNEE EXTERNAL / INTERNAL ROTATION
0
5
10
15
20
25
30
1
26
51
76
101
RADIAL POSITION
Asymptomatic 2x BW
Symptomatic 2x BW
Asymptomatic 3x BW
Symptomatic 3x BW

Table 4.18: Summary of Knee Range in the Transverse Plane; 2x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
TRANSVERSE PLANE KNEE									
CONTROL (CASES)	MAX LEFT (SYMPTOM)2X BW	MAX RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM)2X BW	MIN RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 2X BW	RANGE RIGHT (SYMPTOM) 2X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	3.2	(15.7)	12.5	-2.8	(4.4)		6	(11.4)	5.4
(2)	(5.9)	4.8	1.1	(-6.5)	-3.3	3.2	(12.4)	8.1	4.3
(3)	3.7	(6.2)	2.5	-3.6	(-5)	1.4	7.3	(11.3)	4
(4)	(27.2)	17.3	9.9	(5.9)	4.5	1.4	(21.3)	12.8	8.5
1	17.8	24.4	6.6	3.3	10.2	6.9	14.5	14.2	.03
2	24.1	18.9	5.2	12.7	10.7	2	11.4	8.2	3.2
3	11.6	27	15.4	-1.1	7.2		12.8	19.8	7

* Values are calculated in degrees *(°), measurements of the symptomatic sides are indicated in brackets ().*

Table 4.19: Summary of Knee Range in the Transverse Plane; 3x Body Weight (BW)

CONTROLS (n=3) CASES (n=4)									
TRANSVERSE PLANE KNEE									
CONTROL (CASES)	MAX LEFT (SYMPTOM) 3X BW	MAX RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	MIN LEFT (SYMPTOM) 3X BW	MIN RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT	RANGE LEFT (SYMPTOM) 3X BW	RANGE RIGHT (SYMPTOM) 3X BW	DIFFERENCE BETWEEN LEFT AND RIGHT
(1)	1.7	(14.8)	13.1	-3.6	(3.9)		5.3	(10.9)	5.6
(2)	(6.2)	4.8	1.4	(-6.7)	-5.6	1.1	(12.9)	10.4	2.5
(3)	5.2	(7.1)	1.9	-5.4	(-4.4)	1	10.6	(11.4)	0.8
(4)	(26.5)	16.9	9.6	(7)	5.6	1.4	(19.5)	11.3	8.2
1	18.6	24	5.4	1.6	10.1	8.5	17	14	3
2	24.3	19.2	5.1	14.2	9.9	4.3	10.2	9.3	0.9
3	11.8	27	15.2	-2.3	10.2		14.1	16.8	2.7

** Values are calculated in degrees (°), measurements of the symptomatic sides are indicated in brackets ().*

Chapter 5

5. DISCUSSION

Research regarding asymmetry in joint kinematics during cycling is limited (Smak et al. 1999, Edeline 2004). The aim of our study was to ascertain whether asymmetry of hip, knee and ankle kinematics during cycling is associated with PFP among cyclists compared to those without knee pain. The findings of our study suggest that cyclists with PFP display asymmetry in lower limb joints while cycling, but the similar asymmetry was noted among the cyclists without pain.

5.1 SAGITTAL PLANE KINEMATICS

During cycling, movement of the lower quadrant in the sagittal plane involves flexion and extension of the hip, knee and ankle joints. The objectives were to calculate ROM between maximum and minimum flexion and extension values, and to compare ROM between cases and controls to identify possible differences between groups. Thus, to investigate if cyclists with PFP showed increased asymmetry in sagittal plane kinematics.

5.1.1 Hip and Knee Flexion and Extension

This study indicates no asymmetry in ROM of the hip and knee joint in the sagittal plane among the cyclists included in our study, irrespective of pain. The actual ROM values depicted in *Table 4.10* confirm no intra-cyclist variation. Movement in this plane is expected to display minimal asymmetry as bicycle settings are determined according to the anthropometrics of the cyclists. The seat post, crank length and the front cog have a consistent height, length or size throughout the complete cycle; and with the cyclist connected to the bicycle at the pelvis and the foot, movement in the sagittal plane cannot differ between the right and the left side. Also by the nature of bicycle design, for all cyclists, the flexion/extension pattern started with maximum flexion at TDC and goes into maximum extension at BDC.

Inter-cyclist variation of peak hip and knee flexion and extension were also negligible. This could be expected considering that saddle height greatly affects joint range in the sagittal plane (Ferrer-Roca et al. 2012). If all cyclists had the same, standardised bicycle set-up including saddle height (108.6% – 110.4% inseam length) (Ferrer-Roca et al. 2012), the ROM could be expected to be very similar. Values for hip ROM were previously reported to peak at 90° maximum and 30°minimum flexion (Wozniak Timmer 1991). The findings of our study indicate that hip flexion values for all cyclists ranged between 95.9° and 102.6° maximum and 48.9° and 63.4° minimum (*Table 4.10*). There was no indication that certain values (for instance greater flexion range or lower extension range) could predispose a cyclist to develop PFP as both groups, cases and controls, had cyclists with high and low values (*Table 4.10*). For knee flexion, all cyclists ranged between 110.3° and 117.2° maximum, and 28.1° and 36.6° minimum (*Table 4.10*). Wozniak Timmer (1991) indicated knee flexion range lies between 111.4° and 37°. For both the hip and the knee joint differences were noted in the ROM when compared to other research. It is possible that the differences could be ascribed to the effect saddle height and position has on joint range in the sagittal plane (Ferrer-Roca et al. 2012). With the distance between the saddle and the pedal being secured, the hip, knee and ankle joints are forced into a certain degree of flexion and extension. With change in the saddle height (either higher or lower) the ROM expected from these joints will be decreased or increased because the pelvis and the foot are supported on the saddle and the pedal and the joints must allow the necessary movement to fit the lower limb between the saddle and the pedal.

5.1.2 Ankle Plantarflexion and Dorsiflexion

Intra-cyclist and inter-cyclist variations in peak maximum and minimum values were more prominent in the ankle than in the hip and the knee (*Table 4.10*). However, the asymmetry was present across the whole group (cases and controls) and therefore not seen as an indication in itself for the development of PFP (*Table 4.10*). Dorsiflexion for all cyclists ranged between 1.5° and 16.6° and plantarflexion between 6° and 12.7°. Wozniak Timmer (1991) reported ankle range as 13° in dorsiflexion, 37° in plantarflexion and a total ROM of 50°. Values from this study differ substantially from these peak values. A possible reason could be that saddle height has an influence on sagittal plane joint range as discussed above in Chapter 5.1.1. As this was not controlled, in our study it can be accountable for the difference noted between the current study and published values by Wozniak Timmer (1991).

Contrary to the hip and knee, movement pattern of the ankle did not follow a normal flexion/extension pattern throughout the crank cycle for all cyclists. The power phase depicts a normal movement pattern from flexion to extension, but the recovery phase indicates uncontrolled movement for cases and controls. During the recovery phase there is no consistent change from extension back to flexion. While maximum dorsiflexion is simultaneous with maximum hip and knee flexion, and plantarflexion correlates with hip and knee extension (Wozniak Timmer 1991), most cyclists start to dorsiflex the ankle at the beginning of the recovery phase, only to go back into plantarflexion again before they restart with a dorsiflexion movement to finish the recovery phase in dorsiflexion (*Table 4.3*). This pattern is present for both groups and therefore does not, in itself, present a possible risk factor for PFP development. Possible arguments for this compromised movement pattern could be altered proprioception and neuromuscular control as Blake et al. noticed abnormal joint position sense in the cyclists with PFP (Blake et al. 2012). However, he only investigated this phenomenon in PFP cyclists and could not determine if the deficits preceded or followed the onset of PFP. In this study both cases and controls displayed compromised movement, thus not necessarily predicting development of PFP. Nevertheless it could be a possible cause for the movement pattern seen in the cyclists of this study.

Another possible cause could be compromised muscle function and motor unit (MU) recruitment. MU recruitment of the gastrocnemius and soleus muscles are influenced by fascicle length in these muscles (Lauber et al. 2014). With these two muscles working as the antagonist of the tibialis anterior, plantarflexion or dorsiflexion movement could be influenced by early activation or deactivation of these muscles.

5.2 CORONAL PLANE KINEMATICS

Joint kinematics in the coronal plane has to date only been reported by Bailey et al. (2003). Our findings indicate intra-cyclist asymmetry regarding maximum and minimum peak values as well as ROM between the right and the left leg. However, these asymmetric findings were not specific to one group only but present in the symptomatic and asymptomatic group (*Table 4.9*). While some research found increased hip adduction to be an indication for PFP development (Bailey et al. 2003), the findings of published research do not indicate how extensive the ROM difference has to be for significant effect on joint kinematics. Therefore the findings of this study do not indicate that asymmetry is associated with PFP development.

Hip abduction and adduction movement during cycling indicated that every cyclist has his own individual pattern. The graphs (*Table 4.5*) depict a general trend where the hip alternates between adduction and abduction during a cycle. Both Callaghan (2005) and Ruby et al. (1992) reported a clockwise circular motion with the knee adducted (shifted medially) when pushing down (power phase) and abducted (shifted laterally) when returning to the top (recovery phase). While neither of the authors commented on asymmetry, this study showed intra-cyclist asymmetry in some instances, however, it was not related to the symptomatic cyclists only (*Table 4.5*).

Contrary to this study's results, other authors indicated a correlation between compromised hip mechanics and PFP, where cyclists with PFP showed increased adduction on the symptomatic side (Meira and Brumitt 2011, Van Zyl et al. 2001, Noehren et al. 2012) It is also argued that the adduction/abduction movement indicates hip rotations which could cause high intersegmental loads (Callaghan 2005, Ruby et al. 1992) and that these abnormal loads disrupt tibiofemoral mechanics, which ultimately alter normal patellofemoral mechanics, therefore contributing to PFP aetiology (Gregersen and Hull 2003). However, these conclusions were from studies conducted on walking, walking down stairs, running and jumping. Differences between gait and cycling should not be disregarded as it can contribute to the differences in results between this study and others. Firstly, while both activities are weight bearing and in close kinematic chain, cycling never allows full weight bearing on one leg only due to the fact that the pelvis is always supported by the saddle. Secondly, ROM in gait is affected by the cyclist's motor control ability and muscle strength. In cycling, ROM is influenced by a symmetric bicycle design (extrinsic factors) that has to be matched with asymmetric variations of the human body (intrinsic factors) (Holmes et al. 1994). Therefore, it could be argued that these factors can influence asymmetry during cycling.

In an attempt to standardise the extrinsic factors in the current study; only road cyclists were tested and compared with one another, and each cyclist were tested on his own road bicycle without altering any of his bicycle configurations or set-ups. Cleat positions on the shoes were also left unaltered. As literature states a decrease in asymmetry when pedalling rate (rates per minute) or external workload (resistance) increases (Liu and Jensen 2012, Smak et al. 1999), these two factors were controlled during testing. To equalise resistance, it was calculated according to each cyclist's body weight. First recording was done at a resistance equal to two times body weight and the second recording was at three times body weight. This meant that not every cyclist cycled at the same resistance but that each cyclist cycled at the same power to weight ratio. Lastly, cycling rates per minute (RPM) were standardised and self-controlled at 90RPM for all cyclists. Controlling RPM means that every cycle should take the same time to complete, however, it does not mean that the speed in the power phase (pushing down) is necessarily the same as in the recovery phase (pulling up). Nevertheless it is not considered a contributing factor for asymmetry in joint kinematics in this study.

5.3 TRANSVERSE PLANE KINEMATICS

Maximum and minimum rotation values of the hip and knee were investigated to determine if PFP cyclists showed increased asymmetry in transverse plane movements. Results for both the hip and the knee showed intra-cyclist asymmetry, but this finding was across the whole group, including cases and controls. While the presence of asymmetry is obvious it cannot be considered a sole contributor to the development of PFP seeing that it is present in both groups. Previous research conducted during normal gait and stair decent, showed abnormal tibial and femoral motion in the transverse planes (Powers 2003) in PFP subjects. This malalignment of tibiofemoral rotation (increased medial femoral rotation in relationship to the tibia) may contribute to PFP due to increased forces (Salsich and Perman 2013) and contact pressure (Powers 2003) imposed on the patellofemoral joint. While these studies give valuable information regarding joint kinematics, two components must be kept in mind when comparing it to joint kinematics during cycling. Firstly, during cycling full weight bearing on one leg is never achieved due to the pelvis being supported on the saddle and secondly, the hip and knee joints never reach anatomical extension (Wozniak Timmer 1991) as would be the case during walking. While our findings do not oppose or question the findings in literature, the differences between gait and cycling could explain why this study does not conclude increased asymmetry in PFP cyclists only.

Inter-cyclist comparisons showed great variations in recorded values therefore not suggesting that cyclists with PFP showed increased asymmetric movement in hip and knee rotations. While most studies support the idea that the PFP cyclists displayed greater hip internal rotation (Souza and Powers 2009) and that axial rotation of the tibia affects patellar tracking and therefore increases tension on medial and lateral knee structures (Ruby et al. 1992). Our study cannot conclude that rotation was a contributing factor in the PFP group of this study.

5.4 LIMITATIONS

This study has limitations that should be considered when interpreting the results and outcome.

The study was conducted on a very small study sample which demands caution when generalising results and the interpretations thereof. The small sample was partly due to the strict inclusion and exclusion criteria which greatly limited eligible cyclists to the study. While great efforts were made during recruitment, a lack of interest from the road cycling community had a negative influence on the sample size, yielding a markedly lower number of cyclists than anticipated.

The aetiology of PFP appears to be multifactorial with multiple anatomical abnormalities contributing to the development of symptoms. This study only focused on one aspect namely kinematics, and the interaction between possible contributing factors has been disregarded, whereas challenging and testing these multiple contributing factors together could have yielded valuable and interesting information. Furthermore, comparing results and outcomes of the current study with previous studies was complicated by multiple descriptions used for PFP. This could affect the generalisability of the current study's results.

Literature does not indicate how much intra-cyclist asymmetry in ROM would be deemed significant to have an effect on the development of PFP. Therefore, interpretation of our study results is complicated by the lack of comparative studies and recorded values. The establishment of normal and excessive values would be beneficial to future research.

Joint kinematics were measured by means of reflective markers placed on the skin on predefined body areas. However, measurement is complicated by the amount of skin movement over joint structures during cycling, while it could be that joint range values are influenced by this, at least it occurred across all cyclists tested.

The researcher performed the evaluation test of all cyclists to confirm or negate the presence of PFP. This could raise concerns about the researcher being bias. To prevent this a written protocol that described the tests in detail was employed and the outcome of the test could only be a "yes" or a "no" answer. There was no room for personal interpretation.

5.5 RECOMMENDATIONS

This research study investigated seven subject only; a larger research group would allow for statistical calculations and comparisons which could yield an outcome that may be a better presentation of the cycling population. It may also contribute towards establishing the level of asymmetry that could be present before it is deemed problematic.

While asymmetry was noted during cycling it may be valuable to test where in the crank cycle the maximum and minimum range occur. PFP is multifactorial and patellofemoral kinematics are influenced by the interactions of various segments in the lower extremity, therefore interaction between segments may vary at different radial positions in the crank cycle. It may be valuable to investigate whether or not certain radial positions are high risk areas for unnecessary strain on soft tissue structures related to PFP.

To further extend the field of research, a study combining gait and cycling kinematics could yield interesting results and render cycling data more comparable to the many gait studies regarding PFP and the possible identified risk factors.

Chapter 6

6. CONCLUSION

Cycling relates to a range of musculoskeletal complaints of which PFP is the most common in limiting cyclists during training and performance. While some studies investigated the sagittal plane kinematics; association between PFP and asymmetry during cycling has not been investigated in the coronal and transverse plane. This study endeavoured to do so by comparing maximum and minimum values and to calculate joint range to establish if there is an obvious link between pain development and the presence of asymmetry in joint kinematics during cycling.

Results regarding the sagittal plane showed no intra-cyclist or inter-cyclist asymmetries. Joint kinematics in the coronal and transverse plane showed asymmetry in hip and knee joint kinematics, but the asymmetry was noted across the whole group including both cases and controls. For this reason asymmetry alone does not seem to be an indicator for the development of PFP in cycling.

This research is relevant as it encourage health care providers to take all possible risk factors into consideration when treating cyclists with PFP and not to focus on correcting asymmetry alone while ignoring other possible contributing factors. Asymmetry is most obvious in the coronal and transverse plane, therefore should you wish to correct asymmetry as part of the treatment, these two planes should receive the most attention. Furthermore asymmetry is most apparent during cycling however bike fitment is done statically. Research to improve dynamic bike fitting should be considered.

Biomechanics and kinematics in the lower limb are complex and PFP is multifactorial, therefore it could be valuable to investigate multiple aspects at the same time during further research. Another challenge is that there is no indication in literature as to how much asymmetry would be deemed problematic. Establishing this could be helpful for further research.

Chapter 7

7. REFERENCES

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Chapter 8

8. APPENDICES

8.1 APPENDIX 1: E-MAIL TO CHAIRPERSON OF CYCLING CLUB

Subject: Research: Asymmetry in Cyclists with Knee Pain.

Dear Mr/Ms ______________________

For my master's degree in Physiotherapy I am currently conducting a study to determine the correlation between patellofemoral pain and asymmetry in the hip, knee and ankle joint during cycling. This research will be under the guidance of - and support by the University of Stellenbosch.

For this purpose I need 16 willing cycling participants for an adequate study sample. The cyclists will be asked to complete a questionnaire and they will have to present themselves at the Motion Analysis Clinic, Faculty of Medicine and Health Sciences at the Tygerberg Campus, for data collection. The duration of the data collection will be an hour. There are no risk factors involved and all personal details will be treated as highly confidential.

I am addressing you to obtain your permission to contact all club members with the invitation to participate in the research. With your permission you can either forward my invitation letter to all the club members or you can provide me with their contact details.

Please feel free to contact me at any time if you need more information. My contact details are: erikabrand@gmail.com or +264 81 333 3904.

Kind regards

Erika Brand
(Physiotherapist and Primary Researcher)

8.2 APPENDIX 2: E-MAIL TO CLUB MEMBERS

Dear member,

You are invited to participate in a research study that will investigate the correlation between knee pain (PFP) and asymmetry of hip, knee and ankle 3D-kinematics during cycling. The purpose of the study will be to identify possible causes for development of patellofemoral pain and to adjust physiotherapy treatment and bicycle configuration accordingly.

The data collection will take place at the Motion Laboratory at the Faculty of Medicine and Health Sciences, Tygerberg Campus, Stellenbosch University. Each individual data collection session will last an hour. On arrival you will be asked to sign a letter of consent. A short physical examination, performed by the primary researcher, will follow. For the data collection, you will need to bring your training bicycle and wear your normal cycling clothes. Your bicycle will be fitted to a trainer and a number of reflective markers will be attached to your body to enable the Vicon to capture your leg motion during cycling. An initial period of warm up of 10 minutes will be allowed after which the resistance will be increased. You will be asked to maintain a steady cadence for the entire 10 minute trial. After data collection you will be allowed a 10 minute cool down period.

No risk factors have been identified and personal details will be treated as confidential at all times.

As recruitment is on a voluntary basis, remuneration is not applicable.

Should you be interested to participate in the research, a completed questionnaire must be returned directly to the researcher at erikabrand@gmail.com. It is important that you answer all the questions.

Your participation will be highly valued.

Looking forward to hearing from you.

Kind regards

Erika Brand

(Physiotherapist and Primary Researcher)

8.3 APPENDIX 3: PATELLOFEMORAL PAIN QUESTIONNAIRE

Thank you for taking time to complete this questionnaire. It is important that you complete the questionnaire in all honesty as the information will be used to determine your eligibility for participation. There is no “correct” or “incorrect” answer.

Upon completion please forward the questionnaire to the researcher at erikabrand@gmail.com

Questionnaire

SECTION A

Name and Surname:	
Telephone number:	
E-mail address:	
Date of Birth (D/M/Y):	
Gender (male or female):	
Average cycling hours per week:	
Number of years cycling:	
Do you participate in competitions?	
If yes, how many hours per year?	

SECTION B

Please answer the questions below by ticking (✓) either YES or NO. Ensure that you answer ALL the questions.

History	Yes	No
Have you been diagnosed with Osteoarthritis?		
Have you been diagnosed with Diabetes?		
Did you have a head injury or vestibular disorder within the last 6 months?		
Do you have a neurological disease?		
Do you have an artificial lower limb?		
Any traumatic injuries to the lower quadrant within the last 2 years?		

Any meniscal tear or any intra-articular injury diagnosed?		
Any surgery to your knees?		
Any known articular cartilage damage which has been confirmed by imaging?		
Any known laxity or tears of the cruciate or collateral ligaments?		
Recurrent patellar subluxation or dislocation?		
Any swelling in the knees?		
Do you use of non-steroidal anti-inflammatory drugs or corticosteroids?		
Have you be using it for more than three months?		
Symptoms	**Yes**	**No**
Do you have unilateral knee pain (knee pain only on one side)?		
Was the onset of pain symptoms insidious (without trauma)?		
Have pain symptoms been present for at least 4 weeks?		
Does pain limit your performance or hamper your training?		
Do you feel the need to seek medical advice regarding your knee pain?		
Have you already sought medical advice regarding your knee pain?		
Do you experience knee pain during cycling?		
Do you experience knee pain after prolonged sitting?		
Do you experience knee pain during stair climbing?		
Do you experience knee pain when squatting?		
Do you experience knee pain when kneeling?		

8.4 APPENDIX 4: E-MAIL TO PHYSIOTHERAPIST

Subject: Participation in Research

Dear Colleague,

I would like to invite your patients, involved in cycling, to participate in a research project conducted at the Motion Analysis Clinic at the Tygerberg Campus of Stellenbosch University.

The research will investigate asymmetry of joint kinematics, of the hip, knee and ankle joints in cyclists with unilateral chronic PFP when compared with asymptomatic cyclists. Measurements will be recorded with the Vicon which is an eight camera motion analysis system used to capture joint kinematics.

Cyclists will be asked to spend an hour at the Motion Analysis Laboratory. Each cyclist will be tested on his own bicycle with his bicycle configuration to ensure that asymmetry is not negated or induced by changing settings.

Road cyclists training a minimum of five hours per week and aged between 23 and 45 are invited to participate in the research. The data collection will take place before end of June 2014.

I would appreciate it if you could extend this invitation to your patients who are actively involved in cycling.

You can contact me at any time if you need more information. Interested cyclists can contact Erika Brand at erikabrand@gmail.com or +264 81 333 3904 for more information.

Kind regards

Erika Brand

(Physiotherapist and Primary Researcher)

8.5 APPENDIX 5: INFORMATION TO CYCLISTS SELECTED TO PARTICIPATE IN THE RESEARCH STUDY

Research Topic: Symmetry in Hip, Knee and ankle kinematics in cyclist with chronic unilateral patellofemoral knee pain.

Thank you for your willingness to participate in this research study. Your contribution will help to improve the understanding of development of patellofemoral pain, and advance treatment plans to be more efficient and focused.

Please acquaint yourself with the information below.
Time: A fixed appointment will be scheduled telephonically and/or via e-mail prior to data collection.
Location: You will be expected to arrive on time on the day of data collection at the Faculty of Medicine and Health Science, Tygerberg Campus in Bellville and present yourself at the Motion Analysis Laboratory. Signposts will indicate the way.

Bicycle: You are required to bring your own training bicycle (road bicycle) as you will be tested on your own bicycle with the bicycle configurations you normally train with. Your bicycle will be mounted to the trainer.

Clothes: You will be expected to wear your normal cycling gear including your cycling shorts and cleats (safety helmets are not required as it will be on a stationary bicycle set-up). You can either arrive readily dressed or have the opportunity to change in privacy.

Time Frame: The estimated time required to complete the whole process for data collection is one hour.

What to expect: When you arrive you will be met by the primary researcher (Erika Brand) who will explain the procedures. You will have the opportunity to pose questions which will be answered by the researcher. Once you have been sufficiently informed and before data collection starts, you will be asked to sign a form of consent. You are reminded that you have the right to withdraw from the research at any time without providing reason. Once you are dressed in your cycling gear you will have the markers placed on your ankles, knees, hips and pelvis. You will position yourself on your bicycle and the Vicon measuring tool will be calibrated before the start of data collection. You will start with a 10 minute warm up period. Thereafter the intensity will be increased and you will be asked to maintain a steady cadence for the next 10 minutes. The data collection will be done during this time. Once the data collection was successful you will be free to cool down and leave.

Should you have any questions or need clarification on any matter, please do not hesitate to contact me either by e-mail (erikabrand@gmail.com) or by phone (+26481 333 3904).
Looking forward to meeting you.

Kind regards

Erika Brand

(Physiotherapist and Primary Researcher)

8.6 APPENDIX 6: INFORMED CONSENT FORM

RESEARCH TITLE: Symmetry in hip, knee and ankle kinematics in cyclist with chronic unilateral patellofemoral pain.

REFERENCE NUMBER: S14/02/034

PRIMARY RESEARCHER: Erika Brand

ADDRESS: Ultimate Physio Care

Olympia Health Care, Unit 2

Hamutenya Wanahepo Ndadi Str 33

CONTACT DETAILS: E-mail: erikabrand@gmail.com

Tel: +264 81 333 3904

Research Information

You are being invited to participate in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you have agreed to participate.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the International Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study about?

Cycling has increased in its popularity over the last number of years. Despite the fact that it is seen as a low impact sport, many cyclists experience repetitive strain injuries to the knees, especially patellofemoral pain. Knee pain often hampers training schedules and limits performance.

There is a lack of research regarding the association between patellofemoral pain (pain on the inside and/or front of the knee) and unevenness of leg movement during cycling. To limit the risk of developing injuries or to treat existing patellofemoral injuries effectively, it is important to investigate the unevenness as a possible contributing factor. Therefore this study aims to investigate the possible relationship between patellofemoral pain and unevenness (asymmetry) in joint movement of the hip, knee and ankle joint during cycling.

Each cyclist will be tested on his/her own bicycle. The saddle height will be checked and corrected if need be. You will be expected to wear your normal cycling gear including cycling pants and cleats (safety helmets are not required as it will be on a stationary bicycle setup). A number of reflective markers will be attached with double sided tape to different areas of the body (ankle, knee, hip and pelvis). All reflective areas on your clothes and shoes will be covered with masking tape.

After your bicycle has been mounted to the trainer you will have a 10 minute warm up period cycling at a resistance of 2 times body weight and a 90RPM cadence. Thereafter the resistance will be increased to 3 times body weight and you will be required to maintain the cadence. Data collection will be for ten cycles at each resistance.

All data will be collected at the Faculty of Medicine and Health Science, Tygerberg Campus in Bellville and all data will be analysed by a statistician.

Why have you been invited to participate?

You have been invited because you cycle a minimum of five hours a week and fit the inclusion criteria either for the control group or for the test group. Furthermore, you are willing to contribute to research to advance future treatment techniques and treatment protocols.

What will your responsibility be?

You will be expected to present yourself on the scheduled date and time for data collection. The correct riding gear must be worn during the data collection with the exception of a safety helmet. You should be willing to be evaluated by the researcher and answer related questions in honesty. During data collection you will be expected to perform the task as well as possible.

Will you benefit from participating in this research?

After completion of the study you will receive a report with the findings and conclusion of the research. You will receive this information via e-mail.

Are there any risks involved in your participating in this research?

This study has no risks involved and has been approved by the Human Research Ethics Committee. However, if you have any concerns during or after data collection you can contact the researcher to discuss your concerns. Each eligible cyclist has the right to withdraw from the research at any given time.

Who will have access to your medical records?

Your medical records and personal details will be treated as highly confidential. The research team (primary resercher and supervisors) will have access to your details.

What will happen in the unlikely event of some form of injury occurring as a direct result of your participation in this research study?

In the unlikely event of injury to the participant that has been due to negligence the University of Stellenbosch has an indemnity insurance that will cover the necessary costs.

Will you be paid to participate in this study and are there any costs involved?

This research is done on a voluntary basis; no remuneration will be distributed.

You will not be held accountable for any of the costs incurred during use of the Motion Analysis Laboratory.

Is there anything else that you should know or do?

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by the researcher.

You will receive a copy of this information and a consent form for your own records.

Declaration by participant:

By signing below, I ______________________________agree to participate in a research study entitled "Symmetry in hip, knee and ankle kinematics in cyclist with chronic unilateral patellofemoral pain."

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable
- I have had a chance to ask questions and all my questions have been adequately answered
- I understand that participation in this study is **voluntary** and I have not been pressurised to do so.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interest, or if I do not follow the study plan, as agreed upon.

Signed at (*place*) _____________________________ on (*date*) __________________________ 2015.

______________________ ____________________________

Signature of participant **Signature of witness**

Declaration by researcher

I *(name)* ____ declare that:

- I have explained the information in this document to _________________________________
- I have encouraged him/her to ask questions and took adequate time to answer them
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) ________________________________ on (*date*) __________________________ 2015.

______________________ ____________________________

Signature of researcher **Signature of witness**

Declaration by interpreter

I *(name)* ____ declare that:

- I have assisted the researcher (*name*) ______________________________ to explain the information in this document to (*name of participant*) ______________________________ using the language medium of Afrikaans/Xhosa
- I have encouraged him/her to ask questions and took adequate time to answer them
- I have conveyed a factually correct version of what was related to me
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered
-

Signed at (*place*) ______________________________ on (*date*) ______________________

_________________________ _________________________

Signature of interpreter **Signature of witness**

8.7 APPENDIX 7: FINAL SCREENING FORM FOR CYCLISTS WITH PATELLOFEMORAL PAIN

(For completion by the primary researcher during physical examination)

SECTION A **Please answer the questions below by ticking (✓) either YES or NO. Ensure that ALL questions are answered.**	**YES**	**NO**
Positive patellar apprehension test?		
Positive patella tilt test?		
Positive patella compression test?		
Positive vastus medialis coordination test?		
Positive eccentric step test?		
Tenderness of patellar tendon?		
Tenderness of iliotibial band?		
Tenderness of pes anserines?		
Please indicate the values below, where necessary measurements are done in centimetres. Ensure that ALL questions are answered.	**Left**	**Right**
Leg length measurement		
Trochanteric length (from greater trochanter to the floor)		
Saddle height (from the top of the saddle to the pedal surface with the crank in line with the seat tube)		
Dominant leg for kicking		
Painful knee (indicate right, left or both)		
SECTION B		
Eligible for this research study?		
Research number allocated?		

8.8 APPENDIX 8: TEST DESCRIPTIONS

1. Positive Patellar Apprehension Test

   The cyclist is positioned in supine and relaxed. The examiner pushes the patient's patella as lateral as possible to obtain a lateral patellar glide. Starting with a 30° knee flexion, the examiner takes hold of the ankle with the other hand and performs a slow, combined flexion of the knee and the hip. Throughout the test the lateral glide should be sustained. The test is considered positive when the cyclist's pain is reproduced or when apprehension, by facial expression, anxiety or involuntary quadriceps muscle contraction, is elicited. (Nijs et al. 2006)

2. Positive Vastus Medialis Coordination Test

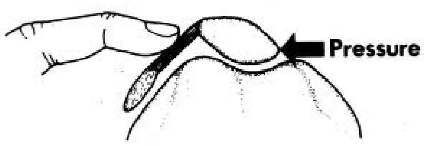
   The cyclist is positioned in supine and the examiner places her fist underneath the painful knee. The cyclist is then requested to slowly extend the knee without pressing down or lifting away from the examiner's fist. The cyclist will be encouraged to try and reach full extension. A positive outcome would be a lack of coordinated extension or difficulty to smoothly accomplish extension or when recruitment of either the extensors or flexors of the hip was present. (Nijs et al. 2006)

3. Positive Eccentric Step Test

   The test must be performed with the cyclist wearing shorts and being bare footed. A step of 25 cm high with a rubber top cover to prevent slipping will be used for all cyclists. First a demonstration will be given on how to step onto the step and how to step down. Afterwards the cyclist will be verbally instructed throughout the exercise. The standardised phrases that will be used will be: "stand on the step, put your hands on your hips and step down from the step as slowly and as smoothly as you can". The procedure will be performed bilaterally. No practice attempt will be allowed. The test will be considered positive when knee pain is reported by the cyclist. (Nijs et al. 2006)

4. Tenderness of Patellar Tendon and/or Medial Retinaculum

   Cyclist is positioned in supine with the knee in extension. Palpation at the apex of the patella and over the patellar tendon will be performed. Afterwards the medial retinaculum will be brought under tension and palpated by pushing down on the lateral aspect of the patella with one hand, while palpating with the other hand. Any tenderness will be noted.



5. Tenderness of Iliotibial Band

   Cyclist is positioned in supine with the knee in extension. Palpation starts medial and superior to the fibula. The insertion on the lateral condyle is palpated after which the examiner moves superiorly along the band palpating the entire length.

6. Tenderness of Pes Anserines

   The aponeurosis of the gracilis, semitendinosus and sartorius muscle will be palpated slightly distal and medial to the tibial tuberosity. Any tenderness will be noted.

7. Clinical Method for Measuring Leg Length Difference

   A tape measure will be used to measure the distance between the Anterior Superior Iliac Spine (ASIS) and the medial malleolus. Measurements will be noted down on the final screening sheet.

8.9 APPENDIX 9: ETHICS APPROVAL 1 AND 2

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Approval Notice

New Application

16-Apr-2014
Brand, Erika E

Ethics Reference #: S14/02/034

Title: **Symmetry of hip, knee and ankle kinematics in cyclists with chronic unilateral anterior-medial pain.**

DearMs Erika Brand,

The **New Application** received on **18-Feb-2014**, was reviewed by members of **Health Research Ethics Committee 1** via Minimal Risk Review procedures on **16-Apr-2014** and was approved.
Please note the following information about your approved research protocol:

Protocol Approval Period: **16-Apr-2014 -16-Apr-2015**

Please remember to use your **protocol number** (**S14/02/034**) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:
Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.
Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.
For standard HREC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further assistance, please contact the HREC office at 0219389657.

Included Documents:
CV Cockcroft
Synopsis
CV EBrand
HREC Checklist

Investigator declaration Cockcroft
Funding
Investigator declaration QLouw
Investigator declaration Crous
CV QLouw
CV Crous
Investigator declaration Brand
Proposal
Application form

Sincerely,

Franklin Weber
HREC Coordinator
Health Research Ethics Committee 1

Investigator Responsibilities

Protection of Human Research Participants

Some of the responsibilities investigators have when conducting research involving human participants are listed below:

1.Conducting the Research. You are responsible for making sure that the research is conducted according to the HREC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research.

2.Participant Enrolment. You may not recruit or enrol participants prior to the HREC approval date or after the expiration date of HREC approval. All recruitment materials for any form of media must be approved by the HREC prior to their use. If you need to recruit more participants than was noted in your HREC approval letter, you must submit an amendment requesting an increase in the number of participants.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the HREC-approved consent documents, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least fifteen (15) years.

4.Continuing Review. The HREC must review and approve all HREC-approved research protocols at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the HREC approval of the research expires, **it is your responsibility to submit the continuing review report in a timely fashion to ensure a lapse in HREC approval does not occur.** If HREC approval of your research lapses, you must stop new participant enrolment, and contact the HREC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, number of participants, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the HREC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written HREC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the HREC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research-related injuries, occurring at this institution or at other performance sites must be reported to the HREC within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the HRECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch Universtiy Health Research Ethics Committee Standard Operating Procedures www.sun025.sun.ac.za/portal /page/portal/Health_Sciences/English/Centres%20and%20Institutions/Research_Development_Support/Ethics/Application_package All reportable events should be submitted to the HREC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research-related records, at a minimum, in a secure location for a minimum of fifteen years: the HREC approved research protocol and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the HREC

8.Reports to the MCC and Sponsor. When you submit the required annual report to the MCC or you submit required reports to your sponsor, you must provide a copy of that report to the HREC. You may submit the report at the time of continuing HREC review.

9.Provision of Emergency Medical Care. When a physician provides emergency medical care to a participant without prior HREC review and approval, to the extent permitted by law, such activities will not be recognised as research nor will the data obtained by any such activities should it be used in support of research.

10.Final reports. When you have completed (no further participant enrolment, interactions, interventions or data analysis) or stopped work on your research, you must submit a Final Report to the HREC.

11.On-Site Evaluations, MCC Inspections, or Audits. If you are notified that your research will be reviewed or audited by the MCC, the sponsor, any other external agency or any internal group, you must inform the HREC immediately of the impending audit/evaluation.

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Ethics Letter

30-Apr-2015

Ethics Reference #: S14/02/034
Clinical Trial Reference #:
Title: Symmetry of hip, knee and ankle kinematics in cyclists with chronic unilateral anterior-medial pain.

Dear Miss Erika Brand,

The HREC approved the following report by expedited review process:

Progress Report dated 15 March 2015

The approval of the project is extended for a further year.

Approval date: 30 April 2015

Expiry date: 30 April 2016

If you have any queries or need further assistance, please contact the HREC Office 219389657.

Sincerely,

REC Coordinator
Franklin Weber
Health Research Ethics Committee 1

"A mind of moderate capacity which closely pursues one study must infallibly arrive at great proficiency in that study."

Mary Shelley, *Frankenstein*