The Effects of Taping on Muscle Activity and Knee Control during Stair Descent in People with and without Patellofemoral Pain

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Abstract

Background: Patellofemoral pain (PFP) is a common musculoskeletal disorder, which is poorly understood and is often associated with poor outcomes. Although there is a lack of consensus linked to many of the factors associated with PFP, key issues for individuals with PFP include impairment of muscle activity and movement control. This thesis explored the effects of a taping technique which purports to inhibit Vastus Lateralis (active tape) on muscle activity and lower limb kinematics during stair descent.

Method: Thirty asymptomatic participants and sixteen participants with PFP performed a stair descent task; the asymptomatic participants under three different taping conditions (active, neutral and a no tape control) and on two different riser heights; and the symptomatic participants under the same three taping conditions but on the high riser height only. For all participants, surface electromyography was recorded from vastus lateralis, vastus medialis and gluteus medius, alongside inertial measurement unit recordings of tibial and patellar accelerations and angular velocities. For the PFP participants, numerical pain rating scale and Likert scale data for perceived stability were also recorded, with the Knee Injury and Osteoarthritis Outcome Score – Patellofemoral and the Targeted Intervention for Patellofemoral Pain Syndrome assessments being recorded to help describe the participants.

Results: In the asymptomatic cohort, the active tape altered the sagittal plane angular velocities, the anterior-posterior tibial accelerations, the patellar coronal plane angular velocity, and the anterior-posterior patellar accelerations, with the neutral tape altering coronal plane tibial angular velocities. The higher riser created significant increases in stance phase duration and muscle activity as well as changes in both the tibial and patellar kinematics. However, the low riser also had an effect on several of the lower limb kinematic parameters The active tape in the symptomatic cohort demonstrated Vastus Lateralis inhibition during the single leg stance sub-phase. Additionally, in the symptomatic cohort, both the active tape and neutral tape conditions significantly decreased perceived pain and improved perceived knee stability. Kinematic changes were also seen in the coronal plane for both the tibia and patellar and transverse plane for the patella, primarily due to the active tape condition.

Conclusion: Both the active and the neutral taping techniques could be a useful adjunct to existing methods of treatment currently used in clinical practice for PFP. However, the active taping technique showed the greater beneficial effect on reported pain and perceived stability, which may be useful in the facilitation of rehabilitative exercises and activities of daily living such as stair descent. This was the first study to investigate these taping techniques on symptomatic participants, and further research is warranted to determine longer term effects.

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I made a promise to the one of the two most influential people in my life before she died that I would complete this PhD, and it is down to you all that I have been able to keep that promise. Thank you all and RIP mum.

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List of Abbreviations

ACL - anterior cruciate ligament

AIIS - anterior inferior iliac spine

AP - anterior-posterior

BMI - body mass index

CNS - central nervous system

CASP = critical appraisal skills programme

EMG - electromyography

ENV - enveloped

FPI - foot posture index

FSR - force sensitive resistor

GM - gluteus medius

HP - high pass (filtering)

IMU - inertial measurement unit

ITB - iliotibial band

KOOS - knee injury and osteoarthritis outcome score

KOOS-PF - knee injury and osteoarthritis outcome score – patellofemoral

MCIC - minimal clinically important change

MCID - minimal clinically important difference

MIC - minimally important change

ML - medial-lateral

MU - motor unit

MUAPT - motor unit action potential train

NPRS - numerical pain rating scale

OA - osteoarthritis

PF = patellofemoral

PFP - patellofemoral pain

PRISMA – preferred reporting items for systematic reviews and meta-analyses

PROM - patient reported outcome measure

RCT – randomized controlled trial

REC - rectified

RM - remove mean (calculation)

sEMG - surface electromyography

SENIAM - surface electromyography for the non-invasive assessment of muscles

SNR – signal to noise ratio

TIPPS – targeted intervention for patellofemoral pain syndrome

UCLan - University of Central Lancashire

VAS - visual analogue scale

VM - vastus medialis

VMO - vastus medialis obliquus

VML - vastus medialis longus

VL - vastus lateralis

WOMAC - Western Ontario and McMaster Osteoarthritis Index

Chapter 1 Introduction

Patellofemoral pain (PFP) is a very common pathology which was identified as being generally poorly understood by McConnell in 1986. Unfortunately, this has changed little over time and PFP is still being labelled as a poorly understood condition (Grant et al 2020, Sinclair et al 2016, Barton et al 2014). There is a lack of consensus of many features and factors associated with PFP which demonstrates that PFP is an intricate condition, and one that has been identified as a “complex and enigmatic” issue (Willy and Meira 2016), and one that can be very frustrating to diagnose and treat (Smith 2012). However, PFP is generally accepted to be a non-specific pain around the front of the knee resulting from dysfunction in the mechanical forces acting on and between the femur and the patella (Saltychev et al 2018). Although it has been widely investigated, PFP still continues to challenge both patients and clinicians (Rabelo and Lucareli 2018). Perhaps unsurprisingly, but not unfairly, it has been called “one of the most vexatious clinical challenges in rehabilitative medicine” (Witvrouw et al 2005).

PFP is typically a diffuse pain around or behind the patella, which can be the result of direct trauma, or more usually from repetitive microtrauma and through chronic mal-alignment and mal-tracking of the patellar in the trochlear groove of the femur (Cheung et al 2006). This can result in increased patellofemoral joint reaction forces which can contribute to the joint being overloaded (Chen et al 2010). Due to these factors, PFP is often aggravated by activities that load the joint, including jumping, hopping, squatting, kneeling, ascending and descending stairs and slopes, prolonged sitting with a flexed knee and rising after prolonged sitting (Lack et al 2018, Crossley et al 2016a). Although its pathogenesis is often unclear, disruption to the normal neuromuscular control of the quadriceps and the interplay between Vastus Lateralis (VL) and Vastus Medialis (VM) are widely believed to be contributing factors (Miao et al 2015). However, whether these factors are causative or develop as a result of pain and/or dysfunction remains unknown. Causative factors for PFP are often hard to elicit. However, in their systematic review, Leibbrandt and Louw (2015) identified intrinsic and extrinsic factors that may be relevant. The intrinsic factors included patellar tracking, increased tibial and/or femoral rotation, increased knee valgus stress, increased subtalar rotation and inadequate flexibility. Meanwhile, highlighted extrinsic factors were; increased training speed and/or volume, altered training surfaces and footwear, body anthropometry and body mass index (BMI). Good quality subjective and objective assessments, carried out by clinicians, should be able to recognise which of these factors apply to individual patients.

Diagnosing PFP is challenging and there have been a number of clinical tests suggested, for example Clarke's test (the patellar compression test), Waldron's test, the active instability test, the eccentric step test, the patellar apprehension test, McConnell's critical test and various soft tissue tests (Arjun et al 2017, Selfe et al 2017 p62/3). However, there is no single gold standard test that has shown sufficient specificity and sensitivity to make it appropriate for clinical assessment (Arjun et al 2017, Crossley et al 2016a). Therefore, PFP is a diagnosis made by excluding other pathologies and recognising patterns of symptoms and symptom behaviour that are accepted as indicative of PFP (Näslund et al 2006).

One pattern of symptoms that is recognised as indicative of PFP is the imbalance between VL pulling the patella laterally and VM pulling it medially, both in terms of onset timing and magnitude of contraction (Khaleghi et al 2016, Giles et al 2015, Bhagat and Bhura 2014, Fagan and Delahunt 2008). This is usually attributed to weakness of VM with respect to VL. However, Giles et al (2015) found that muscle atrophy, which they correlated with muscle weakness, in the quadriceps is not limited to VM, but all components of this muscle group were significantly smaller in participants with PFP compared to those without the condition. This notwithstanding, there is a general consensus in the literature that VM insufficiency with respect to VL, and the consequential abnormal patellar tracking, is a common and prominent feature of PFP (Briani et al 2018, Kaya et al 2012, Chester et al 2008).

At this point, it is relevant to highlight the inconsistency regarding the terminology used when describing the medial vastus muscle of the quadriceps. Since being popularised by McConnell's landmark paper in 1986, the VM has been viewed as having two distinct parts; the vastus medialis obliquus and the vastus medialis longus. However, more recent research has cast doubt on whether the medial vastus muscle of the Quadriceps should be viewed as having these two components. This is discussed in more detail in the literature review chapter (section 2.5.1) of this thesis, but for clarity and consistency, this thesis will use the term VM to describe the medial vastus muscle of the quadriceps.

Once diagnosed, the traditional approach to managing PFP has been general quadriceps strengthening exercises and exercises purported to specifically and preferentially recruit VM. Smith et al (2019a) and Lack et al (2018) are among the authors who have identified exercises as being the cornerstone of PFP interventions. However, there is no consensus as to what type, duration, frequency and dosage of exercise should be prescribed therefore making comparisons within the literature difficult. In their systematic review of exercise parameters, Harvie et al (2011) found high levels of variance in the prescribed repetitions, duration and frequency. There is also variation in the literature as to whether VM can even be preferentially recruited with respect to VL (Eapen et al 2011), and therefore whether specific VM targeted exercises actually work. The same could be considered of therapeutic taping which has been widely investigated in the management of PFP and although it is recognised as a useful adjunct, there is no consensus as to its use or how it actually works (Capin and Snyder-Mackler 2018). This is due in part to studies having different and specific treatment and taping techniques. Although this makes individual studies more robust academically, and therefore repeatable, it limits their clinical applicability.

Currently, PFP is associated with a poor prognosis, with up to 40% of patients reporting unfavourable outcomes at 1-year post treatment (Drew et al 2017, Collins et al 2013), which may also have a negative impact on the psychological well-being of people with the condition (Matthews et al 2016). This, together with the high incidence and prevalence rates with poor prognosis, should make PFP an urgent research priority (Smith et al 2018c).

The balance of the neuromuscular function of, and between, the vasti muscles is most frequently assessed using electromyography (EMG). Generally, there are two approaches to this assessment; the onset of VM relative to VL and the ratio of the EMG signal amplitude of both muscles (Hug et al 2015). EMG assessments can be conducted either by placing electrodes on the surface of the skin (sEMG) or by using intramuscular fine wire electrodes inserted into the target muscle. As will be discussed in the literature review chapter (Chapter 2, Section 2.14), the studies making up this thesis utilised an sEMG technique.

Numerous controversies exist about PFP including its nomenclature, its incidence and prevalence, its aetiology and pathogenesis, how to diagnose and assess it, how to investigate it and how to treat/manage it. Numerous studies have explored the acknowledged imbalance between VL and VM in PFP and the efficacy of patellar taping as a treatment modality (e.g., Ghourbanpour et al 2018, Bhagat and Bhura 2014, Aminaka and Gribble 2008, Cowan et al 2001). However, to the authors' knowledge, little research to date has examined the effect of taping to inhibit VL (McCarthy Persson et al 2009, Janwantanakul and Gaogasigam 2004, Tobin and Robinson 2000). By inhibiting VL, the inter-muscular imbalance could be corrected meaning that this taping technique has the potential to improve the pain and dysfunction of people with PFP and is therefore a worthy area of research to add to the PFP knowledge base that is currently available. Furthermore, given that there has been scant research into VL inhibition taping to date, this thesis is therefore not only relevant, but also necessary.

Chapter 2, the literature review chapter, will discuss each of the identified controversies in more depth, and will also present other relevant issues pertinent to PFP. For example, whilst patellar taping is a common clinical intervention for PFP (Selfe et al 2007), little or no research to date has examined the effect of VL inhibition taping on VL and on the pain and dysfunction associated with PFP. Therefore Chapter 2 includes a detailed explanation of both the theory behind VL inhibition taping and the practical application of it as a modality to manage PFP (Section 2.11). Furthermore, Chapter 2 will also demonstrate the value of this thesis in terms of its' potential to contribute to increasing the understanding and treatment options of this common and often distressing condition.

Chapter 3 will describe the general methodology used in this research pertaining to people from the asymptomatic cohort. It will highlight relevant research to justify each of the decisions made in the construction of the protocol used in the first part of this thesis. This will be followed by Chapter 4 which will outline the methods of analysis used on the data from the asymptomatic study. These data included stance phase duration, muscle activity and movement control, with the results of the study involving asymptomatic participants being presented in Chapter 5 and discussed in Chapter 6, where relevant research will be used to give the current study some context and implications for clinical practice and future research will be highlighted.

Chapter 7 will describe the methodology used for the second study in this thesis involving the symptomatic cohort. It will again use relevant research to justify individual components of the protocol and will demonstrate the knowledge gained from the asymptomatic study. Chapter 8 will then present the results from the PFP cohort, which will be discussed in Chapter 9.

Chapter 10 will conclude the thesis, and, finally, the references and appendices to support the thesis will be presented.

Chapter 2 Literature Review

2.1 PFP Nomenclature

PFP is described as pain that is felt around or behind the patella (Khaleghi et al 2016). However, there is no clear consensus regarding the terminology used to describe it (Witvrouw et al 2005). Terminology found in the literature that have been used synonymously with PFP include; anterior knee pain, retropatellar pain, chondromalacia patella, patellofemoral pain syndrome, patellofemoral disorder, extensor mechanism disorder and excessive lateral pressure syndrome (Janssen in Selfe et al 2017). For some terms, such as chondromalacia patella, it is no longer appropriate to use it synonymously with PFP. Rather, it should be used as a stand-alone term since it is now accepted that chondromalacia patella is a specific condition affecting the articular cartilage of the patella and is not indicative of PFP. However, many of the other names are still in use which causes confusion and difficulty when comparing study cohorts, and this reduces the clinical applicability of any findings. The 2015 Patellofemoral Pain Research Retreat (Crossley et al 2016a) recommended using the term PFP to attempt to standardise the terminology used in the literature. Therefore, for clarity and consistency, this thesis will use the term PFP throughout, in keeping with this recommendation.

2.2 Diagnosing PFP

PFP is difficult to distinguish and/or diagnose, partly because of the plethora of related names and partly because there is no gold standard test currently available (Selfe et al 2017 p61, Cook et al 2010). Although several tests have been proposed, common ones such as Waldron's test I and II and Clarke's test have been found to have limited validity in actually diagnosing PFP (Nijs et al 2006). However, there is some evidence that patellar mobility is affected in PFP and therefore assessing it may contribute to a making a PFP diagnosis (Janssen et al 2019). With the lack of a single test or assessment tool with which to diagnose PFP, a diagnosis of PFP is often made by excluding other pathologies. Thus, the diagnosis is made clinically, depending on an individual patient's symptoms (Leibbrandt and Louw 2017, Dixit 2007, Näslund et al 2006). In theory, any patellofemoral structure with a nerve supply could be a source of nociceptive output and therefore pain in that region (Dye 2001a). Therefore, potential confounding sources of pain have to be ruled out before a diagnosis of PFP can appropriately be made. Conditions and structures that need to be excluded include; intra-articular pathologies, patellar tendinopathies, pre-patellar bursitis, synovial plica syndrome, infrapatellar fat pad irritation, Sinding-Larsen-Johansson syndrome and Osgood-Schlatter syndrome (Janssen in Selfe et al 2017, Lee et al 2017). However, it is acknowledged that it is difficult to distinguish between these conditions (Dragoo et al 2012).

There is a clear tendency towards diagnosing PFP based on symptoms and function using specific aggravating activities (Papadopoulos et al 2015), although even then there still remains a lack of consensus as to any formal diagnostic criteria (Lack et al 2018). Crossley et al reported from the Patellofemoral Pain Research Retreat in 2015 (published 2016a) and identified core criteria with which to diagnose PFP. These criteria included pain around or behind the patella which is aggravated by at least one activity that loads the patellofemoral joint during weight-bearing on a flexed knee, for example squatting, stair ascent/descent, running and jumping. Meanwhile, Cook et al (2010) recommended using two or three positive findings from activities including pain with quadriceps contraction, pain with squatting, stair ambulation, kneeling, prolonged sitting and pain with palpation of the patella. In their later systematic review, Cook et al (2012) found that there were twenty-two independent tests identified for PFP, including the patellar apprehension test, Clarke's test and patellar palpation, which they found were the most commonly used tests. It was also found that in addition to those three tests, the other tests with the best diagnostic accuracy were pain on stair ambulation, pain during prolonged sitting, pain during squatting and patellar mobility (Cook et al 2012). In their 2015 study, Papadopoulos et al found that neither the modified Thomas test nor the patellar compression test were particularly useful in diagnosing PFP, and concurred with Cook et al (2012) that PFP really is a diagnosis of exclusion. Leibbrandt and Louw (2017) added to this debate by creating a checklist by which to diagnose what they called anterior knee pain. This included inclusion and exclusion criteria which were divided into factors that could be identified during the subjective examination and those that needed to be identified in an objective assessment, and both are presented in Table 2.1.

Table 2.1 Checklist for Anterior Knee Pain (Leibbrandt and Louw 2017)

Inclusion Criteria	Exclusion Criteria
Location of the pain (anterior and/or retropatellar)	Referred pain (i.e., from the hip or lumbar spine)
Chronicity (longer than 3 months duration)	Previous lower limb surgery
Pain during aggravating factors in two of the following: 1) Squatting 2) Prolonged sitting 3) Stair ascent and/or descent 4) kneeling	History of trauma or known intra-articular pathology: Patellar fractures or instability Patellar subluxations or dislocations Positive ligament and/or meniscal stress tests
	Knee effusion and fat pad impingement

2.3 Incidence and Prevalence of PFP

PFP has been identified as one of the most common musculoskeletal disorders affecting adults (Mostamand et al 2011) and as the most common cause of knee pain in an outpatient setting (Smith et al 2018c, Dixit et al 2007). Meanwhile, Ghourbanpour et al (2018) identified what they called patellofemoral pain syndrome as the most common source of anterior knee pain. Several potential risk factors for developing PFP have been identified, including quadriceps weakness, hip abductor weakness, and foot mechanics. However, interestingly it was found that a person’s sex, weight, height, BMI and age were not among these identified risk factors (Neal et al 2019). However, the exact incidence and prevalence of PFP is currently unknown, and there is little agreement in the literature (Selfe et al 2011, Syme et al 2009). In order to examine the concepts of incidence and prevalence, it is necessary first to understand them. Incidence is defined as the number of new onsets of a specific condition over a period of time, whereas the prevalence is defined as the number of people within a population that have a specific condition at a specific time (Boling et al 2010, Oakes et al 2009). As they are very different, the terms incidence and prevalence should not be used interchangeably.

It has been said that PFP may account for 25-40% of all knee problems (Ferrari et al 2014, Witvrouw et al 2014). The incidence reported in the literature varies considerably ranging from 22 per 1000 persons per year (Petersen et al 2014), whilst others report 8.75% to 17% in the general population (Oakes et al 2009) and up to 25-30% seen in outpatient musculoskeletal clinics (LaBore and Weiss 2003). As can be seen, there is wide discrepancy in the published literature regarding the incidence of PFP and it may be that the lack of clarity over what to call this collection of symptoms has contributed, at least partly, to this phenomenon.

With respect to the prevalence of PFP, which has been more widely reported than the incidence, it has been said that PFP affects 23-25% of the population at some time in their lives (Capin and Snyder-Mackler 2018, Cardoso et al 2017). Meanwhile, Petersen et al (2017) reported the prevalence at 11-17% in patients who consulted their General Practitioner, with Drew et al (2017) reporting that 1 in 6 adults who consult their General Practitioner will be diagnosed with PFP. Smith et al (2017a) reported the prevalence at 19-35% in the general population, however, in their later paper, Smith et al (2018c) revised their prevalence figure to 15-45%. Finally, Grant et al (2020) reported an annual prevalence for the general population of adults of 23%. Again, this lack of consistency in the published literature may be due in part to the challenges in what to call this condition and the differences in the methods used in making the diagnosis.

It is worth noting at this point that Callaghan and Selfe (2007) reviewed 136 papers in their systematic review and found that many of them employed “tortuous courses of secondary or even tertiary referencing when citing an incidence rate for patellofemoral pain syndrome” which is less than ideal. They also found that incidence and/or prevalence rates cited in the papers reviewed came almost exclusively from military or sports medicine environments so their relevance to the general public may be limited.

Although there is disagreement in the literature as to the precise incidence and prevalence, there is a general consensus that PFP affects around twice as many females as it does males (Smith et al 2018c, Petersen et al 2014, Boling et al 2010, Prins and Van Der Wurff 2009). Anatomical, hormonal and neuromuscular theories have all been proposed to explain this phenomenon (Cowan and Crossley 2009), but further exploration of this is beyond the scope of this thesis.

2.4 PFP Prognosis

It has been identified that once a person has developed PFP, it often becomes a chronic problem with poor long-term outcomes (Smith et al 2017a, Powers et al 2012). This view is supported by Selfe et al (2017) and Collins et al (2013) who both stated that PFP is not a self-limiting condition, and by Crossley et al (2016a) who found that PFP is a recalcitrant condition which can persist for many years. This is further supported by a number of studies that have reported that anywhere between 40% and 96% of patients will still have symptoms of PFP 4-5 years post-diagnosis (Leibbrandt and Louw 2018, Drew et al 2017, Selhorst et al 2015). These poor outcomes are despite the positive short-term results from current treatment methods identified by Lack et al (2018) and by Lankhorst et al (2013), which has led to a belief that PFP, like many other musculoskeletal problems, cannot be cured, only managed (McConnell 2013).

How well a patient with PFP may do in their rehabilitation is hard to predict, and clinicians often rely on prognostic indicators when setting realistic treatment goals. Prognostic indicators are viewed as an important influence on how best to manage a patient’s expectations from the outset of treatment (Matthews et al 2016). Many prognostic indicators have been identified in the literature, and these include; longer duration of symptoms at assessment, older age, greater pain severity, and higher baseline disability (Matthews et al 2016, Collins et al 2010). Interestingly, Collins et al (2013) reported that gender, BMI and foot posture are not believed to be prognostic factors for PFP outcomes. Factors that have been identified as possibly improving outcomes for people with PFP include; gaining a better understanding of cause and effects within PFP populations and successfully identifying characteristics that guide a tailored intervention approach to increase treatment effectiveness (Lack 2013). This is supported by Smith (2012), who stated that although treatment techniques are effective in pain reduction, they often neglect the underlying causes which results in symptom recurrence.

Although not central to this thesis, it is also important to take biopsychosocial factors into account when considering assessment of PFP and also when considering treatment choices and predicting outcomes. As recognized by Powers et al (2012), pain is a subjective experience and therefore the importance of psychological factors cannot be over-stated. Psychological factors such as fear avoidance and catastrophizing can change behaviour, modulate physiological responses and lead to the development of persistent pain (Smith et al 2019a, b, c, Smith et al 2018b). This view is further supported by MacLachlan et al (2017) who identified that the non-physical psychological features also play a role in the development of persistent musculoskeletal pain, and by Barton et al (2018) who recognised that factors such as anxiety, depression, catastrophising and fear of movement may all be elevated in people with PFP. MacLachlan et al (2017) further state that the persistence of PFP, characterised by the co-existence of physical and non-physical factors, means it can no longer be considered to be a self-limiting condition, affected as it is by the psychological barriers to recovery such as pain-related fear, catastrophising, reduced self-efficacy and movement avoidance. This view is supported by Vicenzino et al (2019) and also by Stephen et al (2020), who both state that high levels of psychosocial dysfunction and distress will influence a person's experience of PFP and also their outcome. Meanwhile, De Oliveira Silva et al (2020) cited a growing body of evidence that suggests psychological and/or psychosocial factors can influence levels of pain and function in people with PFP. Indeed, they also identify kinesiophobia as a key driver of persistent pain in many musculoskeletal conditions, including PFP. In their 2019 research paper, De Oliveira Silva et al found that there was a significant correlation between increasing levels of kinesiophobia and the impaired kinematics often found in people with PFP. They further state that people with PFP often adopt or develop compensatory movement strategies in response to their pain, which may be driven by the kinesiophobia and will ultimately lead to the profound loss of physical activity with the accompanying fear avoidance behaviours often found with PFP patients that was identified by Smith et al (2018b). Indeed, fear avoidance and catastrophising have also been identified as playing a pivotal role in a person's physiological response to pain, which has a consequential effect on the development of chronic pain (Smith et al 2017b). These factors will play a significant part in the development of the persistent pain and the poor treatment outcomes often associated with PFP.

In order to further understand the issues around the poor prognosis associated with PFP, it is first necessary to consider the structure and function of the patellofemoral joint complex, the pathogenesis of the condition and the current management strategies employed to address it.

2.5 Patellofemoral Joint Structure and Function

In order to understand its' structure and function, the anatomy of the patellofemoral joint must first be considered. The structural and muscular anatomy of the patellofemoral joint are illustrated in Figures 2.1, 2.2 and 2.3. At a very basic level, the patellofemoral joint is the articulation between the underside of the patella and the trochlear groove of the distal femur (Norris 2017). However, the articulations of the patellofemoral joint cannot be described as basic. They are the result of complex interactions of the patella, the femur and the surrounding soft tissues. The patella is the largest sesamoid bone in the body, and despite the patella not always being in contact with the femur (which depends on the degree of tibiofemoral flexion and which is discussed in more detail in Section 2.5.3), there are seven articular surfaces involved which all have different curvatures and lengths (Wheatley et al 2020). The primary role of the patella is to increase the mechanical advantage of the quadriceps muscles and thereby improve the efficiency with which they work (Callaghan and Selfe 2012). The underside of the patella and its opposing surface on the trochlear of the femur are covered in articular cartilage, with the patellar articular cartilage believed to be the thickest of any articular surface in the lower limb (Shepherd and Seedhom 1999). This can be argued as being reflective of the nature and strength of the forces that the patellofemoral joint must withstand. Depending on the activity being undertaken, the patellofemoral joint reaction forces can be several times a person's bodyweight which makes withstanding these forces a significant challenge. Indeed, given the magnitudes of the forces that the patellofemoral joint must contend with, it is perhaps not surprising that patellofemoral dysfunction is so common (Stephen et al 2020).

Figure 2.1 The Anatomy of the Patellofemoral Joint (lateral view from www.healthjade .com)

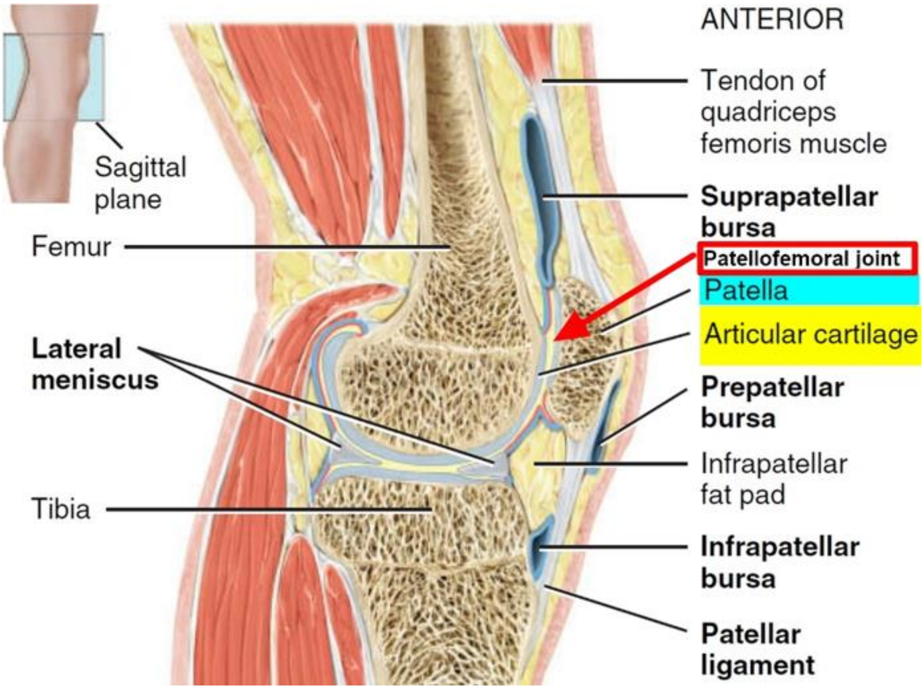


Figure 2.2 The Anatomy of the Patellofemoral Joint (frontal view from www.physiopedia.com)

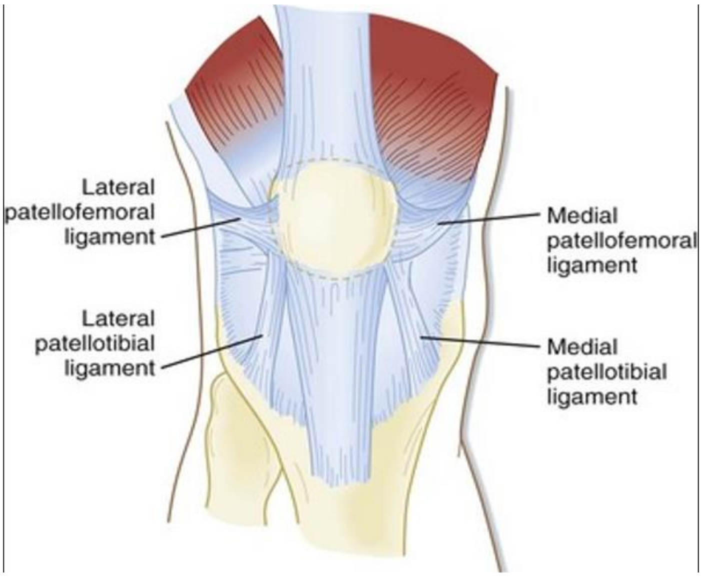
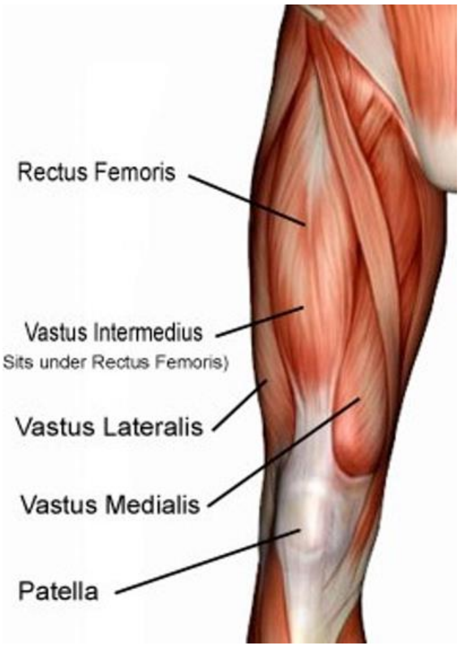


Figure 2.3 The Muscular Anatomy of the Patellofemoral Joint (from www.podiatryfirst .com)



2.5.1 The Vastus Medialis Controversy

Vastus medialis is a controversial muscle, both in terms of its anatomy and its function. With respect to its anatomy, there has been much debate in the literature as to whether it could/should be considered as two discrete muscles namely vastus medialis longus (VML) and vastus medialis obliquus (VMO). In her landmark paper in 1986, McConnell argued for the separation into two component parts with VMO being identified as the only dynamic medial stabiliser of the patella. This was based on the work of Lieb and Perry (1968). In their systematic review, Smith et al (2009c) found that was insufficient evidence to consider VM as being two separate component muscles, either in a population with PFP or in one without PFP. In 2012, Skinner and Adds (2012) then replicated Lieb and Perry's (1968) original work and described the dissection of 40 limbs. Skinner and Adds (2012) found that 55% of these limbs had a distinct change in fibre orientation angle between VMO and VML. In these limbs with this change of fibre orientation angle, they also found that in 54.5% of them there was connective tissue between the two parts of VM rendering them discrete. However, this represented only 30% of their total sample, meaning that a large majority of the limbs dissected did not have a discrete VMO. As Smith et al (2009c) stated, in order to be regarded as separate muscles with individual independent contractile actions and roles, there should repeatedly be evidence of structural and functional independence which is not the case with VM. Therefore, it can be seen that controversy still exists as to whether VM can be divided into two distinct parts. Furthermore, even if they do exist there is the consideration as to whether these parts can then be selectively recruited and therefore trained (Smith et al 2009b). This all adds to the controversy as to whether, even when considering VM as a whole entity, it can be selectively recruited and strengthened with respect to VL.

Knee extensor strength generally, and in VM specifically, has been suggested as an important factor in patellar tracking either to ensure stability in the tibiofemoral joint or to alter the patellar position. However, it has been stated that it is impossible to investigate whether selective dysfunction of VM with respect to VL exists in people with PFP using strength measurements alone, as the force contribution of the individual quadriceps muscles cannot be measured in vivo (Giles et al 2015). In their study, Giles et al (2015) used ultrasound to measure the thickness of VM and VL at the point of maximal cross-sectional area. They found that each component of the quadriceps was smaller in people with PFP compared to healthy participants. They also found that VM was not selectively smaller than VL and concluded therefore that this showed that atrophy, which they correlated with muscle weakness, of each quadriceps component muscle is present in people with PFP. However, the VM controversy still rages in the patellofemoral literature with many authors still regarding selective VM weakness with respect to VL to be an important factor in PFP. Furthermore, many researchers still refer to the muscle as VMO despite the recommendations of the PFP consensus statement to refer to it simply as VM (Crossley et al 2016a).

In their systematic review into whether VM(O) can be preferentially activated, Smith et al (2009b) found that neither altering the joint orientation nor adding lower limb contractions led to VM(O) being preferentially recruited with respect to VL. However, they also found that there were important limitations in many of the studies they included such as the under reporting of basic demographic data, for example age, height, history of knee pathologies, diagnosis and duration of symptoms. They also criticised several of the studies they reviewed for not normalising the EMG data and for not reporting the actual levels of the normalised muscle activation. Nevertheless, Smith et al's (2009b) findings have significant implications for the rehabilitation of PFP patients as VM(O) exercises have long been a cornerstone of the interventions used in clinical practice (see section 2.9).

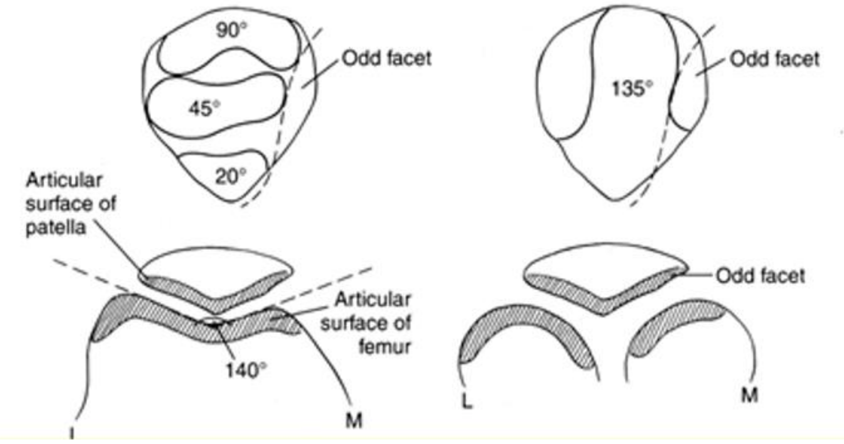
2.5.2 Patellofemoral Joint Biomechanics

The patellofemoral joint is part of the overall knee complex. It must withstand very large compressive forces, and it must also control intricate movements in and around the knee. Many day-to-day functional activities are known to be associated with high force levels and complicated movement patterns. For example, with respect to force magnitude, it has been reported that stair descent generates loading of the patellofemoral joint that is in excess of three and a half times the person's bodyweight (Naserpour et al 2018). When considering the forces acting on the patellofemoral joint, Chen et al (2010) found that the posterior compressive force is the largest component of the overall patellofemoral joint reaction force. The next largest force was in the superior direction due to contraction of the quadriceps, with the laterally directed force being identified as the smallest of the joint forces. Chen et al (2010) postulated that the laterally directed force was due to the larger cross-sectional area of VL with respect to VM. It has been found that patients with patellofemoral pain have higher patellofemoral joint reaction forces and patellofemoral joint stress than their healthy counterparts (Waiteman et al 2018). It has also been proposed that there appears to be a direct correlation between the knee valgus moment and patellofemoral joint contact pressures, with the valgus alignment increasing the lateral forces acting on the patella which in turn increases the lateral pressures within the joint (Waiteman et al 2018).

2.5.3 Patellofemoral Joint Structure

In order to fully understand its function, it is necessary to first provide an overview of the patellofemoral joint structure and how it relates to PFP. Atanda et al (2015) identified five regions of the PF joint that should be considered in what they referred to as anterior knee pain; the central region which includes the patella and the underlying cartilage, the superior region which includes the superior pole of the patella and the quadriceps tendon, the inferior region which includes the inferior pole of the patella, the patellar tendon and fat pads, the medial region which includes the medial retinaculum, plica, pes anserinus insertions, and the lateral region which includes the lateral patellar facet, the lateral retinaculum and the iliotibial band. The implication is that any of these regions can be implicated in PFP. The underside of the patella is known to have different contact areas during different amounts of knee flexion, and these are illustrated in Figure 2.4.

Figure 2.4 Patellofemoral Joint Contact Areas (from www.orthobulletts.com)



The patella has also been described as having poles, with the superior and inferior poles being the accepted terminology. In full knee extension, the patella is not in contact with the femur (Norris 2017). However, as the knee moves from extension through increasing flexion the various areas of the patella come into contact with the femur creating increased contact areas (Besier et al 2005) and causing increasing compression. At approximately 20˚ of flexion, the inferior pole of the patella is the first area to come into contact with the femur, see the top left image in Figure 2.4, and at 30˚ the medial facet then engages with the trochlear (Wheatley et al 2020). With increasing flexion comes increasing lateral translation and lateral tilt of the patella so that at approximately 45˚ of flexion, the middle section of the patella moves into contact with the femur (Wheatley et al 2020). At 90˚ of flexion, the superior pole of the patella is in contact with the femur, and at full flexion the lateral and medial aspects are both in contact with the femur, as is the odd facet (Wheatley et al 2020, Norris 2017). These areas are all shown in Figure 2.4. As the patellar contact area moves from one area to another with increasing flexion, it can be seen that the forces that act on the patella will have a huge influence on how precisely and smoothly these transitions occur. These patellar contact areas take on further significance when it comes to considering patellofemoral joint loading since the joint loading increases if either the joint forces increase or the contact area decreases (McKenzie et al 2010).

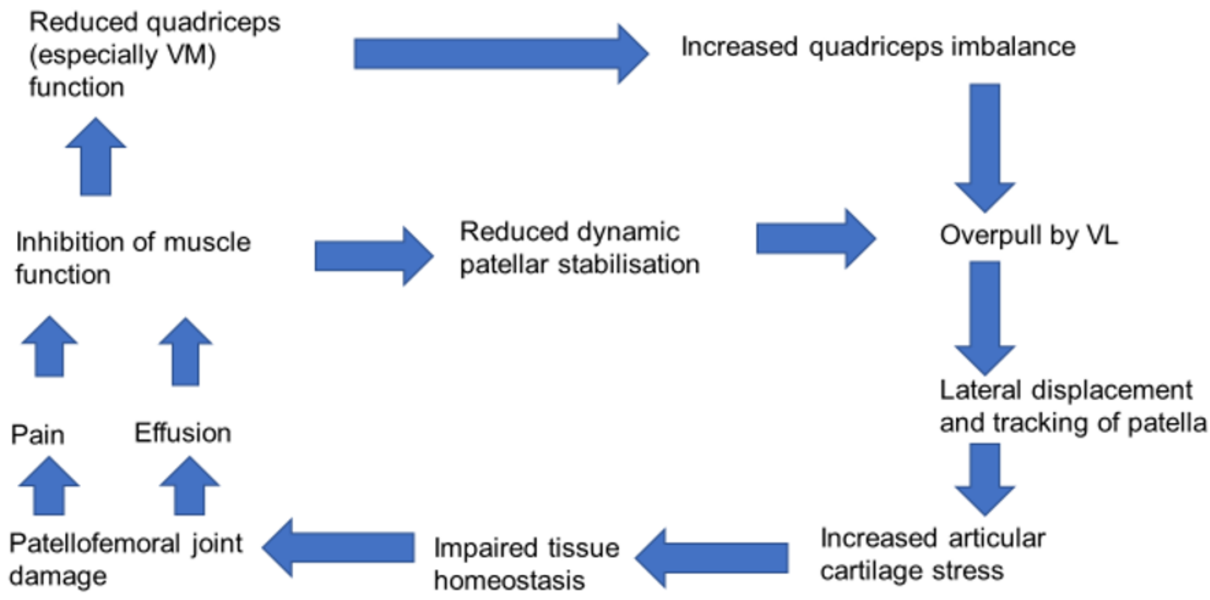
The patella being a sesamoid bone within the knee extensor mechanism means that it is heavily influenced by factors that affect its static position and dynamic tracking. Although much of the literature describes and discusses the patellar component(s), it should be remembered that the femoral component(s) are also relevant, with, for example, a shallow femoral trochlear groove being associated with abnormal patellar alignment and tracking (Powers 2000b). Both the passive and active structures that surround the patella control its' kinematics, which in turn has been acknowledged as influencing patellar contact area and mechanics (Wheatley et al 2020). LaBore and Weiss (2003) identified the patellofemoral joint as a complex region that is susceptible to imbalances, especially of strength. Mal-tracking of the patella is often cited as a cause of PFP, and it can be caused by a dysfunction of both static and dynamic structures. Statically, both the lateral and medial retinaculum attach to the patella and offer collateral support in both extension when the patella is not in contact with the femur and by tightening as the knee flexes (Roy et al 2016). Excessive tightness, usually of the lateral retinaculum, has been cited as a causative factor, with a surgical release of this tissue having previously been a standard treatment option (Dye et al 1999). Iliotibial band tightness has also been identified as a factor causing mal-alignment of the patella, with tightness of this tissue also being associated with lateral patellar tilt and lateral patellar tracking (Rouse 1996). Meanwhile, dynamic structures usually involve the quadriceps, although problems with the iliotibial band, the pes anserine muscle group, the hamstrings, the gluteal muscles and the calf muscles have also been implicated (Tang et al 2001). Whatever the cause, patellar mal-tracking, which is discussed in more detail throughout the rest of this literature review, tends to be most noticeable when weight-bearing. This can indicate that although they may not have structural deformities, dynamic malalignment and muscle activity could be the primary influence on patella position and tracking in people with PFP (Petersen et al 2017). Although they are antagonists, VM and VL work synergistically to control the mediolateral component of patellar movement (Kim and Song 2012). As such, they need to be activated at appropriate times relative to each other and with appropriate magnitudes to achieve normal patellar tracking, and dysfunction of this mechanism is a known factor in the pathogenesis of PFP (Saltychev et al 2018). It has also been stated that in order to load the lower limb appropriately, various physiological mechanisms must occur at the right speed, in the correct plane of motion and with precise timing (Smith 2012). This includes, but is not limited to, the interaction between VM and VL.

2.6 PFP Aetiology

Although the aetiology of PFP is known to be multifactorial (Lankhorst et al 2013, Lack 2013, Cavazzuti et al 2010), there is no consensus as to its origins (Cook et al 2012). However, the abnormal position of the patella and the abnormal tracking of the patella within the femoral trochlear groove are widely accepted as being significant features (Grant et al 2020, Barton et al 2014, Bolgla and Boling 2011a, Akkhurt 2010, Fagan and Delahunt 2008). It is also an accepted hypothesis that poor lower limb alignment, especially into a valgus orientation causes excessive patellofemoral joint stress (Novello et al 2018, Salsich et al 2002). Furthermore, repetition of dynamic knee valgus, during everyday functional tasks such a stair descent has been identified as contributing to cumulative biomechanical stress at the patellofemoral joint and the consequential development of PFP (Scholtes and Salsich 2020).

There is also a theory that excessive rearfoot pronation induces internal rotation of the tibia which in turn induces an internal rotation of the femur. The rotations of the tibia and femur are a strategy to maintain the relative lateral rotation of the tibial plateau with respect to the femoral condyles (Aliberti et al 2010). However, in PFP patients, this rotation can become excessive, and Aliberti et al (2010) hypothesised that increased medial femoral rotation increases the compression between the lateral joint surfaces of the patella and the lateral femoral condyle, which increases patellofemoral joint stress. As VM and VL work antagonistically to control the mediolateral component of patellar movement (Kim and Song 2012), they need to be activated at appropriate relative times and with appropriate magnitudes to achieve normal patellar tracking. Thus, the interplay of the quadriceps muscles becomes significant in PFP since delayed VM onset relative to VL and decreased VM contraction strength with respect to VL leads to abnormal patellar tracking (Briani et al 2015, Leibbrandt and Louw 2015, Mostamand et al 2011, Ryan and Rowe 2006, Cowan et al 2000). More discussion regarding the aetiology of PFP was provided by Grant et al (2020) who identified imbalances around the knee as causing abnormal patellar alignment and tracking, i.e., abnormal patellar position and kinematics, which in turn cause abnormal stresses and loading on the sub-chondral bone due to altered patellofemoral contacts, thus causing pain. Furthermore, Grant et al (2020) then found that there was strong evidence that both lateral patellar shift and patellar mal-tracking had a significant association with the development of PFP. The potential aetiology of PFP, and the cycle of the dysfunction created has been illustrated in Figure 2.5 below.

Figure 2.5 Pathogenesis of PFP (adapted from Tobin and Robinson 2000)



2.7 Factors Influencing Patellofemoral Joint Function

The stability and function of the patellofemoral joint are controlled by local, proximal and distal factors. These factors must work in a co-ordinated fashion if normal patellofemoral joint function is to be achieved. The importance of focussing on the joints proximal and distal to the PF joint, as well as the PF joint itself has been identified by, amongst others, Powers et al (2003).

2.7.1 Local Factors

Locally, the patella functions to provide a link for the convergent quadriceps muscles into the common patella tendon, thereby increasing the quadriceps lever arm and therefore offering a mechanical advantage (McConnell 1986). The VM (obliquus) has been identified as the only medial stabiliser of the patella and any weakness in it allows the patellar to track laterally (Duffell et al 2011, McConnell 1986), with lateral tracking of the patella being acknowledged as a primary determinant of PFP (Fagan and Delahunt 2008). Weakness of VM is pivotal in PFP since its role is crucial for correct patellar alignment with respect to the femur during knee movements. Therefore, the interplay between the quadriceps muscles becomes significant in PFP since delayed VM onset relative to VL and/or decreased VM contraction strength with respect to VL could lead to abnormal patellar tracking (Leibbrandt and Louw 2015, Ryan and Rowe 2006, Cowan et al 2000). However, although Chester et al (2008) found in their systematic review and meta-analysis that there is evidence that VM(O) activation is delayed in people with PFP, they also found that not all studies agreed and thus there is a discrepancy in the research.

With respect to the relative strengths of VM and VL, it has been demonstrated that in asymptomatic populations, the VM to VL ratio is 1:1. However, in symptomatic populations this ratio falls to less than 1:1, which can result in patellar mal-tracking (Nar 2013). Furthermore, it has been found that concentric quadriceps strength is reduced by 30% and eccentric strength by 40% in people with PFP when compared to an asymptomatic population (Guney et al 2016). This has clear implications for the type of exercise prescribed by clinicians and these are addressed later in this literature review.

Imbalances in the forces controlling the patella have been identified as a causative factor for PFP (Duffell et al 2011, Eapen et al 2011, Earl et al 2005). These imbalances, primarily between VL and VM, cause mal-tracking of the patella which in turn causes dysfunction and pain (Fagan and Delahunt 2008), with Hug et al (2015) and Miao et al (2015) both stating that alteration of forces within the quadriceps is an important component in the pathogenesis of PFP. This imbalance may also be associated with reduced overall quadriceps strength

(Toumi et al 2013). Imbalance between VM pulling the patella medially and VL pulling it laterally has long been implicated in PFP (Bhagat and Bhura 2014). This view is supported by Lack et al (2018) who stated that patellar mal-tracking causes increased patellofemoral joint contact pressures and loss of tissue homeostasis, and by Kim et al (2017) who documented that persistent failure of the normal quadriceps activation is commonly seen in patients with PFP. Normally, VL and VM work together to align the patella appropriately with the trochlear groove of the femur as the knee goes through its flexion and extension movements (Miao et al 2015). Imbalance between VL and VM, which is usually due to VM insufficiency, leads to lateral deviation and tracking of the patella (Mostamand et al 2011). This imbalance, which has been consistently reported in the literature, can be a dysfunction of the normal onset timings and/or weakness of VM with respect to VL (Petersen et al 2017 and 2014, Lankhorst et al 2013, Lee and Cho 2013, Spairani et al 2012, Stensdotter et al 2007). The imbalance between VL and VM is also one of the main factors underpinning this thesis, and will therefore be a recurrent theme throughout this literature review.

Changes in the timing of VM onset relative to that of VL is another key factor in the development of PFP (Khaleghi et al 2016). It is a phenomenon that is most commonly investigated using EMG (Hug et al 2015). In asymptomatic populations, it is believed that the onset of VM precedes that of VL. It is theorised that the early onset of VM, which has a relatively small cross-sectional area, helps it to resist the lateral pull of the much larger VL. However, in symptomatic populations this timing may change, with VM onset happening at the same time as or even after VL (Miao et al 2015, Kim and Song 2012, Cowan et al 2001). Fagan and Delahunt (2008) also found that delayed onset and reduced activation of VM with respect to VL leads to abnormal lateral patellar tracking. However, it should be noted that there is little consensus in the literature as to whether VM(O) activity is reduced or delayed (Stensdotter et al 2007).

Increased dynamic knee valgus is also often a key feature of PFP (Capin and Snyder-Mackler 2018, Rabelo and Lucareli 2018). Poor hip muscle function producing a lack of proximal control has been identified as a cause of dynamic knee valgus (Song et al 2015, Selfe et al 2011), and this is often reinforced by internal rotation of the femur and/or tibia which in turn influence local patellar tracking (Petersen et al 2014). Although the exact aetiology of PFP is unclear (Saltychev et al 2018, Petersen et al 2014), factors that have been identified as causative include abnormal patellar tracking. This in turn can be caused by both extrinsic factors such as body anthropometry and increased training, and intrinsic factors such as patellar malalignment, increased Q-angle, increased femoral rotation, increased knee valgus stress, increased tibial rotation, increased subtalar rotation, muscle tightness, weak quadriceps with VM (obliquus) insufficiency, delayed activation of VM, weak hip abductors and lateral rotators, tight lateral retinaculum, tight hamstrings, tight iliotibial band and excessive foot pronation (Saltychev et al 2018, Cardoso et al 2017, Leibbrandt and Louw 2015, Nar 2013, Rouse 1996, McConnell 1986). Meanwhile, Logan et al (2017) identified anatomical, mechanical and training factors and both Nar (2013) and Spairani et al (2012) state that the most common causes of PFP are overuse, trauma and particularly malalignment. Abnormal patellar tracking, whether due to delayed VM onset or muscle imbalance between VM and VL, has been linked to the development of PFP, possibly due to the increased local stresses on the patella which may excite subchondral nociceptors (Hedayatpour and Falla 2013). Grant et al (2020) also identified elevated mechanical stress on the subchondral bone as a potential source of PFP. Whilst they acknowledged that there have been studies that contest the role of patellar mal-tracking in the pathogenesis of PFP, Grant et al (2020) then found strong evidence to support the association between patellar mal-tracking and PFP.

2.7.2 Proximal Factors

Proximally, the dynamic knee valgus just described in section 2.7.1 is influenced heavily by weakness in the hip muscles, specifically the abductors and lateral rotators (Capin and Snyder-Mackler 2018, De Oliveira Silva et al 2016, Bolgla et al 2008). It has been theorised that impaired gluteal muscle function may result in increased hip adduction and internal rotation during functional activities (Barton et al 2013), of which stair descent is one. Drew et al (2017) identified that a tendency towards hip adduction and medial rotation is a significant predictor in the likelihood of developing PFP. Weakness of the hip abductors has been acknowledged as leading to the increased femoral adduction and increased dynamic valgus often seen at the knee of people with PFP (Prins and van der Wurff 2009, Piva et al 2005). It has also been proposed that weakness of the hip external rotators causes increased femoral internal rotation which could in turn lead to increased stress on the lateral femoral condyle and the lateral facet of the patella (Rabelo and Lucareli 2018). Increased internal rotation at the hip has also been identified as contributing to the dynamic knee valgus often seen in patients with PFP (Salsich et al 2012). Lack (2014) also identified reduced hip abduction and external rotation as being frequently seen in people with PFP, whilst Rabelo and Lucareli (2018) state that weakness in the hip abductors and external rotators contributes to increased hip movements in the transverse and frontal planes. Furthermore, abnormal movement of the tibia and of the femur in the transverse and frontal planes has also been identified as impacting upon the PF joint (Powers et al 2003). These movements are important to the functioning of the patellofemoral joint and movements in the coronal and transverse planes, as well as the sagittal plane movements, should be considered when investigating PFP (Selfe et al 2007). Indeed, in a later paper, Selfe et al (2008) found that ranges of movement and knee moments were reduced in the transverse plane as a result of applying a patellofemoral brace which was more effective than using a patellar taping technique. Regardless of the technique used, Selfe et al’s results indicate that patellar movements can be influenced by external factors, a finding which underpins many current PFP interventions.

2.7.3 Distal Factors

Distally, over-pronation has been cited as causing increased internal tibial rotation which then increases the forces acting on the patellofemoral joint (Lack 2014). The over-pronation, caused by excessive rear foot eversion, is due to the joint coupling of the foot/ankle complex (De Oliveira Silva et al 2016). This mal-alignment of the lower leg is now one of the most accepted clinical causes of PFP with the increased internal tibial rotation altering the mechanics of the patellofemoral joint, which over time leads to dysfunction and pain (Cheung et al 2006). It has been theorised that controlling this over-pronation with appropriate foot orthoses can reduce the tibial and femoral rotation which have been identified as kinematic variables associated with increased and abnormal loading of the patellofemoral joint (Barton et al 2011). This is supported by Mølgaard et al (2018) who found that patients who were given targeted knee exercises and orthoses had better outcomes than those who were given targeted knee exercises alone.

Muscle flexibility has also been highlighted as an important factor that needs to be considered. Piva et al (2005) found that people with PFP had significantly less flexibility of the gastrocnemius, soleus, quadriceps and hamstring muscles than those without PFP. This has implications for the prescription of appropriate exercises for individuals with PFP, which is covered later in this literature review in section 2.9.2.

2.8 Patellofemoral Joint Homeostasis

Witvrouw et al (2005) stated that the function of the patellofemoral joint can be characterised by a load/frequency distribution (the envelope of function) that defines a range of painless loading compatible with homeostasis of joint tissues. Dysfunction in the patellofemoral joint is associated with abnormal tissue homeostasis (Dye 2001b). The source of homeostasis loss can be excessive loading of the patellofemoral joint which can be the result of either a single traumatic event or of repetitive abnormal loading. Once the homeostasis is disrupted, the patellofemoral joint and associated structures may no longer tolerate normal levels of loading during routine activities (Willy and Meira 2016), and thus normal activities become painful. This can be the case even in the absence of any identifiable structural abnormality which is very common in people with PFP (Dye et al 1999). Dye et al (1999) state that tissue homeostasis is actually more important than any structural characteristics of the knee, or more specifically of the patellofemoral joint. Restoration of homeostasis can be achieved by placing a load restriction within the patient’s reduced envelope of function, i.e., the loads that the patellofemoral joint is subjected to need to be reduced, so that further tissue damage and irritation of the associated structures is negated and the normal tissue repair mechanisms can then proceed (Dye et al 1999). Advocating a conservative approach to the management of PFP, Dye et al (1999) identified three factors that need to be considered in any treatment protocol: firstly, the pathokinematics must be addressed; secondly, anti-inflammatories should be prescribed; and finally, there should be rehabilitation tailored to each individual. This rehabilitation should be pain-free, i.e., the patient should only undertake activities that allow them to remain within their envelope of function. This fits with the ethos of McConnell’s patellar taping programme where the goal is to reduce pain by at least 50% by taping the patellar correctly to address its identified malalignment (tilt, glide and/or rotation) which then allows the patient to complete their rehabilitation in a pain-free manner or with their pain significantly reduced. Rehabilitating in a pain-free or reduced pain state facilitates the efficacy of that rehabilitation since pain has a strong inhibitory effect on muscle function (McConnell 1986). Once the pain is resolved, the patient can gradually and incrementally increase patellofemoral loading. Restricting loading to within the envelope of function allows normal tissue healing processes to occur and homeostasis to be restored (Witvrouw et al 2005).

However, there is a counter argument. It may be that emphasizing the need to work in a pain-free way can cause or increase pain related fear avoidance. Smith et al (2019a) identified that the fear of the pain can actually amplify the patient's experience of pain. Patients often report fear of pain, believing that it is indicative of doing more damage. However, it has been reported that challenging this belief and encouraging patients to think differently about pain and tissue damage by prescribing painful exercises may confer some benefits over working solely in a pain-free manner (Smith et al 2019a). This view was also reported by Smith et al (2017b) who found in their systematic review that there was evidence of a short-term benefit from exercising into pain. They proposed that addressing factors such as fear avoidance, kinesiophobia and catastrophising can reduce central nervous system (CNS) sensitivity, thereby reducing pain output. Furthermore, Smith et al (2017b) stated that experiencing pain during therapeutic exercises may not be a barrier to successful treatment outcomes for chronic musculoskeletal pain, of which PFP is an example.

2.9 Management of Patellofemoral Pain

2.9.1 Introduction

PFP can arise from any PF joint structure that is innervated (Powers et al 2012), which, as there are many, makes it a complex condition to treat. Currently, conservative management with a multi-modal approach is most commonly recommended to address PFP (Leibbrandt and Louw 2018, Drew et al 2017, Logan et al 2017), with physical therapy interventions having been shown to be superior to both sham interventions (Selhorst et al 2015) and to no interventions

(Moyano et al 2012). The current gold standard for the conservative treatment of PFP is therefore multi-modal and may involve quadriceps strengthening and stretching, patellar taping, hamstring stretching, hip abductor and external rotator strengthening, bracing and the provision of foot orthoses (Lack et al 2018, Barton et al 2014). It has been said that treatment should aim to re-establish homeostasis through a temporary reduction in patellofemoral loading following by an incremental restoration of the envelope of function to its baseline level or even higher (Willy and Meira 2016, Witvrouw et al 2005). The multi-factorial nature of PFP has been identified as meaning that better treatment selection is needed in order to increase intervention efficacy and improve clinical outcomes (Lack et al 2014). Interventions such as taping and bracing have been shown to be effective as well as cheap and associated with minimal adverse effects (Warden et al 2008). Another advantage of these techniques is that they can be taught to patients to increase their ability to self-manage their treatment which is an important rehabilitation outcome. However, it is believed that patellofemoral mobilisations, which have been advocated as a treatment modality for PFP, should not be included as they are unlikely to either affect or improve outcomes (Lack et al 2018).

One of the treatment techniques used most frequently involves patellar taping in a variety of forms combined with quadriceps stretching and quadriceps strengthening, especially of the VM(O) (Mason et al 2011, Aminaka and Gribble 2008). Unsurprisingly then, much of the work on PFP treatment describes protocols involving these modalities (Paoloni et al 2012, Irish et al 2010, Smith et al 2009b). However, controversy still exists as to the efficacy of these modalities. This is particularly the case when considering if the VM can be recruited preferentially with respect to the VL during exercises or functional activities. Smith et al (2009b), and Powers et al (1996) have all argued that it cannot be, whilst Osorio et al (2013), MacGregor et al (2005), Willis et al (2005) and Parsons and Gilleard (1999) are amongst those who have argued that it can be. It would seem from the more recent literature, that current thinking is that VM cannot be preferentially recruited with respect to VL, although this is still the subject of some debate. This then creates the problem of how to address the VL to VM imbalance that is still recognized as a feature of PFP. It would seem to be reasonable to believe that if VM cannot be preferentially recruited with respect to VL, then regular quadriceps exercises and functional activities will merely strengthen the two muscles together and will not address the imbalance between them. Therefore, it would also seem logical that in order to address the imbalance, a way of inhibiting the stronger more dominant muscle (VL) should be explored.

When considering the management of PFP, it is always pertinent to consider proximal and distal factors as well as local factors. Proximally, it is usual to target the weak abductors and lateral rotators while distal interventions are primarily aimed at controlling over-pronation, and almost invariably involve the prescription of foot orthotics. However, it has been reported that 'off the shelf' prefabricated shoe insoles are as effective as bespoke foot orthotics (Lack et al 2018). It has also been proposed that distal interventions may not be as important as proximally targeted ones, and that they may only be clinically relevant to a small proportion of PFP patients (De Oliveira Silva et al 2016).

A further way of assessing PFP was proposed by Mbuli et al in (2018) who advocated using the concept of assessing pain, alignment, strength and stability (PASS) in order to identify individual treatment needs and thereby employ a patient-centred approach to assessing and treating PFP. They discuss each of these factors in turn, related to PFP, and identify strategies to address each factor. For example, assessments of strength are important as weakness, especially within the quadriceps, are known to be a key feature of PFP. However, if it is not considered along with the other factors, over-strengthening could occur which could result in muscle imbalance and/or overloading of the joint. Therefore, strengthening work must be considered in view of the other factors and individual patient needs in order to avoid these issues which could negatively impact on an individual patient's rehabilitation.

2.9.2 Exercise Therapy

Since PFP is a multi-faceted pathology, it requires a tailored, individualised approach to each patient to address their specific impairments, dysfunctions and functional restrictions (Capin and Snyder-Mackler 2018, Lack 2013). This was also advocated as a treatment approach over 20 years ago by Dye et al (1999), with pain being the singular most important guide to the treatment process (Kaya et al 2012). In 2012, Papadopoulos et al found that the most common treatment methods utilised by physiotherapists treating people with PFP were muscle strengthening, patient education, closed kinetic chain exercises, stretching and taping. By 2014, Lack et al had identified the gold-standard multi-modal approach to be vasti muscle retraining, gluteal strengthening, stretches, patellar mobilisations and patellar taping. Smith et al (2017a) in their survey of 99 physiotherapists then found that the five most common management strategies used for PFP treatment were closed kinetic chain exercises, advice and education, open kinetic chain exercises, taping and stretches. However, these studies only provide an overview since all these techniques are non-specific. For example, vasti muscle retraining can be done with open and/or closed kinetic chain exercises.

It has been found that closed kinetic chain exercises are more functional and more effective than open kinetic chain exercises (Tang et al 2001), and are the best way to strengthen the quadriceps while having manageable levels of patellofemoral joint loading (Willy and Meira 2016, Dragoo et al 2012). However, it would appear from the Smith et al (2017a) study described above that open kinetic chain exercise are still widely used. This is despite Irish et al (2010) finding that closed kinetic chain exercises produced significantly greater VM(O) activation than open kinetic chain exercises. Furthermore, Irish et al (2010) also found that open kinetic chain exercises produced significantly greater activation of VL with respect to VM. The implication of this is obviously that, potentially, open kinetic chain exercises can actually increase the imbalance within the quadriceps and therefore will propagate the symptoms associated with this imbalance. Also, there is no ideal exercise prescription in terms of dosage, i.e., the number of repetitions and sets to complete and how frequently these are to be performed (Smith et al 2017a, Callaghan in Selfe et al 2017 p82).

In her defining paper of 1986, McConnell strongly advocated the training of VMO (now known as VM) in isolation to VL by using weight-bearing exercises and activities which would preferably involve eccentric muscle work. The eccentric muscle work could be squats, lunges or step-down activities, all of which are functional activities that involve loading the PF joint. Although eccentric loading is therefore a key functional component of a comprehensive exercise programme for PFP, it has been argued that it should be done within the person's envelope of function (Dye et al 1999), or when there has been at least a 50% reduction of their pain by the application of appropriate taping (McConnell 1986).

The view that training VM is important was also acknowledged by Powers (2000a) who wrote that improving VM(O) force is seen by some as essential in overcoming the lateral pull of VL. However, Smith et al (2009b) and Spairani et al (2012) state that VM(O) cannot be preferentially enhanced with respect to VL, which is despite Hug et al (2015) stating that treatments should aim to restore the force balance between VL and VM by specifically enhancing VM activation. However, the statements that VM cannot be preferentially recruited reflects modern thinking on quadriceps rehabilitation. Even McConnell who first proposed selective strengthening of VM as a management strategy for PFP agreed that it was yet to be established that muscle imbalance and timing of muscle recruitment can be changed with treatment (McConnell 2000). Conversely, evidence for selectively increasing VM activity came from MacGregor et al (2005) who found that patellar taping increased VM(O) activity via cutaneous stimulation of the skin over the patella. However, this was a small study (n=8) and its clinical applicability is unknown. Dysfunction of the correct timing of firing between VM and VL is a critical factor in the malalignment and tracking of the patella, and until it is restored, the malalignment and mal-tracking, and therefore the PFP, will be ongoing (Witvrouw et al 2005). Therefore, another way of addressing the imbalance between VM and VL needs to be found.

The two most recent consensus statements from the Patellofemoral Pain Research Retreat (Collins et al 2018 and Crossley et al 2016a and b) state that exercise therapy is good for the medium-term and long-term management of PFP. Exercises discussed include those involving both the hip and the knee which are cited as being better than exercises involving the knee alone. This was also the finding from the study of Lack et al (2018) and the meta-analysis by Cardoso et al (2017). Indeed, it has been proposed that proximally targeted exercises may even be more beneficial than locally directed exercises and have fewer adverse effects (Petersen et al 2017, Alba-Martin et al 2015). This view is supported by De Oliveira Silva et al (2016) who found that most PFP patients require proximally targeted interventions. Further support for this strategy is provided by Crossley and Collins (2019) who stated that exercises focussing on the hip with or without quadriceps exercises are better than quadriceps exercises alone. However, although reduced knee extensor strength has been highlighted as a feature of PFP (Witvrouw et al 2005), strength training alone is not sufficient to gain changes in the mechanics of the PF joint, with task-specific training also being necessary (Capin and Snyder-Mackler 2018). Although there is no ideal dosage with which to prescribe therapeutic exercises, in general it is believed that the more exercise a patient does, the better their long-term pain and functional improvement will be (Smith et al 2018a). However, although exercise is acknowledged to be the foundation of the management of many musculoskeletal conditions, and of PFP in particular, there is little if any consensus as to what the optimal type or dose of exercise that should be prescribed is (Smith et al 2019a), and although beyond the scope of this thesis, this is an area worthy of further research.

2.10 Therapeutic Taping

2.10.1 Introduction

Therapeutic taping is an umbrella term that encompasses all taping techniques. It has been developed to help to relieve pain and improve functional performance (MacDonald 2004 p4), and is a widely used treatment modality for physiotherapists working with people with musculoskeletal disorders (Chen et al 2018a, McDonald 2004 p15, Alexander et al 2003). These disorders include PFP (McConnell 1986) which is the focus of this thesis, but uses for other joints and tissues are also advocated which include, for example, shoulder impingement and other shoulder pathologies (Smith et al 2009a). The underlying mechanisms by which taping works are poorly understood (Shaheen et al 2015, Aminaka and Gribble 2005), but it is accepted as an effective treatment modality, especially for reducing pain (Kim and Kim 2016). However, it should be noted that it is also accepted that taping alone is not enough to address the complexities of musculoskeletal disorders and that it should be used as an adjunct to other treatment modalities such as exercise therapy (Capin and Snyder-Mackler 2018, Norris 2017, Logan et al 2017, Lack 2014, Petersen et al 2014).

Therapeutic taping has many purported clinical effects described in the literature including; pain relief (Ng and Cheng 2002) which has been identified as the most important effect (McConnell in Selfe et al 2017 p93), compression of a recent injury (MacDonald 2004 p3), protection of structures from further injury (MacDonald 2004 p4), improvements in blood and lymph flow (DeJesus et al 2017), improved joint alignment (Kim and Kim 2016), improved alignment of fascial tissues (Aytar et al 2011), limitation of excessive joint movement (Cupler et al 2020) and increased proprioception (Ho et al 2017). Specific patellofemoral taping has been shown to reduce patellofemoral joint reaction forces (McConnell in Selfe et al 2017 p93) with other techniques including the unloading of irritable structures such as; neural tissue (Alexander et al 2008), muscle tissue (Hug et al 2014), and fat pads (McConnell in MacDonald 2004 p16). Therapeutic taping has been reported as being relatively cheap, quick and simple to use clinically. It has also been identified as providing external support, motion control, proprioceptive input, kinesthetic reminders and/or stress redistribution (Song et al 2015). With respect to PFP, taping techniques can be used to attempt to correct patellar mal-alignment in the frontal plane i.e., to mitigate the lateral displacement of the patella (Ho et al 2017). In their meta-analyses, Chang et al found that elastic K-tape and McConnell tape have both been found to significantly improve muscle activity, motor function and quality of life (Chang et al 2015).

Therapeutic taping is also advocated as a method of addressing muscular imbalance issues by facilitation of underactive muscles or inhibition of overactive muscles (Guner et al 2015, McConnell in MacDonald 2004 p26, Smith et al 2009a, Alexander et al 2003). Although patellar taping has been widely researched, using muscle facilitation or muscle inhibition taping is an as yet under investigated area of research in PFP. With regard to inhibition taping, only a few studies have been found that address this (McCarthy Persson et al 2009 and 2007, Janwantanakul and Gaogasigam 2004, Tobin and Robinson 2000).

Broadly speaking, there are two acknowledged approaches to therapeutic taping (Ouyang et al 2017): -

1) Using rigid non-elastic tape as pioneered by McConnell (McConnell 1986). This has been described as a biomechanical approach (McNeill and Pederson 2016).

2) Using elastic tape, or kinesio-tape, as pioneered by Kase (De Jesus et al 2017, Guner et al 2015), which has been described as a neurophysiological approach (McNeill and Pederson 2016).

The mechanisms by which taping has its clinical effects are poorly understood (McConnell 2000), and several different theories have been proposed. Leibbrandt and Louw (2015) identified neuromuscular, biomechanical, proprioceptive and placebo mechanisms, whilst Shaheen et al (2015) suggest that changes in muscle force, neuromuscular control and proprioception may be involved. Osorio et al (2013) made a direct comparison between elastic and non-elastic taping stating that a neurosensory mechanism is associated with McConnell (non-elastic) taping whereas elastic (kinesio-tape) works by providing the central nervous system with increased afferent input via the stimulation of mechanoreceptors. Choi and Lee (2018) state that kinesio-tape works by stimulating afferent nerves and mechanoreceptors to enhance proprioception. Meanwhile, Houglam (2004) identified three potential mechanisms to explain the effects of taping; biomechanical factors such as changing patellar position, neurological factors such as altered neural input and muscle response, and psychological factors. It should also be noted that any biomechanical effects of taping may be short-lived and only occur whilst the tape is in situ (Ouyang et al 2017).

2.10.2 Patellar Taping

With respect to PFP, specific patellar taping dominates the literature and therefore is worthy of mention here. This is the case for both rigid and elastic tapes with Ho et al (2017) identifying that both kinesio-tape and McConnell taping for the patella aim to correct frontal plane malalignment. Selfe et al (2007) stated that patellar taping is now so popular that it can be considered to be part of standard clinical practice. Lack (2014) and Barton et al (2014) found that there was good evidence to support its use in managing PFP, with Chen et al (2018a) reporting that systematic reviews confirm the effectiveness of patellar taping. McNeill and Pederson (2016) also support patellar taping as a treatment for PFP, stating that its efficacy is not under debate. This is reinforced by Campolo et al

(2013) who found that both kinesio-tape and rigid tape (McConnell tape) reduced the pain experienced when their subjects ascended stairs.

When considering patellar taping, there are four components that can be addressed, not all of which need to be applied to every patient. These components are medial glide, medial tilt, anterior tilt, and rotation, with McConnell advocating addressing the worst component first (McConnell 1986). Since these techniques are all different, it makes it difficult to compare studies where the umbrella term of patellar taping, or McConnell taping (Chang et al 2015) or even therapeutic taping (Tamaria et al 2016) is used. Nearly all the literature on taping for PFP have focused on these components, sometimes with the use of a neutral or placebo control tape condition. Furthermore, there is good evidence that taping to correct these components is effective at reducing the patient's pain (Lack et al 2018, Petersen et al 2014, Mostamand et al 2011). However, even with appropriate therapeutic exercises, this may not be enough to address the acknowledged imbalance within the quadriceps muscle group and may go some way to explaining the poor longer-term outcomes that are common with PFP.

2.10.3 Taping Techniques

A further complication with therapeutic taping is the lack of standardisation of how much tape to use, and how much tension to use when applying it. McConnell advises that only as much tape with as much tension as is needed to reduce the patient's pain by at least 50% should be used (McConnell 1986 and 2004). This pain reduction is highly relevant since it is important for people with PFP to train in a pain free manner (Dye et al 1999), as pain is known to have a strong inhibitory effect on muscular performance (Lack 2014, McConnell 1986). Therefore, tape is applied to allow pain free, or reduced pain, performance of the prescribed exercises and/or the patient's aggravating activity (Leibbrandt and Louw 2015). Callaghan in Selfe et al (2017 p75) states that a key aspect of any physiotherapist's treatment for PFP is a patient's self-management strategy which can only be successful if the patient adheres to it. This requires good patient education, which has been identified as a vital component of PFP treatment (Lack et al 2018). Callaghan also stated that it is likely that 50-70% of patients are either non-adherent or only partially adherent to their home exercise programmes. Therefore, it is necessary to find ways that are both pain free and functionally relevant to the patient in order to improve compliance. With exercise interventions, it has been stated that the more the patient does, the better their pain and long-term functional improvement will be (Smith et al 2017b). However, this broad statement does not consider the complexities of the condition or take account of the potential for over-use or overloading tissues that may have been influential in the development of PFP in the first place. Therefore, finding ways that enable people with PFP to exercise in a pain-free way is important as patients are more likely to comply if something does not hurt, and if it makes sense to them. Callaghan (in Selfe et al 2017 p80) stated that there is a general consensus in clinical practice that people with PFP should be rehabilitated in their pain free zone. This ties in nicely with the approach advocated by both Dye et al (1999) and McConnell (1986).

McConnell has stated previously that a symptom/pain reduction of at least 50% is required to allow the patient to participate fully in their rehabilitation, which is in agreement with Mostamand et al (2011). Both Lack (2014) and Barton et al (2014) hypothesized that this level of pain reduction could help to reduce the muscle inhibition that accompanies the pain in PFP and thereby improve the patient's ability, and willingness (Callaghan in Selfe et al 2017), to participate in their rehabilitation and therefore improve their recovery. In their 2006 study, Cowan et al found that although therapeutic taping altered both the patient's pain and the onset timings of the vasti muscles, it had no significant effect on the magnitude of muscle contraction. Therefore, concurrent modalities aimed at re-strengthening the quadriceps are also necessary.

2.10.4 Mechanisms and Evaluation of Taping Techniques

As with many aspects of PFP, the mechanism by which patellar taping has its effect(s) is unclear. Fagan and Delahunt (2008) proposed that taping the patella reduces the neural inhibition of the quadriceps due to proprioceptive feedback to A-β afferents, which reduces pain and increases the force with which the quadriceps can be contracted. This view is supported by Willy and Meira (2016) who stated that quadriceps strengthening can be enhanced by taping the patella. However, it may be that the way in which the component quadriceps muscles are recruited is more important than the activity of the whole group (Barton et al 2014). Other hypotheses include improved proprioception with patellar taping and increased cutaneous stimulation, which are associated with an increased ability to generate appropriate muscle forces (Aminaka and Gribble 2005).

The generation of appropriate muscle force(s) is a key component of PFP management strategies, and there are different ways of manipulating this. Alexander et al (2003) stated that to facilitate a muscle, the tape should be applied along the underlying muscle fibres whereas taping across a muscle will inhibit it. However, they also state that the mechanisms by which these effects occur are “inconclusive”. Meanwhile, Serrao et al (2016) assert that applying kinesio-tape from the muscle origin to the insertion produces a concentric pull which facilitates the underlying muscle whereas reversing this and applying the tape from insertion to origin produces an eccentric pull which inhibits the muscle. This is a somewhat controversial statement as it could be argued that any tension generated in the tape will have the same effect irrespective of whether it is applied origin to insertion or vice versa. It has also been reported that when using kinesio-tape, a 50-75% stretch is needed for muscle facilitation and 15-25% is required for muscle inhibition (Mohammadi et al 2014).

It is believed that rigid tape may provide greater force than elastic tape (Chen et al 2018a). The studies included in this thesis used tapes as advocated by McConnell, namely the hypoallergenic underlay Fixomull® and the rigid, high-tensile zinc oxide tape Leukotape®. When using rigid non-elastic tape, the techniques should involve the use of a hypoallergenic underlay applied without tension to protect the skin followed by the rigid tape, which is then applied with tension to affect the underlying structures and soft tissues (Alexander et al 2008). When applying these tape layers, it is recommended that each successive strip should overlap its predecessor by half the tape width to prevent slippage and gapping (MacDonald 2004 p6).

The recommended duration that the tape can be left in situ varies. MacDonald (2004) states that rigid tape should be left on for no more than 24 hours unless a hypoallergenic tape is used, with McNeill and Pedersen (2016) identifying that the manufacturers of Fixomull® and Leukotape® recommend that the tape should be removed after 18 hours. This is in part due to the fatigue of the rigid tape and the tendency for it to creep back against the pull/stress it was applied with, which potentially causes it to lose its effect (McNeill and Pederson 2016). It is also to protect the skin, giving it a chance to recover from the tape before the tape is reapplied the following day.

2.10.5 Tape Removal and Skin Care

When removing tape, care should be taken not to traumatise the skin and the tape should be gently peeled back on itself while gently pushing the skin away from the tape (MacDonald 2004 p7). This is important as removing the tape too quickly can cause friction rub and damage to the skin (McConnell in Selfe et al 2017 p97). Other causes of tissue damaging friction rub include applying the tape too firmly and applying the tape with uneven tension (McConnell in Selfe et al 2017 p97). McConnell also identified that along with friction rub, allergic reactions to the tape are the only other documented problems caused by taping as a therapeutic modality. Once the tape has been removed, it is important to rehydrate/moisturise the skin to counter any unwanted effects of the tape and to prepare the skin for repeated application of the tape.

2.11 VL Inhibition: A Systematic Review

2.11.1 Introduction

VM's insufficiency to pull against a stronger VL is a generally accepted phenomenon in patients with PFP, with the consequential abnormal lateral tracking of the patella within the femoral trochlear groove being widely agreed to be a significant aetiological feature of PFP (Grant et al 2020, Barton et al 2014, Bolgla and Boling 2011a, Akkhurt 2010, Fagan and Delahunt 2008). The mediolateral component of patellar movement is controlled dynamically by the interplay between VL and VM (Kim and Song 2012), and hence these muscles need to be activated at appropriate and coordinated relative times and with appropriate magnitudes to achieve normal patellar tracking. Any disruption to this interplay will lead to muscular imbalance which in turn may lead to abnormal patellar tracking and consequential pain (Briani et al 2015, Leibbrandt and Louw 2015, Mostamand et al 2011, Ryan and Rowe 2006, Cowan et al 2000). This pathogenesis pathway, which is illustrated in Figure 2.5, was reinforced by Grant et al (2020) who found that there was strong evidence that both lateral patellar shift and lateral patellar mal-tracking had a significant association with the development of PFP. Thus, there is an important need to redress any imbalance between VL and VM. Historically, this has been done by attempting to preferentially recruit VM with respect to VL through therapeutic exercises with no clear consensus on how to achieve the preferential recruitment of VM or even if it can be achieved at all (Singer et al 2015, Cavazutti et al 2010, Bennell et al 2006). Given this controversy, with Singer et al (2015) going as far as to say that it is physiologically impossible to isolate VM from VL and therefore impossible to preferentially recruit it, the possibility of inhibiting VL in order to redress the imbalance between these two muscles becomes an important concept to investigate.

Among the studies that have investigated inhibiting VL, Singer et al (2015) conducted a study involving patients with PFP and found that botulinum toxin injections into VL significantly reduced its activity and provided a window of opportunity to address the imbalance within, and dysfunction of, the quadriceps with appropriate therapeutic exercises. Interestingly though, they do not recommend this as a first line treatment. Rather they state that it could be used when other less invasive treatments have failed to produce the desired result and where there is an identifiable imbalance between VL and VM. In this context, taping would be considered to be a less invasive treatment. Investigations into taping to inhibit VL involve applying tape to the skin over the VL muscles of participants in an attempt to disrupt the muscle’s normal function. The relative merits of these VL taping studies will be addressed later in the discussion section of this systematic review.

Although this thesis is concerned with PFP, and the potential to inhibit VL with tape, the possibility of inhibiting muscles with tape as a concept has also been investigated with other muscles. For example, a McConnell technique has been used successfully to inhibit the upper fibres of trapezius in subjects with subacromial impingement (Alexander et al 2003), and there have also been studies that have found that elastic kinesio tape can also be used to inhibit muscle activity (Guner et al 2015, Smith et al 2009a, Alexander et al 2003). Although it has been found that it is possible to inhibit muscles with the judicious application of therapeutic tape, the specific effect of inhibitory taping on VL is not well understood. Therefore, the following systematic review was conducted to examine the effectiveness of inhibitory taping on VL muscle function.

This systematic review has been registered with PROSPERO and the registration number is CRD 4202314032.

2.11.2 Methodology

2.11.2.1 Eligibility Criteria

The broad eligibility criteria were that any full text research paper published in English which evaluated the effectiveness of inhibition taping in people aged between 18 and 40 with patellofemoral pain would be considered. Therefore, studies from any setting would also be considered. Studies were excluded if they included participants with other lower limb pathologies either co-morbid or in isolation, participants selected from specific disease populations for example diabetes, osteoarthritis or rheumatoid arthritis, studies using animals or cadavers, and finally, systematic reviews and meta-analyses were also excluded.

2.11.2.2 Search Strategy

The final search was conducted on 19.02.2022 using several electronic databases including AMED, CINAHL, the Cochrane database, EMBASE, Medline, Ovid, PubMed, SPORTDiscus and Web of Science. The search terms used were "patellofemoral pain OR PFP OR patellofemoral pain syndrome OR PFPS OR anterior knee pain OR AKP OR chondromalacia patella OR retropatellar pain AND tape OR taping", with the search domains being the title and abstract. The search terms were deliberately broad initially so as to minimise the risk of missing any relevant papers. However, although it could lead to publication bias, no attempt was made to find unpublished research as this was deemed to be impractical.

All the results were exported into EndNote X9.3.3 where any duplications were identified and removed. Visual inspection of the remaining titles was undertaken to identify any further duplications. Two reviewers (ST and GJC) independently reviewed all the remaining titles and abstracts from the search results. If agreement regarding the inclusion could not be reached, a third reviewer (JR) provided further insight. Where it was unclear from the title/abstract whether a paper was about PFP and/or inhibitory taping, full manuscripts were sought and assessed. Where full manuscripts could not be found, contact was made with the corresponding author to request a copy of their paper. The process followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines, and the quantification of the search strategy steps can be seen in Figure 2.6.

2.11.2.3 Data Extraction

Data were extracted independently by two reviewers (ST and GJC) onto a predefined bespoke data extraction form. Data extracted from all eligible studies included sample size and characteristics, study design, taping technique description, which muscles were targeted, whether rigid or elastic tape was used, what the experimental task was, how inhibition was measured and whether it was achieved, any other outcomes measured and finally any relevant methodological limitations. Any disagreement in data extraction between the two reviewers were resolved through discussion to gain consensus.

2.11.2.4 Critical Appraisal

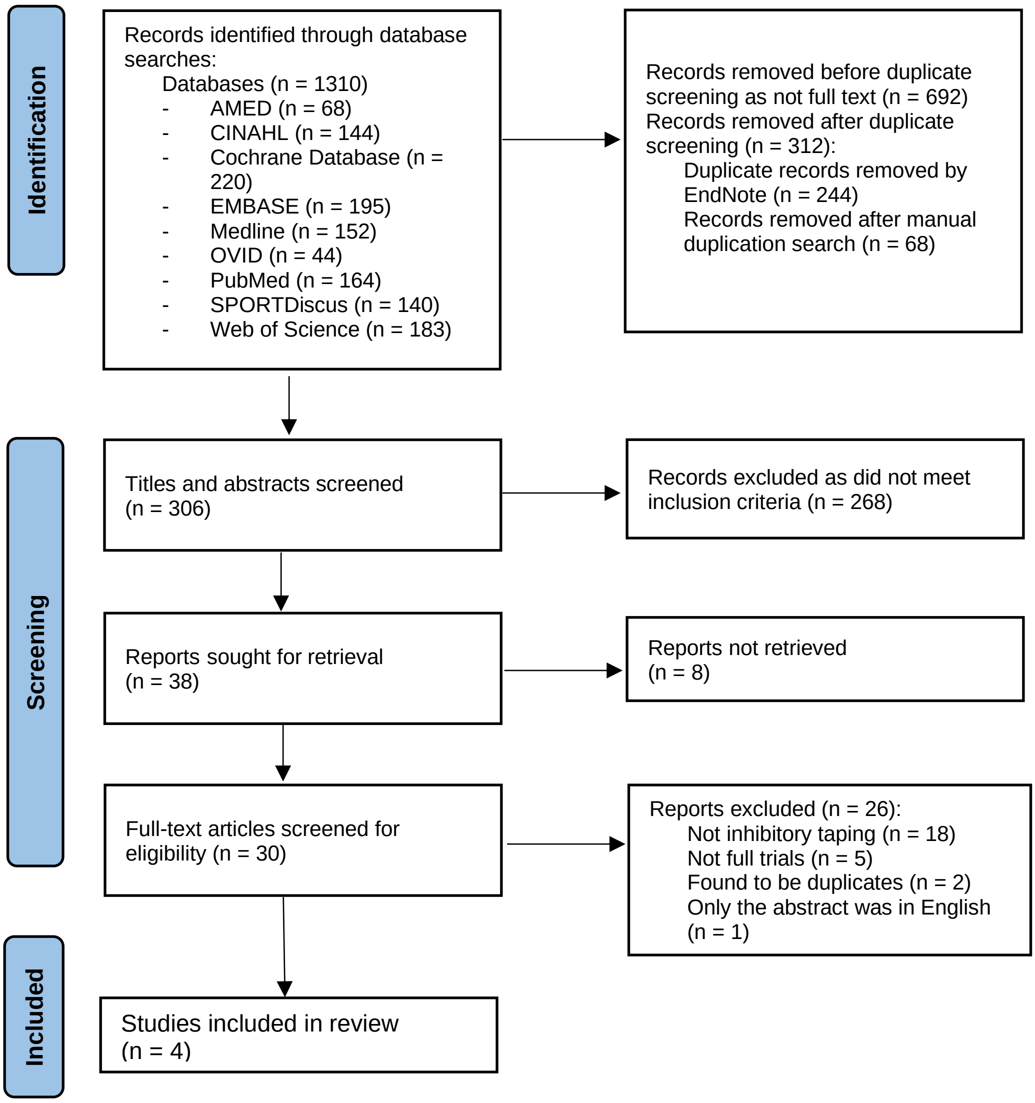
Eligible studies were critically appraised independently by two reviewers (ST and GJC). The appraisal tool was developed in part from the Critical Appraisal Skills Programme (CASP) 2020 and in part from previously used appraisal tools (Smith et al 2009). A total of fifteen questions were included covering validity of the results, clarity of the results and value of the results. Each question was answered with ‘yes’, ‘no’ or ‘unsure’. Any disagreements were resolved through discussion with no need to introduce a third party to help with this process, with the ‘unsure’ items also being discussed with the third reviewer (JR). The critical appraisal results are presented in Table 2.3., which can be found in the results section of this systematic review.

2.11.3 Results

2.11.3.1 Search Results

Figure 2.6 summarises the search results. It can be seen that the initial search identified an unfiltered cache of 1310 studies, 692 of which were immediately discarded as the full text was not available. Through automatic and manual screening processes, 312 were then found to be duplicates leaving 306 abstracts to be screened. This screening led to a further 268 studies being removed, mainly because they involved patellar taping techniques rather than VL inhibition taping techniques. This left 38 full text articles to be reviewed. However, despite strategies including contacting the authors, eight full texts were unable to be found. Of the remaining 30 studies, only four studies met all the inclusion criteria, and these are described in Table 2.3.

Figure 2.6 PRISMA Flow Chart Summarising the Search Strategy Results



2.11.3.2 Characteristics of Included Studies

Table 2.2 presents the characteristics of the studies included in this review. Of the four studies, three were cross sectional studies and one was a single blind randomized controlled trial (RCT). Of the four studies, only one, Sinaei et al (2021) studied symptomatic PFP participants. In total 90 participants were recruited across the four studies, of which 80 were female. 32 participants were symptomatic for PFP with the remainder being asymptomatic. Three studies reported participant demographics (Janwantanakul and Gaogasigam 2005, McCarthy Persson et al 2007, Sinaei et al 2021) with the reported age ranging between 18 and 34 years with a mean age of 24.9 years. Two studies (McCarthy Persson et al 2007 and Sinaei et al 2021) also reported height (mean 163.19cm) and weight (mean 60.35kg).

In terms of the taping techniques employed in these studies, both McCarthy Persson et al (2007) and Tobin and Robinson (2000) used a hypoallergenic underlay before applying a rigid zinc oxide tape. The described techniques for the inhibition tape were virtually identical and mirrored the technique as explained by McConnell in her handbook (McConnell 1995). Briefly, the underlay was applied without tension and the rigid zinc oxide tape was applied on top of the underlay on the anterior thigh, and was then pulled firmly in a posterolateral direction while simultaneously collecting the lateral thigh tissues and pulling them anteriorly with the other hand. The tape was then attached to the underlay on the posterolateral thigh. For a full description of the taping technique used, please refer to section 3.4 Taping Conditions. However only Tobin and Robinson (2000) also had a no tension control condition. They were also the only one of these two studies to measure VL activity, which they did using sEMG, and they found that the active tape condition induced inhibition in VL. By contrast, both Janwantanakul and Gaogasigam (2005) and Sinaei et al (2021) used an elastic tape in their studies. Janwantanakul and Gaogasigam (2005) attempted to both inhibit VL by applying the tape laterally and posteriorly across VL, and to facilitate VL by applying the tape superiorly along the muscle. However, they did not report how much tension was used when applying the tape. Sinaei et al (2021) attempted to inhibit VL by applying a "Y-shaped strip of kinesio tape at 15% of its available tension from the insertion to the origin of the muscle". Although they both used an elastic tape, the techniques used in the studies by Janwantanakul and Gaogasigam (2005) and

Sinaei et al (2021) were very different, which may go some way to explaining their differing results, as Sinaei et al (2021) found that their technique did inhibit VL as measured by sEMG whereas Janwantanakul and Gaogasigam (2005) found no such effect. It is also worth noting that these two studies had different experimental tasks, with Janwantanakul and Gaogasigam favouring stair descent while Sinaei at al (2021) used the modified star excursion balance test.

Table 2.2 Study Characteristics

Study	Sample Size	Gender	Symptoms	Study Design	Taping Technique
Janwantanakul and Gaogasigam 2005	30	All female	Asymptomatic	Cross-sectional	Inhibition and facilitation
McCarthy Persson et al 2007	10	7 female 3 male	Asymptomatic	Cross-sectional	Inhibition (McConnell)
Sinaei et al 2021	32	All female	Symptomatic	Single blind RCT	Inhibition and facilitation (Kase)
Tobin and Robinson 2000	18	11 female 7 male	Asymptomatic	Cross-sectional	Inhibition (McConnell)

Study	Taping Conditions	Tape Used	Muscles Targeted	Experimental task	How Inhibition Measured
Janwantanakul and Gaogasigam 2005	Inhibition, facilitation, no tape	Elastic	VL	Stair descent	sEMG
McCarthy Persson et al 2007	Inhibition	Rigid zinc oxide with underlay	VL	No task	Not measured
Sinaei et al 2021	Inhibition, facilitation	Elastic (kinesio)	VL and VM	Modified star excursion balance test	sEMG
Tobin and Robinson 2000	Inhibition, facilitation, no tape	Rigid zinc oxide with underlay	VL	Stair descent	sEMG

Study	Inhibition Achieved?	Other Outcomes	Main Limitations
Janwantanakul and Gaogasigam 2005	No	None	Asymptomatic females only, no muscle “furrow” created, short washout period,
McCarthy Persson et al 2007	N/A	Skin displacement	Small convenient asymptomatic sample, didn’t measure inhibition
Sinaei et al 2021	Yes	Pain and balance	Female athletes only, no placebo tape.no control group
Tobin and Robinson 2000	Yes	None	Small convenient asymptomatic sample, inconsistent washout periods, low sEMG sampling frequency

2.11.3.3. Critical Appraisal Outcomes

The data extracted using the bespoke critical appraisal tool are presented in Table 2.3. They reveal that all studies had a focused research question that they were seeking to answer. It is interesting though, that only one study, Sinaei et al (2021), described their recruitment methods and that this was the only study employing a prospective power calculation to calculate a sample size, Janwantanakul and Gaogasigam (2005) performing a retrospective post-hoc power calculation. Sinaei et al (2021) was also the only study to report on randomisation and blinding, whilst Tobin and Robinson (2000) reported on the variance and Janwantanakul and Gaogasigam (2005) reported their confidence intervals. None of the studies were deemed to be generalisable, although all except McCarthy Persson et al (2007) appeared to interpret their findings appropriately and to discuss the clinical relevance of their findings.

Table 2.3 Critical Appraisal Checklist

Study	Focused Research Question	Population Defined	Recruitment Methods Described	Sample Size Defined by Power	Study Setting Described
Janwantanakul and Gaogasigam 2005	Yes	Yes	No	No (did post-hoc)	No
McCarthy Persson et al 2007	Yes	Yes	No	No	No
Sinaei et al 2021	Yes	Yes	Yes	Yes	No
Tobin and Robinson 2000	Yes	Partial	No	No	No

Study	Randomized	Blinding Information	Treated Equally Except Intervention	Statistical Methods Described	Variance Described
Janwantanakul and Gaogasigam 2005	Yes	No	Yes	Yes	No
McCarthy Persson et al 2007	No	No	Yes	Yes	No
Sinaei et al 2021	Yes	Yes	Yes	Yes	No
Tobin and Robinson 2000	No	No	Yes	Yes	Yes

Study	Confidence Intervals Presented	Appropriate Interpretation	Generalizable	Clinical Relevance Discussed
Janwantanakul and Gaogasigam 2005	Yes	Yes	No	Yes
McCarthy Persson et al 2007	No	N/A	No	No
Sinaei et al 2021	No	Yes	No	Yes
Tobin and Robinson 2000	IQ Ranges	Yes	No	Yes

Key: IQ = inter-quartile, N/A = not applicable

2.11.4 Discussion

This systematic review was conducted to synthesize the findings of previous research into the use of VL inhibition taping. Reviewing the studies in chronological order. Tobin and Robinson (2000) were the first to investigate this concept, and found a significant decrease in VL activity under the active (inhibitory) tape condition. However, there were limitations with the EMG processing, such as sampling the EMG data at a low frequency, that may have had an effect on the results. Janwantanakul and Gaogasigam (2005) then recruited 30 asymptomatic young females to conduct a similar investigation, and found no difference in the VL activity between their taping conditions. However, they used an elastic tape instead of the rigid tape recommended by McConnell. They also used non-normalised EMG data, which has since been criticised by McCarthy Persson et al (2007) as it may mask subtle but important changes in muscle activity.

The taping technique described by Janwantanakul and Gaogasigam (2005) involved no downward pressure into the muscle when applying the tape and there was no attempt to create a furrow in the muscle or skin. This is an important factor to note as the downward pressure and furrow creation are key characteristics of McConnell's technique, and therefore non-identical taping techniques are being highlighted. McCarthy Persson et al (2007) investigated VL inhibitory taping, this time using the rigid zinc oxide tape recommended by McConnell (1986), and explored the effect of skin displacement in relation to the downward force used when applying inhibitory tape. They found no difference in these parameters between their test conditions. However, this was a small study (n=10) and did not directly look at the EMG patterns of the muscles or measure potential inhibition of the muscle. Rather, they measured the downward pressure used and the skin displacement seen when applying the tape. Finally, Sinaei et al (2021) investigated the effects of inhibitory kinesio taping on VL, as well as the effects of facilitatory taping on VM(O), on sEMG activity, pain and balance. Although they used an elastic tape similar to Janwantanakul and Gaogasigam, the VL inhibition taping technique used by Sinaei et al differed considerably, which may account for their differing results. These techniques were described in section 2.11.3.2. Sinaei et al (2021) found that, although the VM(O) facilitatory technique led to improvements in all parameters, the inhibitory VL taping technique produced greater effects which led them to conclude that the VL inhibitory tape was more effective than the VM(O) facilitatory tape. Although Sinaei et al (2021) were the first authors to investigate inhibitory taping on a symptomatic cohort, the lack of a placebo and/or control group together with the sample being exclusively female athletes limits the generalisability of their results.

It is important at this stage to review the selection strategy employed by this systematic review. This is because, despite using broad search terms within this systematic review, to the authors knowledge there was at least one study which was not captured within the search. McCarthy Persson et al (2009) examined the effect on the sEMG activity of VL of an inhibition taping technique compared to a control taping technique (no tension). Therefore, this paper would have been relevant to this systematic review however, as none of the search terms were reported in the title or abstract or found from reviewing the references lists of the eligible studies, it was not included in the main systematic review. However, McCarthy Persson et al (2009) found a significant decrease in the sEMG activity of VL with both of their taping techniques in 25 asymptomatic participants, although the effect was greater with the inhibition taping technique than it was with the control tape technique. This contrasts with the findings of Janwantanakul and Gaogasigam (2005) who found no inhibition, and also with those of Tobin and Robinson (2000) who although found inhibition of VL with the "active" tape technique, found facilitation of VL with their control tape technique.

2.11.5 Conclusion

As can be seen, the studies relating directly to VL inhibition in PFP are few in number and as highlighted by this review are themselves contradictory in their findings (Sinaei et al 2021, McCarthy Persson 2007, Janwantanakul and Gaogasigam 2005, Tobin and Robinson 2000). Furthermore, although Sinaei et al (2021) investigated balance, none have looked at kinematic control which limits their findings as biomechanical considerations cannot be extrapolated from their work. Moreover, Sinaei et al (2021) used kinesio tape in their study, meaning that, to the authors knowledge, there still remain no studies that have investigated the possibility of inhibiting VL with a rigid zinc oxide tape in a cohort of participants with PFP. Therefore, there not only remains a large gap in the research knowledge base as to the efficacy with which VL can be inhibited by taping and therefore its' ability to address the VL:VM imbalance, especially in a symptomatic cohort, but also on the control of the joint. It is currently unknown whether taping techniques designed to inhibit VL may also have an effect on lower limb control as, to the author's knowledge, there are no studies known to have explored this. Finally, the clinical relevance of this line of research, i.e., does it reduce the pain and/or increase the perceived stability and/or improve the control of the lower limb in people with PFP, has yet to be established as the author is aware of only one study (Sinaei et al 2021) that has looked at VL inhibition taping in a symptomatic cohort. Thus, more research is needed on inhibitory taping, especially on symptomatic participants and particularly during functional activities.

2.12 Targeted Interventions for Patellofemoral Pain

Keays et al (2014) identified that often in the relevant literature, participants are treated identically regardless of their individual presentations. Although this makes studies repeatable and academically robust, the clinical relevance may be limited as the results will be influenced by this lack of acknowledgement of individual characteristics. This is supported by Saltychev et al (2018) who stated that as PFP is a multi-factorial problem, it may be that a treatment that is effective for some aetiologies will have no effect on others. They recommended that further studies examine whether subgroups of patients with PFP with different characteristics may benefit differently from particular individualised treatments. This builds on from the statement by Petersen et al (2017) that individually tailored multi-modal treatment plans are required for each patient based on their underlying pathology. In their 2013 paper, Selfe et al proposed that the PFP population may be able to be divided into discrete sub-groups associated with; i) hip abductor weakness, ii) quadriceps weakness, iii) patellar hypomobility, iv) patellar hypermobility, v) pronated foot posture and vi) lower limb biarticular muscle tightness. This was followed by Selhorst et al (2015) who proposed that four subgroups may exist; fear avoidance, flexibility, functional malalignment and strengthening which they recommend should be addressed in this order. Selfe et al (2015) then proposed three subgroups: strong, weak and tighter, and weak and pronated foot. This subgrouping, based on the use of six objective assessment tests, allows patients to receive specifically targeted interventions to address their individual issues as advocated by many authors in the PFP literature. These tests were passive prone knee flexion to measure the length of the bi-articular rectus femoris, passive knee extension in supine to measure the length of the bi-articular hamstrings, calf flexibility in standing with knee extension to measure the bi-articular gastrocnemius length, hip abductor strength, quadriceps strength, total patellar mobility and the foot posture index (FPI) assessment to measure pronation of the foot. The FPI evaluates the multi-segmental nature of foot posture in all three planes (Barton et al 2011), and provides a way of determining whether foot orthoses may be a useful treatment. This stems from the understanding that assessing and then controlling foot pronation will reduce the tibial and femoral rotation, which may be associated with PFP (Barton et al 2011). The FPI consists of six assessment measures; the position of the head of the talus, lateral malleolar curvature, calcaneal frontal plane position, prominence in the region of the talonavicular joint, congruence of the medial longitudinal arch and abduction/adduction of the forefoot on the rearfoot. Subsequently, Selfe et al removed the hamstring length measurement from their assessment battery as it was found to be ‘not informative’ with respect to their subgroups. Therefore, their targeted intervention for patellofemoral pain syndrome (TIPPS) now includes five measures of factors believed to influence PFP and the 6-item FPI (see section 6.4.5 for more details and appendix 14).

Further work on subgrouping in the PFP population has been completed by Drew et al (2019). As a result of their study, they proposed four subgroups, which they acknowledge have similarities to those proposed by Selfe et al (2015). Drew et al’s (2019) subgroups were; strong, pronation and malalignment, weak, and active and flexible. The similarities they drew with the work of Selfe et al (2015) were that both had a strong subgroup, and that Drew et al’s weak subgroup was akin to Selfe et al’s weak and tighter subgroup. Finally, Selfe et al’s third group of weak and pronated shows similarities with both Drew et al’s pronation and malalignment and active and flexible subgroups. The key message from both Selfe et al (2015) and from Drew et al (2019) is that these subgroups have potentially modifiable characteristics which facilitate the provision of targeted tailored interventions for individuals with PFP. It is proposed that by tailoring interventions according to the characteristics of each subgroup, that the rehabilitation and prognosis of people with PFP can be improved.

Yosmaoğlu et al (2020) used Selfe et al's assessments in their study into targeted treatment protocols. They gave what they called standard multimodal treatment to 61 participants which comprised ice, transcutaneous electrical neural stimulation, therapeutic ultrasound, hamstring/tensor fascial lata and iliotibial band stretching exercises, open kinetic chain quadriceps and hip abductor strengthening exercises, and a home exercise programme made up from the stretching and strengthening exercises. They found that 21 participants improved but 40 were classed as non-responders. These 40 participants were then given further targeted treatment based on their sub-group classification; strong, weak and tight, and weak and pronated foot. The strong group were given balance and proprioception exercises, patellar bracing and advice regarding activity modification. The weak and tight group were given closed kinetic chain strengthening exercises, quadriceps and gastrocnemius stretching exercises and weight management advice. Finally, the weak and pronated foot group were given closed kinetic chain strengthening exercises, foot orthoses and advice regarding activity modification. They found that following the targeted interventions, 29 of the 40 participants were then classed as recovered. Although there was no washout period between the two treatment programmes, meaning that the non-responders got 12 weeks of treatment, this study does provide support for the targeted intervention approach with PFP patients.

2.13 Stair Descent

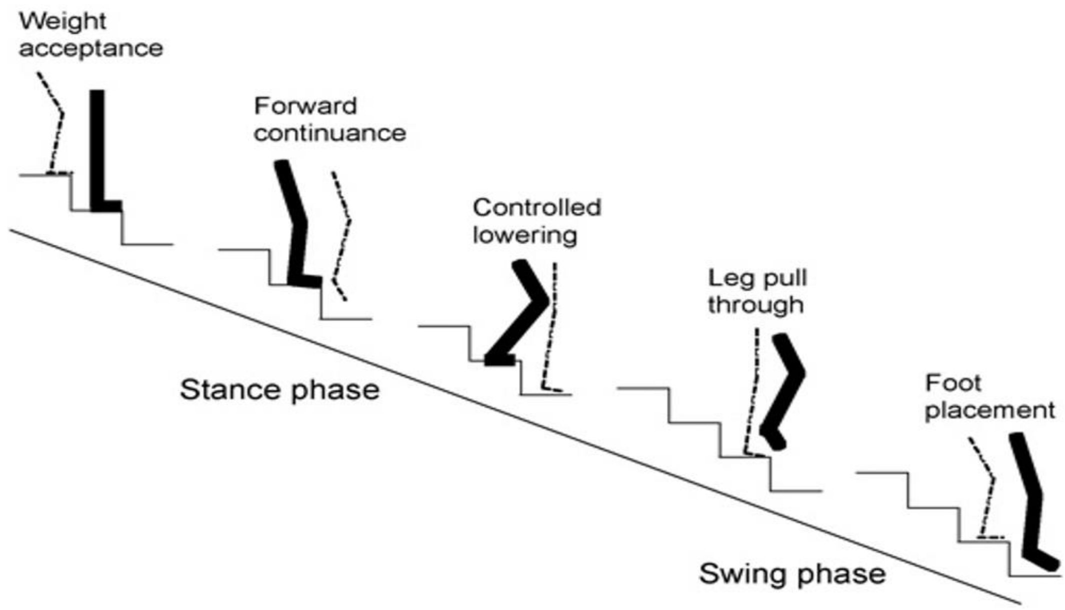
Stair descent is an everyday task that provides a dynamic challenge to the knee and is a common aggravating factor for people with PFP, which makes this a clinically relevant task in the assessment of PFP (Baldon et al 2013). It has been found to create greater PF joint stress than stair ascent/step ups which has been identified as being consistent with reports of PFP patients having more pain on stair descent than ascent (Chinkulprasert 2011). Stair descent has also been identified as an activity that exposes the patellofemoral joint to great loads, with difficulty negotiating stairs being a hallmark of patellofemoral disorders (Fok et al 2013). It has also been identified that during stair descent, the main requirement is to control the rate of body lowering (the centre of mass) while progressing to the next step with the vasti and GM playing a vital role in supporting this, especially during the first half of the stance phase (Lin et al 2015). The slower the descent, the greater the quadriceps muscle strength that is required to control it, making it even more challenging for people who tend to descend the stairs slowly, such as those with knee pain (Caruthers et al 2018). Stair descent has been identified as one of the most painful activities of daily living for people with PFP (Brechter and Powers 2002), and is an activity associated with greater demands on the knee than those of level walking, requiring greater knee flexion angles and greater knee extensor moments (Aliberti et al 2019). It has also been found that stair descent has a significantly lower cycle duration than stair ascent (Protopapadaki et al 2007), which may reflect reduced eccentric capabilities and reduced control of the descent. The height of the step has also been shown to be relevant, as an increase in the step height leads to increased reported pain in participants with PFP (McClinton et al 2007). Furthermore, stepping down from a step of greater than 10cm involves forefoot landing as opposed to the heel strike/landing which is typically employed during level walking (Aliberti et al 2019). Aliberti et al (2019) proposed that forefoot landing is a strategy to reduce the functional impact of the step height by increasing plantar flexion which in turn provides a way of physiologically decreasing the stair height. This physiological reduction in step height therefore reduces the impact and forces going through the knee complex (including both the tibiofemoral and patellofemoral joints), rendering the step down less of a problem for the patellofemoral joint in particular.

Stair descent can be described as a closed kinetic chain activity and can generate forces of up to nine times bodyweight (Norris 2017). It is also functional and requires good eccentric control over relatively large ranges of knee movement with increased quadriceps activity (McFadyen and Winter 1988). As a task, stair descent is also achievable by all participants, which is important when considering the clinical relevance of functional tasks in assessment (Burston et al 2018, Drew et al 2017). This is supported by Selfe et al (2007), who stated that when looking at the patellofemoral joint, research activities should be “functionally relevant as well as sufficiently challenging to the patellofemoral joint”.

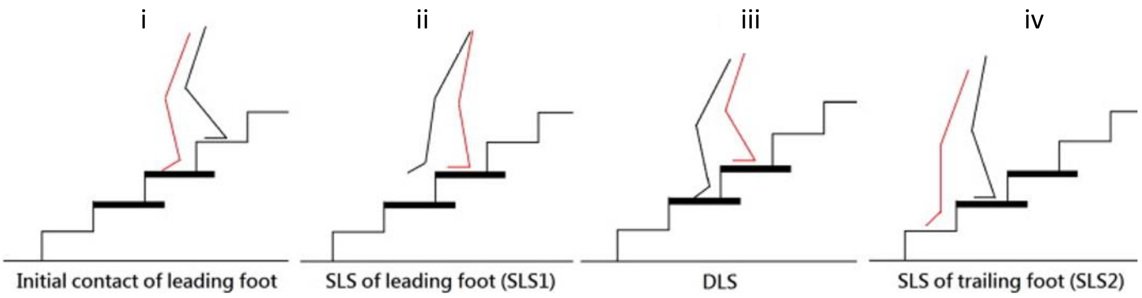
As stated above, stair descent is an activity that demands high levels of eccentric control, and a loss of eccentric strength and control is a common feature of PFP (Eapen et al 2011). Stair descent is more challenging than stair ascent due to the centre of mass being moved both forwards and downwards in the controlled lowering phase with eccentric muscle activation (Bonifacio et al 2018). It is known to induce pain, with reduced control of the patellofemoral joint and increased patellofemoral joint reaction forces having been acknowledged as causative factors for PFP (Guney et al 2016). Stair descent is a cyclic activity comprising of several phases which have been variously described by different authors, see Figure 2.7 a and b. Initially, each stair descent cycle can be considered in terms of a stance phase and a swing phase, as illustrated in Figure 2.7a.

Figure 2.7 The Stair Descent Cycle

a) – adapted from Novak et al (2010)



b) – reference Hsue and Su (2014)



(SLS = single limb support. DLS = double limb support)

The whole of the stance phase takes about two thirds of the entire stair descent cycle, with Zachazewski et al (1993) quantifying it as approximately 68%, see Figure 2.8. The swing phase, which itself can be further divided into leg pull through phase and the period just before foot placement occurs, comprises the rest of the cycle (Zachazewski et al 1993), and accounts for the other 32%. This is also illustrated in Figure 2.8.

Figure 2.8 Quantified Phases of Stair Descent (Zachazewski et al 1993)

<table>
<tr><td>Double support</td><td colspan="2">Single support</td><td>Double support</td><td rowspan="2">Leg pull through</td><td rowspan="2">Foot placement</td></tr>
<tr><td>Weight acceptance</td><td>Forward continuance</td><td colspan="2">Controlled Lowering</td></tr>
<tr><td colspan="4">Stance phase</td><td colspan="2">Swing phase</td></tr>
</table>

0 14% 34% 53% 68% 84% 100%

The stance phase, which is the part of the step descent cycle that the studies in this thesis are focussing on, can also be divided into separate phases. The first of these phases is weight acceptance which occurs immediately after foot placement on the step followed by forward continuance and controlled lowering stages (see Figure 2.7a). An alternative way of describing the stance phase of stair descent is based on whether both limbs are in contact with the stair, known as double limb support phase or one limb on the stair, known as single limb support phases (see Figure 2.7b). The first of the two double limb support phases involved in the stance phase occurs at the beginning of the cycle, starting immediately as foot placement is achieved (Figure 2.7b(i)), and ends when the contralateral limb begins the swing phase. The single limb support phase (Figure 2.7b(ii)) then occurs and accounts for approximately 39% of the whole stance phase (Zachazewski et al 1993). Finally, there is a second double leg support phase at the end of the stance phase (Figure 2.7b(iii)).

The stance phase has also been described as having three sub-phases with these phases being determined temporally; the early phase which accounts for the first 20% of the stance phase, the mid phase which accounts for 21-50% of the stance phase and the late phase which accounts for 50-100% of the stance phase (McFadyen and Winter 1988, Aliberti et al 2019). However, Bolgla et al

(2011b) use the terms loading response to describe the early part of the stance phase and single leg stance and pre-swing to describe the latter phases. By adapting Zachazewski et al's (1993) model where the various phases are named and quantified (Figure 2.8) and combining it with McFadyen and Winter's (1988) original temporal work, a new stance phase only figure can be created; see Figure 2.9a and b.

Figure 2.9 Quantified Phases of the Stance Phase of Stair Descent

a) – McFadyen and Winter (1988)

Early stance phase	Mid stance phase	Late stance phase

0 20% 50% 100%

b) – Combining the Phases of Zachazewski et al (1993) with those of McFadyen and Winter (1988)

<table>
<tr><td>Double support</td><td colspan="2">Single support</td><td>Double support</td></tr>
<tr><td>Weight acceptance</td><td>Forward continuance</td><td colspan="2">Controlled Lowering</td></tr>
<tr><td colspan="4">Stance phase</td></tr>
</table>

0 20% 50% 78% 100%

During the single leg support phase, the muscles stabilising the hip and pelvis, including the abductors and lateral rotators, are maximally challenged (Baldon et al 2013). Biomechanically, maximum medial-lateral displacement of the centre of mass occurs at mid-stance at the end of the forward continuance phase. Immediately after the forward continuance phase the centre of mass travels forwards and medially during the controlled lowering phase until it and the centre of pressure are coincident at the mid double support phase (Zachazewski et al 1993), which occurs as the other limb achieves foot contact on the next stair down at the end of its swing phase.

During stair descent the knee moves from a relatively stable extended position and moves through phases where it becomes increasingly less stable during the controlled lowering (Bonifacio et al 2018, Selfe et al 2007). The increasing flexion requires progressively increasing amounts of eccentric control of the supporting musculature until the limb leaves the stair and the swing phase starts. Furthermore, as the knee angle increases during the controlled lowering phase, the knee flexion angle also increases which results in greater patellofemoral contact forces, due to greater quadriceps force resulting in a greater patellar tendon force.

To ensure that the limb is loaded appropriately, several physiological and accessory movements need to occur in a completely co-ordinated manner (Smith 2012). As the centre of mass descends into the weight acceptance phase, the limb is progressively loaded until forward continuance is achieved, at which point downward displacement stops (Zachazewski et al 1993). Once controlled lowering starts, the centre of mass moves anteriorly, which requires the co-ordinated function of both static and dynamic stabilisers of the patellofemoral joint (Dixit et al 2007) and of the hip muscles, especially GM (Lin et al 2015). Failure of, or disruption to, any of these structures can result in the elevated patellofemoral joint reaction forces that are associated with excessive patellofemoral joint stress and ultimately PFP (Chen et al 2010).

It has been shown that patients with PFP had 50% greater knee varus/valgus range of motion of the tibiofemoral joint than healthy individuals during a step-down task (Richards et al 2019). It has also been found that subjects with PFP had a longer single limb stance phase, a greater maximum knee flexion angle, a greater range of flexion, a greater coronal and transverse plane range of movement, and lower maximum abduction/adduction angles than did their asymptomatic counterparts (Burston et al 2018). Furthermore, in Burston et al’s study, they also found that subjects with PFP had greater peak flexion moments during the lowering phase and greater knee adduction moments during the forward continuum phase, with greater coronal plane movement being noted in both phases. Coronal plane movement has been identified as a measure of knee control and therefore the greater coronal plane movement indicates that the PFP subjects had poorer control of their knee than asymptomatic subjects.

2.14 Electromyography

2.14.1 Introduction

“Electromyography is a seductive muse because it provides easy access to physiological processes that cause the muscle to generate force, produce movement, and accomplish the countless functions that allow us to interact with the world around us" (De Luca 1997). EMG is used to detect the electrical signals emanating from muscle contractions, and this is achieved by utilising sensors either placed on the skin surface above the muscle in question (sEMG) or within the muscle by means of an intramuscular needle or fine wire electrode. The EMG signal has been described as the electrical manifestation of the neuromuscular activation associated with a contracting muscle (Basmajian and De Luca 1985 p65). EMG is widely used to measure muscle activation but it should be noted that although the amplitude of the EMG signal typically increases as the force of the muscle contraction increases, it does not provide direct information regarding muscle force (Hug et al 2015). However, this does not mean that it does not provide valuable information about the neural control of movement, just that it does not provide direct information about muscle force. De Luca (1997) also stated that although it has many potential applications, it must be remembered that EMG also has some limitations that must be addressed. These include a myriad of factors that affect the fidelity of the EMG signal, crosstalk where the electrode picks up signals from muscles other than the intended one, and the stationarity of the signal which is to do with the changing length of the muscle during the contraction and the activation pattern of the motor units. It has been stated that normalisation, which is discussed in section 2.14.6, may remove the influence of many of these variables on the EMG signal (De Luca 1997).

When considering which type of sensor to use, there are advantages and disadvantages with both sEMG and intramuscular EMG. However, since the studies within this thesis used sEMG, only this will be reviewed. The main advantages of sEMG are that it is non-invasive therefore sterilisation and infection risks are irrelevant, that there is no potential for tissue damage and that it can detect a greater number of motor units (see section 2.14.2) within the target muscle than an intramuscular electrode can (Nawab et al 2010). It also produces an EMG signal of high fidelity and is generally convenient to use, especially when the electrodes are "dry" and can then be used without coupling gel (Basmajian and De Luca 1985 p26). However, limitations of sEMG include the need to use it on superficial muscles only (Contessa et al in Richards 2018 p215) and it is very difficult to use it to detect signals from small muscles as this has a high risk of cross-talk interference from other muscles (Basmajian and De Luca 1985 p26).

However, the muscles studied in this thesis, i.e., GM, VM and VL, are all large and superficial, and therefore judicial placement of the sensors can significantly reduce this risk (see section 2.14.6).

2.14.2 Muscle Activity and Activation

In order to explain EMG in general and sEMG in particular, it is necessary to consider muscle activity and activation. When an individual motorneurone fires, the impulse (action potential) travels to the neuromuscular junction where it innervates a number of individual muscle fibres. The number of muscle fibres innervated by one motorneurone varies widely, with the motorneurone plus its muscle fibres being known collectively as a motor unit (Basmajian and De Luca 1985 p11/12). Generally speaking, the larger the muscle, the larger the motor units within it (Basmajian and De Luca 1985 p12). In the absence of pathology, once started, an action potential will result in the activation of all the muscle fibres supplied by the branches of that motorneurone (Basmajian and De Luca 1985 p66). Once the muscle fibre is activated, the accompanying depolarisation of its membrane occurs in both directions from the neuromuscular junction with each action potential resulting in a muscle fibre twitch or contraction. However, human function demands more than just single twitches of muscles and in order to prolong or sustain a muscle contraction, repeated motor unit activation is required, a concept which is known as a motor unit action potential train (MUAPT) (Basmajian and De Luca 1985 p72). Varying either the number of active motor units and/or their firing rate will determine the force produced by the muscle (Contessa et al in Richards 2018 p211). An electrode placed on the skin over the contracting muscle will detect the action potential(s) and result in the sEMG signal being observed (Basmajian and De Luca 1985 p67).

2.14.3 Skin Preparation

When collecting sEMG, it is recognised that effective skin preparation is required to reduce electrical impedance and improve the fidelity of the sEMG signal (Chen et al 2018b). However, there is variation in the literature regarding what preparation of the skin prior to sensor placement is necessary. Some authors (Cowan et al 2001 and 2006) advocate shaving, abrading and cleansing the skin while others (Chen et al 2018b, Briani et al 2015, Duffell et al 2011, Irish et al

2010 and Ryan and Rowe 2006) believe cleansing alone to be sufficient. Both studies within this thesis used the cleansing only method, using alcohol wipes to clean both the skin and the sensors/electrodes, see section 3. 3.1. Once the sensors were positioned, the quality of the signals were checked by checking the signal-to-noise ratio (SNR) while contracting the relevant muscles by performing a gentle squat. The SNR is discussed more fully in section 2.14.7. Where signals were not of a good quality, the processes of skin and sensor cleansing and sensor placement (see section 2.14.5 for sensor placement) were repeated until the SNR was acceptable. The SNR was deemed to be acceptable when the SNR check display on the computer screen indicating a green SNR was displayed.

2.14.4 Sensor Configuration

In addition to the placement of the sensor (see section 2.14.5), the configuration of the sensor itself is also important, with a bipolar arrangement being identified as the most favourable (Basmajian and De Luca 1985 p37). This is also in accordance with the current Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines which restricts use to bipolar sensors only. The bipolar sensors used in this thesis had two EMG electrodes with two stabilising reference electrodes arranged as four bars (see Figure 3.1). This configuration negates the necessity for a separate reference electrode and allows the bars to be orientated perpendicular to the muscle fibres when placing the sensors on the skin overlying the muscle(s) of interest. Bipolar sensors also have the advantage over their monopolar counterparts as they reduce the potential of detecting unwanted signals, which would otherwise contaminate the EMG signal (De Luca 1997).

As described above in section 2.14.1, the desired sEMG signal is detected by sensors placed on the skin overlying the target muscle. This signal is influenced by the size, shape and configuration of the sensors which together with the inter-electrode distance and sensor location determines how much of the muscle tissue is investigated. Clearly, the bigger the sensor is, the larger the area underneath it will be, meaning the activity of more motor units can be detected. However, the greater the size of the sensor, the greater the potential for crosstalk from surrounding muscles (Roy et al 2007).

As with the size of the sensor, the greater the inter-electrode distance, the greater the number of motor units that will be detected. Taken at face value, this would tend to indicate that large inter-electrode distances would be preferable. However, sEMG users again need to consider the potential for crosstalk. De Luca et al (2012) found that increasing the inter-electrode spacing from 10mm to 40mm significantly increased cross-talk during both isometric contractions and a dynamic activity (gait), and concluded that 10mm was in fact the optimal inter-electrode spacing for sEMG. However, this differs from the survey-based guidelines produced by SENIAM, which recommended an inter-electrode distance of 20mm. It should be noted here that the SENIAM recommendations are drawn from a survey of published authors using sEMG whereas De Luca et al's (2012) recommendation comes from specific experimental data. It should also be noted that however superficial the muscle may be, it will still have layers of other tissue overlying it, for example fascia, subcutaneous fat and skin. These layers of tissue can also affect the integrity of the detected sEMG signal (Contessa et al in Richards 2018 p215).

2.14.5 Sensor Placement

The positioning of the sEMG sensor has been identified as the most important factor in achieving a good SNR and signal fidelity (De Luca 1997). Sensor location is defined as the position of the centre of two bipolar electrodes on the muscle (SENIAM) and three major factors have been identified that need to be considered; SNR, signal stability and cross-talk (De Luca 1997). It has been recommended that sEMG sensors should be placed in alignment with the muscle fibres, i.e., longitudinally, so that the electrodes housed within them are perpendicular to the muscle fibres (De Luca et al 2012). It has also been advised that placing the sensor in the middle of the muscle belly, as opposed to the edge of the muscle or near the musculotendinous junction, reduces the potential for crosstalk. (De Luca et al 2012). The placement of the EMG sensors in this thesis are described in detail in section 3.4.3.

2.14.6 Confounding Noise

Unfortunately, the sEMG signal is not made up entirely from MUAPTs, it also contains noise from other sources which are both “endemic and unavoidable” (De Luca et al 2010). This noise is known to contaminate the sEMG signal and may therefore lead to incorrect conclusions being drawn from the data. Unfortunately, this is often more evident during dynamic movements, as opposed to static isometric contractions (De Luca et al 2010). As the activity investigated in this thesis was a dynamic task, this is an especially relevant consideration.

There are several sources of noise, which can be classified as intrinsic and extrinsic. Intrinsic noise is generally due to the amplification system within the sEMG sensor (thermal noise) and also occurs at the skin-sensor interface (electrochemical noise). The noise from the skin-sensor interface is generated by two processes; the movement of the muscle under the skin and movement of the sensor which is known as motion artefact (De Luca et al 2010). Meanwhile, extrinsic sources include noise from power lines and from movement of wired sensors. De Luca et al (2010) found that using their state-of-the-art equipment minimised both the extrinsic noise sources and the intrinsic thermal noise, which leaves only the electrochemical noise from the skin-sensor interface to be considered. They included a high-pass filter in their sEMG processing which reduced baseline noise and movement artefact, and also minimised the removal of the desired sEMG signal. Furthermore, it has been found that the electrochemical noise can be further reduced by cleansing the electrodes and the skin (Contessa et al in Richards 2018 p219). The final consideration is movement artefacts., and these can be reduced with high quality double sided adhesive patches and by using dry electrodes, i.e., electrodes without any coupling gel (Roy et al 2007). The advantages of a wireless sEMG system, which not only allows the subject to move freely, but also reduces the noise from movement artefacts at the skin-sensor interface (Contessa et al in Richards 2018 p216). This is achieved by ensuring that movement of the sensor on the skin during the muscle contraction is minimised.

2.14.7 sEMG Signal Quality

The best indication of the quality of the sEMG signal is the SNR (Contessa et al in Richards 2018 p217, Basmajian and De Luca 1985 p52). The SNR measures the ratio between the wanted EMG signal and the unwanted noise signal arising from variables including baseline noise and movement artefacts De Luca et al 2010). The unwanted noise can be reduced by careful consideration of the causative factors described in section 2.14.4, and therefore, it is imperative that the sEMG sensors need to be carefully placed on the skin over the target muscle(s) in order to not only optimise the SNR but also to improve signal stability whilst reducing or negating crosstalk.

2.14.8 EMG Normalisation

It has been suggested that EMG normalisation is not required when the participants in a study act as their own controls with all testing being done in one session and with no electrode movement (Toumi et al 2013). However, normalisation is a very important process in sEMG data processing as it allows the comparison of data collected from different subjects and different muscles (De Luca 1997). Normalisation provides the basis from which a comparison of the differing force capabilities of a given muscle(s) can be made. Normalisation is often achieved by normalising the force generated within the muscle with respect to a maximal isometric contraction. However, this method assumes that; a) the subject can in fact generate a maximal isometric contraction on demand, and b) the force generated is directly related to the muscle under investigation (De Luca 1997). Within a PFP study cohort, the ability to generate maximal voluntary isometric contractions of the knee extensors is often compromised by the pain that this activity provokes. It is also very difficult to ensure that the only muscle force being generated is in fact generated from the knee extensors, i.e., the quadriceps. Therefore, in this situation, the process of normalising the sEMG signal with respect to a maximal voluntary isometric contraction is rendered inadequate.

Another method of normalisation is to use the maximum observed sEMG signal. This involves identifying the maximum sEMG signal within the chosen activity for each muscle being investigated and from every trial in each condition, and then dividing this signal value against the overall sEMG signal from the task (Richards et al 2008). The maximum observed signal method negates the need for maximal contractions while still allowing the comparisons between muscles and subjects to be made.

2.14.9 sEMG Filtering

sEMG signals are stochastic by nature (De Luca 1997), meaning that the data collected are variable and require filtering in order to smooth the data and allow the activity of the muscle(s) to be identified accurately. The aim of sEMG filtering is to filter out as much noise as possible while retaining as much of the EMG signal as possible in order to maximise the fidelity of the signal being analysed (De Luca et al 2010). De Luca et al (2010) reported that the sEMG frequency spectrum frequently ranges from 0 - 400Hz, being influenced by factors including the amount of adipose tissue involved, the muscle type and the electrode spacing. They recommended that at the high end of the sEMG signal spectrum, the low-pass filter frequency should be set “where the amplitude of the noise components surpasses that of the sEMG signal”; i.e., 400 - 450Hz. Following their study, which investigated the effect of various filter frequencies on sEMG data, De Luca et al (2010) found that at the low end of the sEMG signal spectrum, a high-pass Butterworth filter with a corner frequency of 20Hz gave the best compromise between filtering the noise and retaining the EMG signal, and therefore recommended that it be employed for what they called general use. This includes “natural and common movements”, a category into which it could be argued that stair descent would fit. Applying an appropriate high-pass filter is also used to remove the direct current (DC) offset; the DC offset being a product of the recording equipment and seen where the EMG signal oscillates either side of a value that is not zero (Contessa et al in Richards 2018 p224).

2.14.10 sEMG Processing

There are several methods that can be employed to process sEMG data including rectification and enveloping. Rectification can be either half-wave which discards the negative values leaving only the positive values for analysis whereas full-wave rectification converts the negative values into positive ones thus allowing all the values to be analysed. It is generally accepted in the literature that full-wave rectification is preferable, with many studies using this technique (Gerstle et al 2018, Briani et al 2015, McCarthy Persson et al 2009, Cowan et al 2001 and 2002). Furthermore, rectification also facilitates further EMG data analysis since the valuable integrated EMG signal is derived from the rectified signal (see section 4.4.4.)

Enveloping is a process by which the raw EMG traces can be smoothed. This is a useful processing technique to use on EMG data as it reduces the variance within the recorded EMG signal. It is achieved by applying a low-pass filter to the EMG data which allows the retention of the low frequency components of the signal while rejecting the higher frequency components. This has the effect of reducing the variability of the sEMG signal. The effect of both rectifying and enveloping the EMG data can be seen in section 4.4.2.

2.15 Inertial Measurement Units

Inertial measurement units (IMUs) are small, lightweight sensors used to collect data regarding human movement, measuring both linear and angular movements (Brabants et al 2018). They usually include accelerometers which measure acceleration, gyroscopes which measure angular velocity and magnetometers which measure magnetic direction and yaw angle rotation (Ahmad et al 2013). IMUs can be used for 3-dimensional movement analysis (van der Straaten et al 2020) and have been described as bridging the gap between large, expensive laboratory-based systems and systems that may be used clinically (Budini et al 2018). The advantages of using IMUs include them being relatively inexpensive, easy to set up, more portable so they can be used in clinical settings and not just in laboratories settings, and that they also allow relatively unconstrained movements (O'Reilly et al 2017, Kavanagh and Menz 2008). Saber-Sheikh et al (2010) examined the use of IMUs to assess hip movement during gait and found that IMUs were comparable to a motion tracking system and concluded that IMUs provide a viable alternative to the much more expensive and difficult to use motion capture systems. This finding was replicated by Hu et al (2014) in their study using single leg squats and hops and by Kavanagh and Menz (2008) and Washabaugh et al (2017) in their studies of gait parameters. IMUs being an appropriate alternative to motion capture systems was also found by Budini et al

(2018), who used the star excursion balance test to examine the effect of medial glide patellar taping and bracing on dynamic postural stability of the knee. During the studies in this thesis, IMU sensors were used to capture movement data from the tibia and patella in both the asymptomatic group and the symptomatic group. In each case, the tibial sensor was placed distally on the skin over the bone. This made these sensors more likely to detect movement and acceleration as distal sensors have been found to record greater movement and acceleration when compared to proximally placed sensors (Lucas-Cuevas et al 2016). This is supported by O'Reilly et al (2017) who found that a single IMU placed on the shank (distal lower leg) could detect movement pattern differences while their participants performed a single leg squat with 76% accuracy, 75% sensitivity and 76% specificity. These numbers compared favourably with a three-sensor set-up and suggest that just a single IMU can provide high quality information regarding kinematic and kinetic data that could be readily used in clinical environments.

2.16 Chapter Summary

PFP is a common, yet poorly understood musculoskeletal condition. It is multi-factorial in nature, and there are numerous treatment techniques designed to address what can be very debilitating and long-lasting symptoms. Given the lack of gold-standard evidence-based treatment techniques, it is appropriate to explore as yet under-researched techniques that may have the potential to add to the body of research into PFP.

2.17 Aims and Objectives

The first study in this thesis was conducted on an asymptomatic sample. The main aim of this first study was to investigate the efficacy of a taping technique designed to inhibit VL by measuring the sEMG activity within VL in an asymptomatic sample. The sEMG activity of VM and GM, and information regarding the control of the lower limb during stair descent were also collected. This gave rise to several objectives, which were:

i) To explore the efficacy of a specific taping technique purported to inhibit VL.

ii) To explore the effect of different taping conditions and different stair riser heights on the stance phase during stair descent

iii) To explore the effect of different taping conditions and different stair riser heights on the sEMG activity and on lower limb control parameters.

iv) To explore the control of the lower limb during stair descent using IMUs which are recognized as an appropriate way to measure joint stability in different planes of movement and can be integrated with the EMG data collection.

The second study in this thesis used the findings of the first study to hone the methodology of the data collection from a symptomatic population. The specific objectives of the second study were:

i. To describe the symptomatic cohort in terms of their KOOS-PF scores and their TIPPS classification.
ii. To further explore the efficacy of the taping technique designed to inhibit VL on individuals with PFP, including the effects of the taping technique(s) on self-reported pain and perceived stability scores.

2.18 Hypotheses

2.18.1 First study with asymptomatic participants

1. sEMG
    a. That the active tape condition will decrease the sEMG activity of VL with respect to the no tape baseline condition.
    b. That the active tape condition will increase the sEMG activity of VM and GM with respect to the no tape baseline condition.
    c. That the neutral tape condition will decrease the sEMG activity of VL with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.
    d. That the neutral tape condition will increase the sEMG activity of VM and GM with respect to the no tape baseline condition but with a smaller effect size than that seen with the active tape condition.

2. Acceleration and Gyroscope
    a. That the active tape condition will increase the control of the lower limb with respect to the no tape baseline condition which will be reflected by decreased acceleration and angular velocity values.
    b. That the neutral tape condition will increase the control of the lower limb with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.

2.18.2 Second study which involved symptomatic participants

1. sEMG
    a. That the active tape condition will reduce the sEMG activity of VL with respect to the no tape baseline condition.
    b. That the active tape condition will increase the sEMG activity of VM and GM with respect to the no tape baseline condition.
    c. That the neutral tape condition will reduce the sEMG activity of VL with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.
    d. That the neutral tape condition will increase the sEMG activity of VM and GM with respect to the no tape baseline condition but with a smaller effect size than that seen with the active tape condition.

2. Acceleration and Gyroscope
    a. That the active tape condition will increase the control of the lower limb with respect to the no tape baseline condition which will be reflected by decreased acceleration and angular velocity values.
    b. That the neutral tape condition will increase the control of the lower limb with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.

3. Pain
    a. That the active tape condition will decrease the pain as reported by the participants on a numerical pain rating scale with respect to the no tape baseline condition.

b. That the neutral tape condition will decrease the pain as reported by the participants on a numerical pain rating scale with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.

4. Perceived Stability
    a. That the active tape condition will increase the perceived stability as reported by the participants on a Likert scale with respect to the no tape baseline condition.
    b. That the neutral tape condition will increase the perceived stability as reported by the participants on a Likert scale with respect to the no tape baseline condition but with a smaller effect than that seen with the active tape condition.

Chapter 3 General Methods

3.1 Introduction

The first of the two studies in this thesis involved data collection from asymptomatic participants which was deemed necessary to determine the effect of the taping conditions on the muscle activity and movement control data before proceeding to data collection from symptomatic participants with PFP. It also provided an opportunity for the methodology to be further explored prior to working with a symptomatic cohort.

3.2 Delsys Trigno System

The Delsys® Trigno™ Wireless EMG System (Delsys Inc. Boston, USA) was used to collect synchronised muscle activity (sEMG) and movement control (IMU) data (see Figure 3.1). This hardware comprises of a Trigno base station which receives transmitted data from Trigno wireless sensors. The sensors are small and lightweight, with the dimensions being 27 x 37 x 13mm, with a weight of 14g. There was an internal signal bandwidth of 20 - 450Hz and an inter-electrode distance of 10mm. The relative merits of these factors are reviewed in section 2.14.

Figure 3.1 The Delsys® Trigno™ Wireless sEMG System – Base Station (left) and sEMG/IMU Sensors (right)

3.3 Sensor Details and Placement

3.3.1 The sEMG Sensors

Three Trigno™ sEMG sensors were used to capture sEMG data from VM, VL and GM, i.e., one per muscle. Prior to the sensors being attached to the skin over the relevant muscles, the skin was prepared to reduce electrical impedance and improve the fidelity of the sEMG signal (Chen et al 2018b). Section 2.14.3 presents the arguments for various ways to prepare the skin prior to electrode attachment. In order to minimise the impact of their participation on the participants whilst still obtaining sEMG signals of high fidelity, this study used the cleansing only method, using alcohol wipes to clean both the skin and the sensors/electrodes.

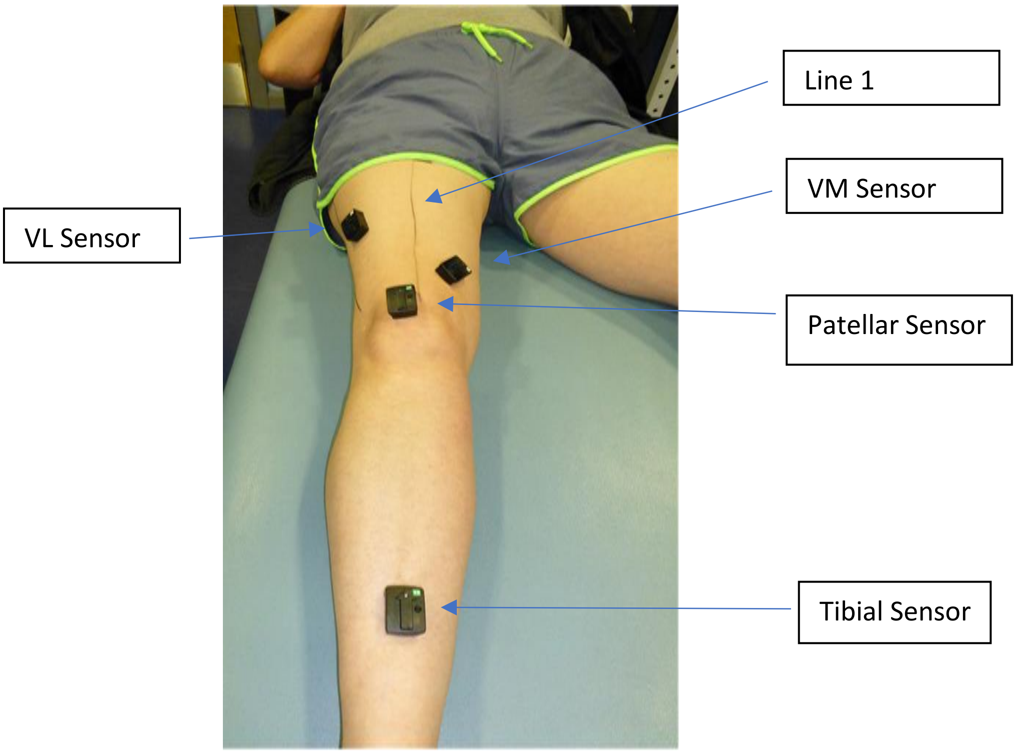
With the exception of the GM sensor, the positions of the sEMG sensors can be seen in Figure 3.2. The VM sEMG sensor was placed approximately 4cm superior to and 3cm medial to the superomedial border of the patella. The sensor was orientated approximately 55° medially to the vertical (Lee et al 2012, Akkurt et al 2010, and Cowan et al 2006), in order to align it with the underlying muscle fibres with the arrow on the sensor pointing towards the origin of the muscle. The VL sEMG sensor was placed approximately 10cm superior to and 6-8cm lateral to the superior border of the patella. The sensor was aligned approximately 15° to the vertical to aligned to the underlying muscle fibres with the arrow on the sensor pointing towards the muscle origin (Lee et al 2012, Akkurt et al 2010, and Cowan et al 2006). The GM sEMG sensor was placed just distal to the lateral portion of the iliac crest (Earl et al 2005), with the arrow on the sensor pointing towards the iliac crest. Each of the sensors was placed over the belly of the muscle to reduce the potential for crosstalk (Basmajian and De Luca, 1985). Confirmation that the electrodes were indeed placed over the muscle belly in question was achieved through visual inspection and palpation during muscle contractions of VM and VL elicited by extending the knee. For GM, this confirmation was achieved by visual inspection and palpation of the muscle during an exercise known as “the clam” which is known to require GM recruitment. The clam exercise was performed whilst side lying with the testing leg uppermost. The participant was then required to raise their uppermost knee without lifting the ankle, thus recruiting GM to abduct and externally rotate their hip. All sEMG sensors were fixed using hypoallergenic adhesive interfaces, with the stability of each attachment being tested manually. Finally, all the sensors were drawn around to facilitate accurate replacement in case there was intra-testing movement, although, no sensors were dislodged once they had been suitably placed.

Once the sEMG sensors had been placed and checked, the SNR was checked to gauge the fidelity of the signal. This was done before data collection began for each participant and was monitored throughout the data collection session.

3.3.2 The IMU Sensors

Two Trigno™ IMUs (see Figure 3.2) were used to evaluate the movement control of the lower limb during stair descent. One sensor was placed centrally over the patella with the arrow pointing proximally. The second IMU sensor was placed on the anterior surface of the tibia, one third of the tibia length proximal to the ankle joint line and in a direct vertical line with the patellar sensor with the arrow again pointing proximally. Both sensors were fixed with double sided hypoallergenic adhesive interfaces, and their positions are shown in Figure 3.2.

Figure 3.2 The Placement of the sEMG and IMU Sensors (Gluteus Medius not shown).



3.3.3 The Force Sensitive Resistor

A Trigno™ force sensitive resistor (FSR) was taped to the underside of the head of the first metatarsal on the study limb (see Figure 3.3) which was used to identify the timing of foot contact and toe off during stair descent. This has been described previously by McCarthy Persson (2009). Participants were encouraged to use their own flat footwear during testing, as described by Crossley et al (2004). Care was taken when placing the foot into the participants' footwear to minimise the risk of dislodging the FSR.

Figure 3.3 The Placement of the Force Sensitive Resistor

The FSR signal was checked by examining the signal trace which was completed prior to proceeding to the test trials. If the FSR signal was poor, the FSR was repositioned and the process was repeated until the signal trace was acceptable. This was deemed to be when there were clear increases in force coinciding with the participant putting pressure on the head of their first metatarsal.

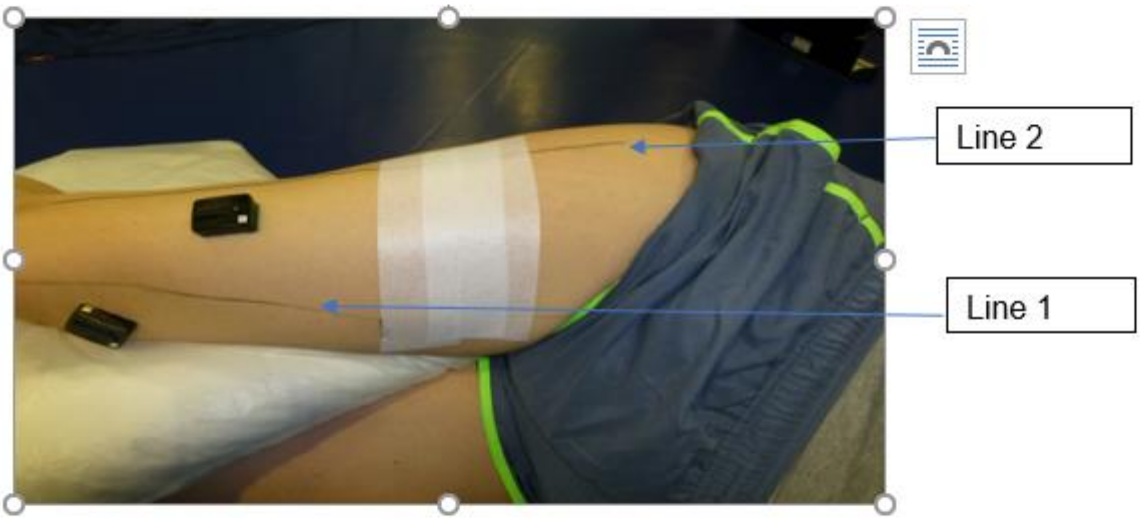
3.4 Taping Conditions

Three conditions were chosen; i) taping with tension, hereafter called the active tape condition, ii) taping without tension, hereafter called the neutral tape condition and iii) a control condition of no tape. The neutral tape condition is not associated with any discomfort until it comes to the removal of the tape at the end of testing. However, the active tape condition can be uncomfortable whilst it is in situ as well as when it is removed. Potential participants were informed of this in the participant information sheet and through verbal explanation prior to them giving their consent. All taping conditions were applied by the researcher who is an experienced physiotherapist. The tape used for all applications was the Leukotape® P combi pack (BSN Medical (Pty) Ltd, South Africa).

In order to standardize placement of the tape for the two taping conditions, two lines were drawn on the study limb which is consistent with previous research (Tobin and Robinson, 2000). The first line was drawn from the anterior inferior iliac spine (AIIS) to the centre of the superior border of the patella, outlining the Rectus Femoris muscle and therefore the anterior border of VL which is shown as line 1 in Figure 3.2 and Figure 3.4. The second line ran from the greater trochanter to the head of the fibula, thereby outlining the iliotibial band (ITB) and the lateral border of VL, which is shown as line 2 in Figure 3.4. The half way point of the AIIS to patella line was also marked, to be used as a guide for the application of the first piece of tape.

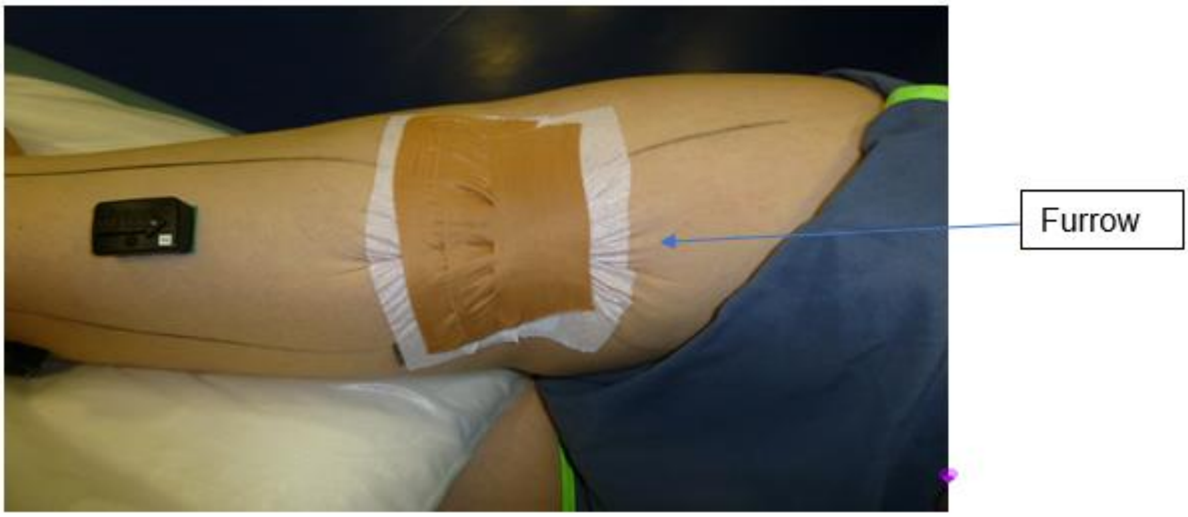
The application of the active taping technique followed the method set by McConnell in her 1995 course notes and described by Tobin and Robinson (2000). Firstly, three strips of hypoallergenic Fixomull® tape were used and applied without tension and care was taken to ensure there were no wrinkles. The first strip was applied transversely between the two lines previously drawn on the test leg with its distal edge alongside the pre-marked halfway point on the AIIS to patella line. The other two pieces of tape were applied more proximally, each one overlapping its predecessor by half the width of the tape (see Figure 3.4).

Figure 3.4 The Three Strips of Fixomull Tape in Situ



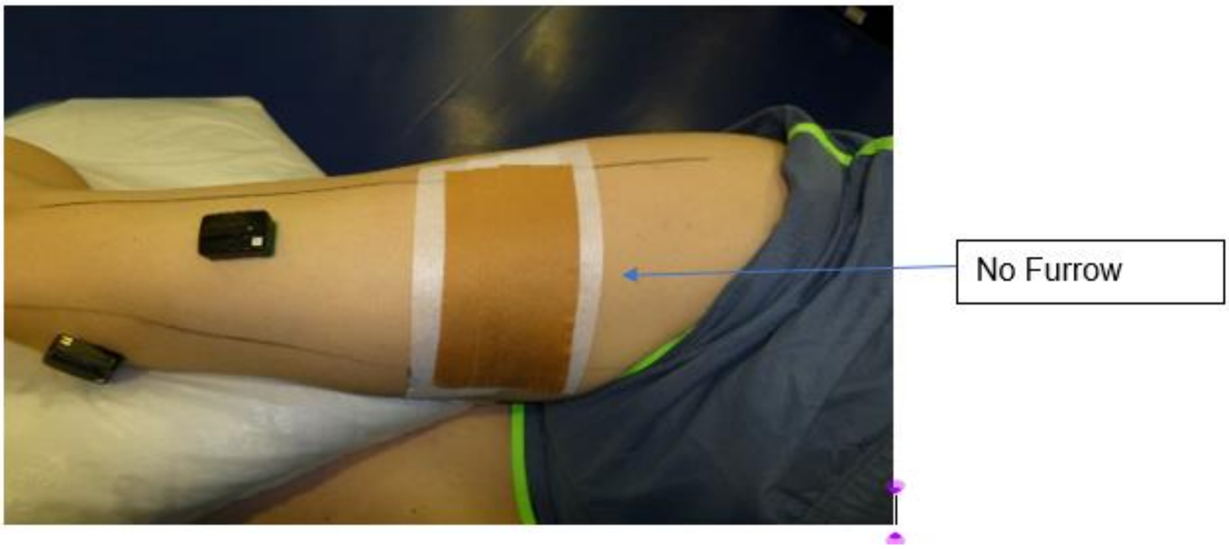
Three strips of rigid Leukotape® were then placed on top of the Fixomull® tape. The first piece was applied to the distal portion of the Fixomull® on the anterior thigh, and was then pulled firmly in a posterolateral direction while simultaneously collecting the lateral thigh tissues and pulling them anteriorly with the other hand. The tape was then attached to the Fixomull® on the posterolateral thigh. Strips two and three were applied in exactly the same way as the first strip, with each being positioned half a tape's width proximal to its predecessor and the desired outcome being the creation of a longitudinal furrow in the skin over VL (see Figure 3.5).

Figure 3.5 The Three Strips of Leukotape over the Fixomull Tape for the Active Tape Condition.



For the neutral tape condition, the same amount of Fixomull® tape was applied in exactly the same way but the Leukotape® was applied without tension or tissue movement (see Figure 3.6).

Figure 3.6 The Full Taping In Situ for the Neutral Tape Condition.



For the current study, the right leg of each participant was chosen to be the study limb. This followed the precedent of Brindle et al (2003) and Brechter and Powers (2002).

3.5 Testing Order and Washout Period

The order in which the three test conditions were applied was randomized using a dice where numbers 1 and 2 represented the no tape condition, numbers 3 and 4 represented the neutral tape condition and numbers 5 and 6 represented the active tape condition. To minimise the possibility of any carry-over effects of each taping condition, a washout period of five minutes was included in the testing procedure, as recommended by Selfe et al (2011), Aminaka and Gribble (2008) and Cowan et al (2006).

3.6 Participant Recruitment and Demographics

A convenience sample of thirty asymptomatic participants were recruited from the staff and student population at the University of Central Lancashire (UCLan). Although this was a convenience sample, it is possible that some people within this population could have PFP and therefore this sample still has relevance and some generalisability. All potential participants were screened for the inclusion/exclusion criteria for the study. Inclusion and exclusion criteria were:

1) Aged between 18 and 60 years old. Although there is often an upper age limit of 40 for symptomatic participants in patellofemoral research, this is

usually to negate the possibility of there being PF OA changes influencing the symptoms (Leibbrandt and Louw 2018). However, this is not an issue with an asymptomatic sample.

2) No history of lower limb or spinal pathologies (Selfe et al 2008).
3) No known allergy to tape (Hinman et al 2003).
4) Able to attend UCLan for a data collection session

Two potential participants were excluded based on their previous history of lower limb surgery.

3.7 Ethical Considerations and Approval

Prior to data collection commencement, all participants were given a participant information sheet to read and all participants gave written informed consent (see Appendices 2 and 3) and were informed of their right to withdraw at any time during the data collection session without giving any reason. All participant information was coded and fully anonymised. All paper-based data collected for each participant, including their informed consent, was stored in a locked cabinet at UCLan. Furthermore, the muscle activity and movement control data were collected on a password-protected laptop and stored on OneDrive. Ethical approval was granted by the University of Central Lancashire's Science, Technology, Engineering, Medicine, Health Ethics Committee (STEMH 283).

3.8 Data Collection

3.8.1 Sample Size

A previous study (Roy et al 2016) found a mean difference for tape applied without tension of 1.08 degrees with a SD of 1.08 degrees. When considering 90% power and 5% significance level, at least 22 participants are needed to detect a difference. The current study elevated the size of the cohort to 30 participants to allow for any drop outs and because this was a new exploratory study meaning that more participants may be needed in order to detect any differences.

3.8.2 Demographic Data

For each participant, their sex, age, height and weight were recorded and their BMI was calculated.

3.8.3 Stair Descent Tasks

Participants were required to descend a series of steps to examine the effect of the taping conditions on the muscle activity and lower limb control. Stair descent is a functional, everyday activity and it has been previously reported that people with PFP often experience pain during this task (Leibbrandt and Louw 2017, Selfe et al 2008). It has also been described as a clinical criterion in the diagnosis of PFP (Selfe et al 2013). However, most studies have only explored the effect of one stair riser height (De Oliveira Silva et al 2016; McCarthy Persson et al 2009). This current study used a stair unit with two riser heights, one with four steps with a 13cm riser height and the other with three steps with a 18cm riser height (see Figure 3.7). The use of two different stair riser heights allowed the exploration of the effects of riser height on muscle activity and lower limb control during stair descent.

Each asymptomatic participant descended the lower riser height first followed by the high riser height. Participants were instructed to lead with the study limb and descend the stairs at their own, self-selected speed whilst not using the handrails unless required to maintain balance (DeOliveira Silva et al 2016, Crossley et al 2004). Had a participant used the handrail, that trial would have been repeated, however this was not necessary at any point in the study. Although a number of studies have used a metronome to control participants' stair descent speed (Kim and Song 2012, Cowan et al 2006), others have not (Burston et al 2018, Aminaka et al 2011, Cavazzuti et al 2010 Zachazewski et al 1993). Within the current study, participants were asked to descend the stairs at a self-selected speed as this more closely reflected real-world situations. A cue was given to start each trial "3-2-1-Go", and five trials were conducted under each taping condition, for each stair riser height, with the number of repetitions being consistent with past research (Selfe et al 2011, Cavazzuti et al 2010, Janwantanakul and Gaogasigam 2004 and Gilleard et al 1998).

Figure 3.7 Corner Step Unit with Two Riser Heights

Chapter 4 Methods of Analysis

4.1 Introduction

This section describes the steps taken in processing the collected muscle activity and movement control data in order to ensure that they are clear, repeatable and offer appropriate functional analysis.

4.2 Data Collection

The data from the eccentric phase from the middle step, as identified from the FSR data, was collected and subsequently used for analysis. This reflects the protocol used in studies by Aminaka et al (2011) and Cowan et al (2006 and 2001). The muscle activity (sEMG) and the movement control (IMU) data were collected using the EMGworks Acquisition (version 4.2) software (Delsys, MA, USA). Once collected, the data from each trial for each condition were exported to *.c3d file format and resampled at 2000Hz using Delsys File Utility (Delsys, MA, USA), and were imported into Visual 3D (C-Motion Inc., USA) for further processing and analysis.

4.3 Identification of Step Events

Once in Visual 3D, the FSR, VM and tibial sagittal plane angular velocity profiles were inspected visually to identify the different phases of stair descent, for example the stance phase of the study limb on the step. The study limb's stance phase on the middle step was chosen for data analysis, with the start and end of the stance phase being represented by the purple vertical lines within the traces highlighted in Figure 4.1. Foot contact, which signified the onset of the stance phase, was depicted as the increase of the FSR signal from the baseline (see Figure 4.1), and corresponded to the moment the head of the first metatarsal made contact with the step of interest, as described by Paoloni et al (2012) and McCarthy Persson et al (2009). In addition, this FSR signal was cross referenced with the onset of VM activity and the sagittal plane tibial angular velocity as there were distinct changes in muscle activity and tibial kinematics during the stance phase. The end of the stance phase was identified by the FSR signal returning to baseline, corresponding to the moment when the head of the first metatarsal was no longer in contact with the step. The areas outside the purple vertical lines were not part of the stance phase and were therefore not used in subsequent analysis.

Figure 4.1 Identification of the Footswitch (FSR), VM Activity and Sagittal Plane Angular Velocity Events for the Contact Phase of the Stair Descent

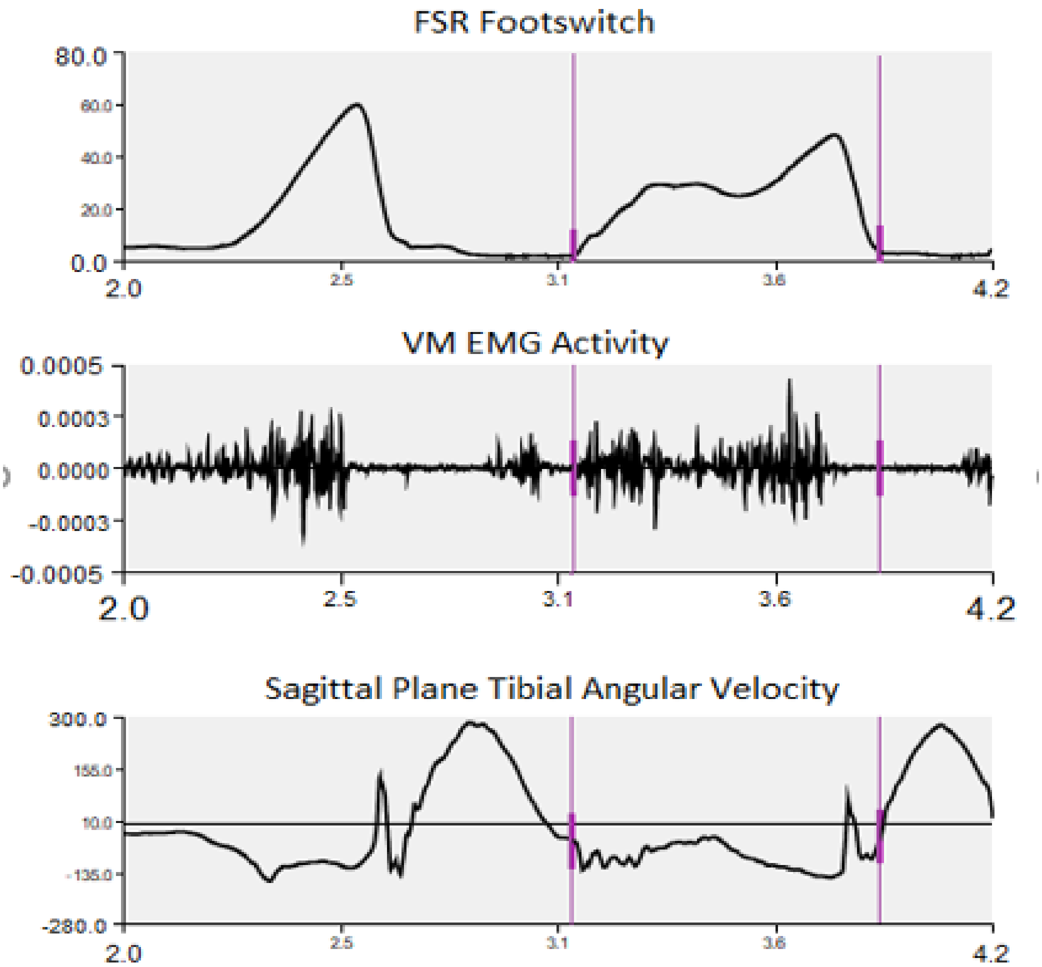
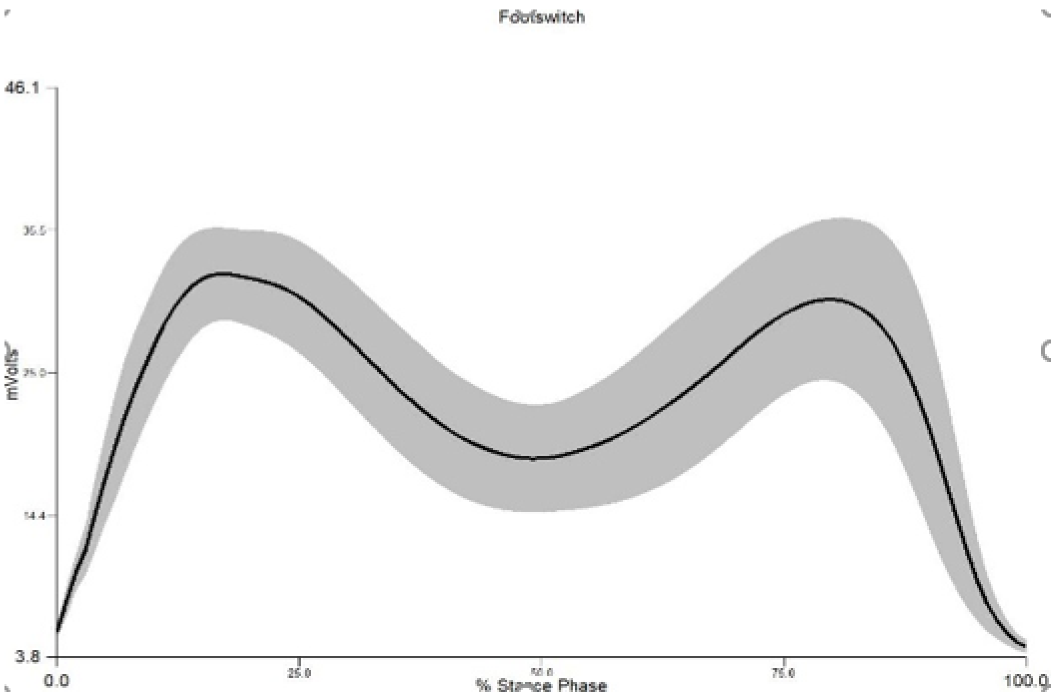


Figure 4.2, with its two peaks and relative middle area trough, can be viewed as clear evidence that there were different sub-phases within the stance phase. The initial steep increase (from 0% on the x axis) corresponds to the first contact of the foot on the step and the start of the stair descent cycle with weight acceptance in double leg support. This correlates with the early phase, i.e., the first 20% of the stance phase, described by McFadyen and Winter (1988). The sharp drop towards the end of the graph corresponds with toe-off at the end of the cycle and this time correlates with the late phase, i.e., the final 50% of the stance phase, again described by McFadyen and Winter (1988). The middle portion of the graph represents the move from the double limb support phase into the single limb

support/controlled lowering phase where the foot becomes flat on the step, before moving into the second double limb support phase. This would correlate with the mid-phase, described by McFadyen and Winter (1988) as occupying 21-50% of the whole stance phase. To explore these events in more detail a second footswitch on the contralateral foot was subsequently added when testing the patient cohort (See chapter 6 for more details), however a second sensor was unavailable during the time of testing of the healthy cohort.

Figure 4.2 FSR Images from Visual 3D



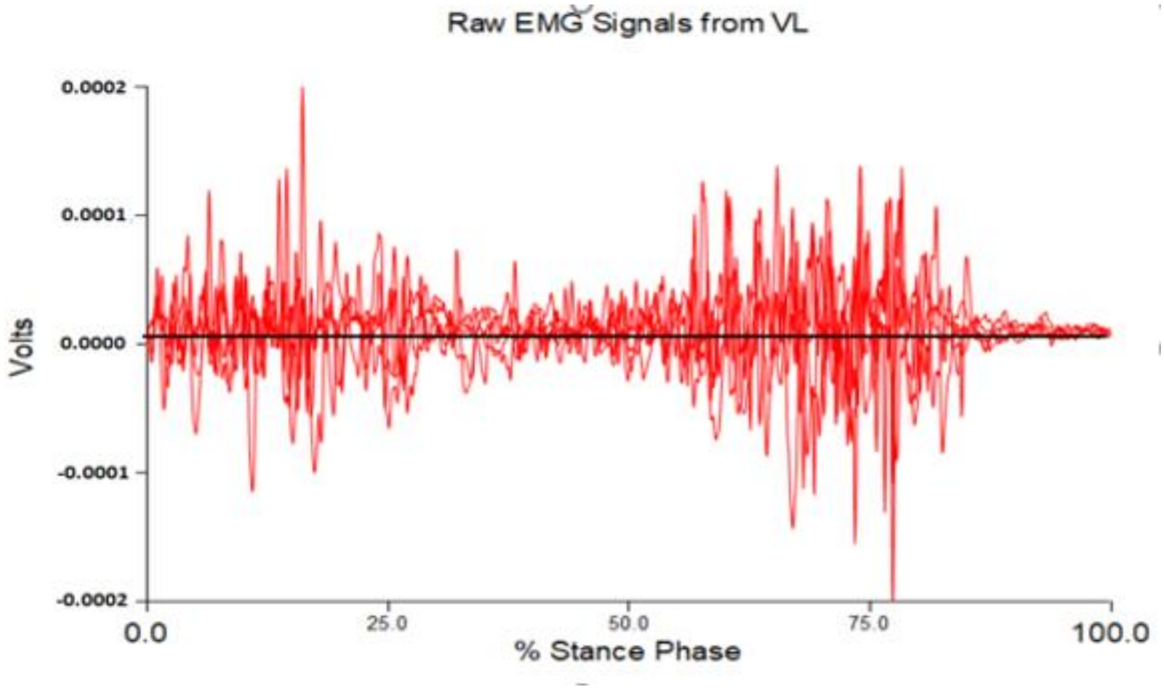
4.4 sEMG Processing

4.4.1 Raw sEMG Traces

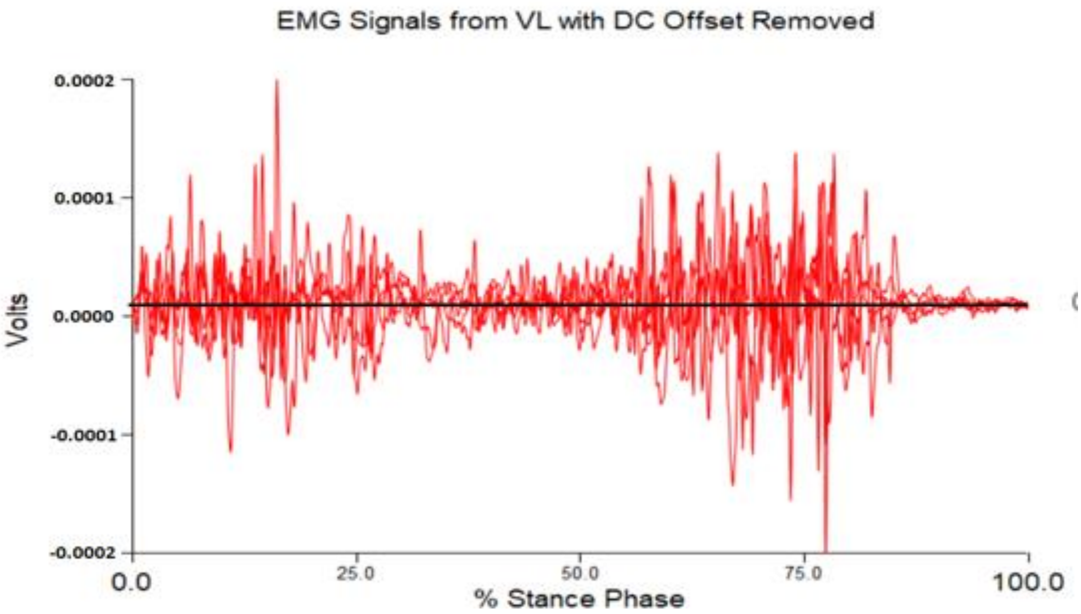
The graphs comprising Figure 4.3 all clearly illustrate that there were two distinct phases of increased activity within the stance phase. Figure 4.3a depicts the raw sEMG signal for VL during the foot contact (stance) phase of stair descent. Figure 4.3b illustrates the same VL sEMG signal with the DC offset removed, which was achieved by subtracting the mean of the signal from the raw sEMG data. As discussed in section 2.14.7, this corrects the oscillation of the signal from being above or below the zero line to around the zero line (De Luca 2010). This signal was then high pass filtered with a cut off frequency of 25Hz to reduce movement artefact, and this is illustrated in Figure 4.3c.

Figure 4.3 a) Raw sEMG Traces from VL, b) sEMG Traces from VL with DC offset removed, c) High-Pass Filtered sEMG Traces from VL

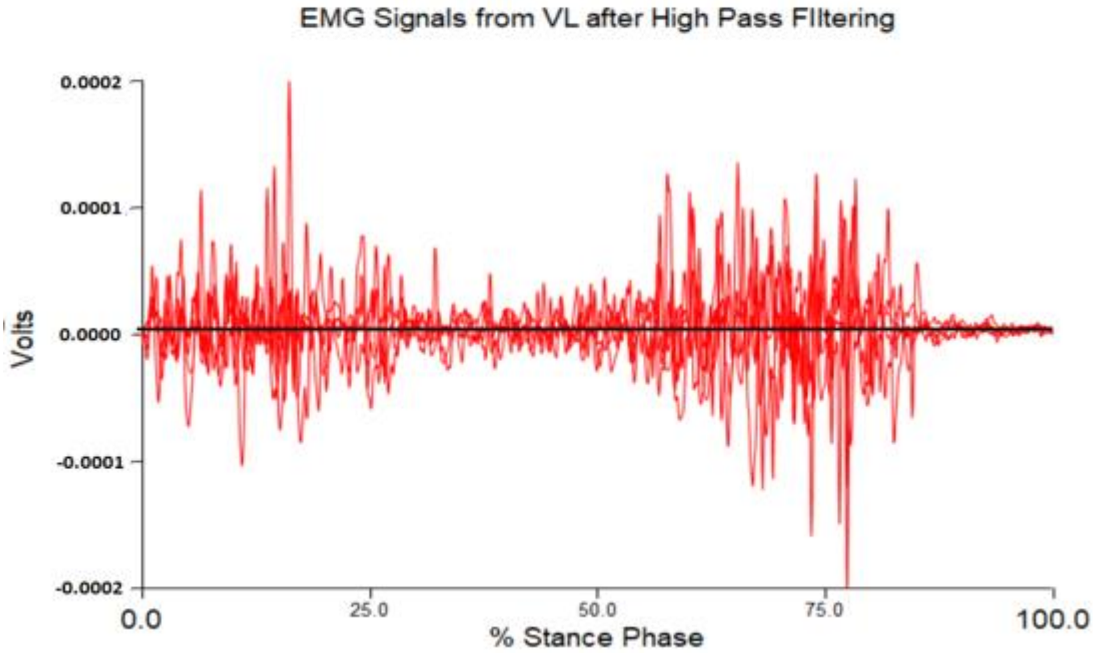
a)



b)



c)



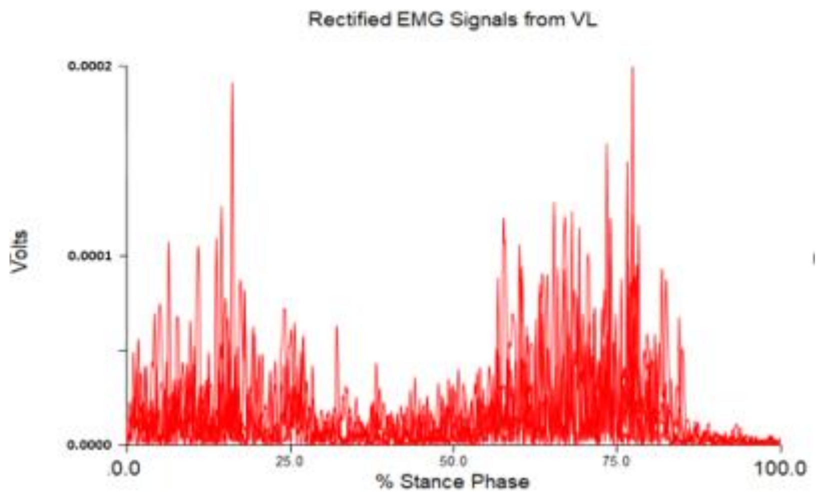
4.4.2 sEMG Rectification and Enveloping

As highlighted in section 2.14.9, rectification is a useful process to apply to raw sEMG data. It can be either half-wave or full-wave; with half-wave discarding all the negative values and full-wave retaining all the values by converting the all the negative values to positive values. Section 2.14.9 also highlighted that rectification also facilitates further sEMG data analysis since the integrated sEMG signal, which is important for determining the work done by a muscle, is derived from the rectified signal. Within this thesis, both studies used full-wave rectification, which was achieved by first squaring all the values then taking the square root of these values to render their original value as positive. The effect that full-wave rectification has on the raw data is illustrated in Figure 4.4a and can clearly be seen by comparing it with Figure 4.3a.

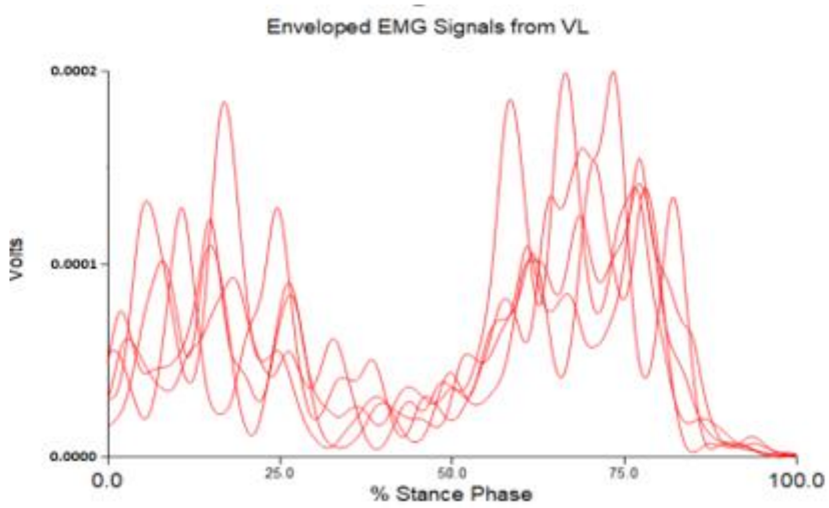
Again, as highlighted in section 2.14.9, enveloping is a process by which the raw sEMG traces can be smoothed by applying a low-pass filter to the EMG data which allows the retention of the low frequency components of the signal while rejecting the higher frequency components. The two studies within this thesis used a low pass frequency of 20Hz, in accordance with the recommendations of De Luca et al (2010), Figure 4.4b illustrates the smoothing effect of enveloping the rectified sEMG signal.

Figure 4.4 a) Rectified sEMG Signals from VL, b) Enveloped sEMG Signals from VL

a)



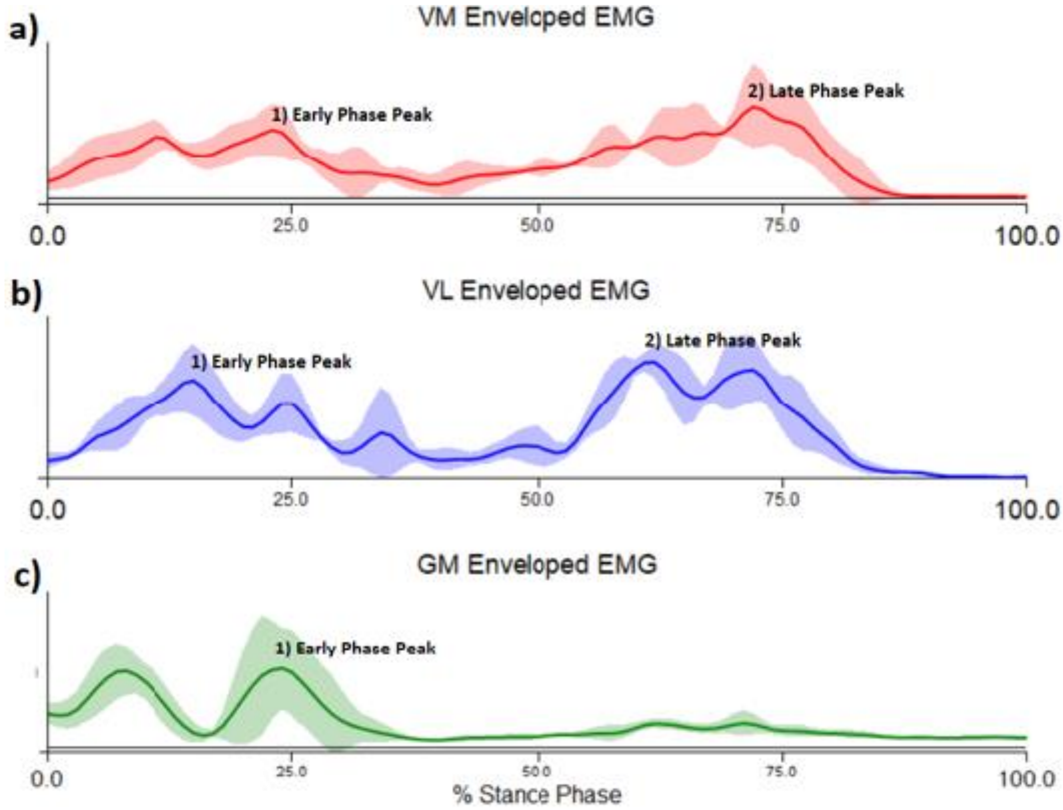
b)



4.4.3 Patterns of sEMG signals from VM, VL and GM

Figures 4.5a and 4.5b illustrate the VM and VL traces and highlight that there were two periods of increased activity, one at the start of the step descent; (1) early phase peak which corresponds with the early phase described by McFadyen and Winter (1988) as being the first 20% of the stance phase, and the other increase in muscle activity towards the end (2) late phase peak, which represents the late phase or the final 50% of the stance phase (McFadyen and Winter 1988). The VM and VL traces look very similar to each other but very different from the GM trace which can be seen in Figure 4.5c. The GM trace shows an initial period of increased activity followed by a period of consistent, lower-level activity during the rest of the stair descent. The VM and VL traces in contrast indicate a clear period of increased activity as the participant moved into double leg support, i.e., the initial contact or toe strike of the tested leg with the step. There was then a period of lower-level activity which corresponds to the double support phase before a longer period of increased activity which corresponds with the participant moving into single support during the controlled lowering phase. Finally, the period of lower-level activity at the end of the trace corresponds with the weight acceptance of the contralateral limb as the participant moved into the second period of double support, towards the end of the step descent cycle. This allowed for the peak enveloped sEMG for VM and VL to be identified during these two phases, points 1 and 2 in Figure 4.5 a and b, along with the peak sEMG during the early phase in the GM data, point 1 in Figure 4.5 c.

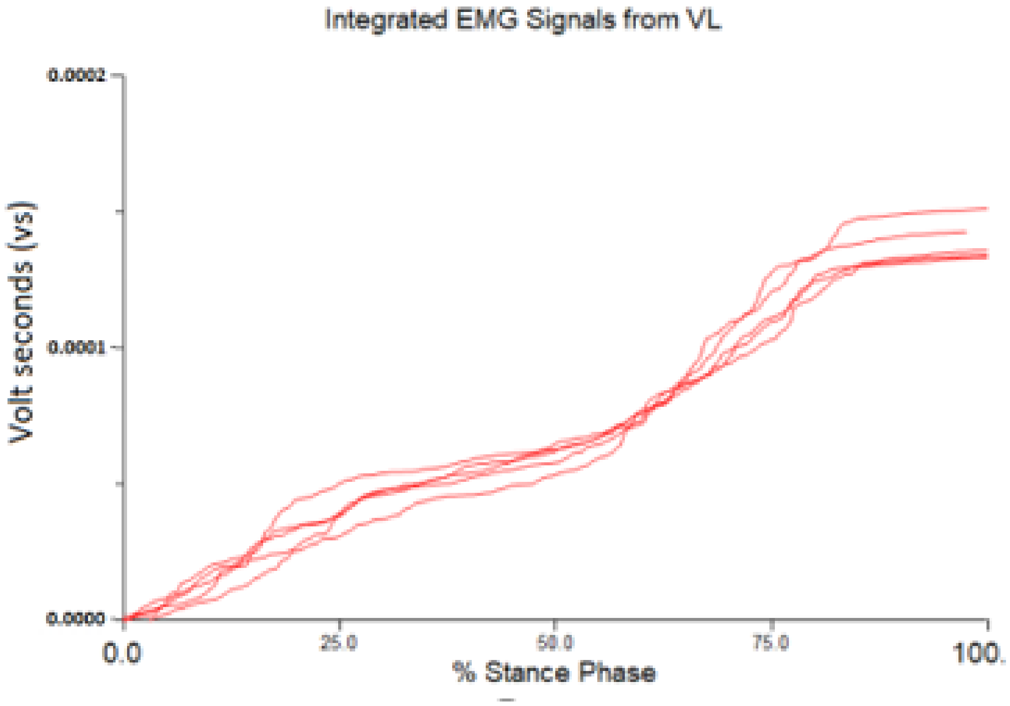
Figure 4.5 Patterns of a) VM, b) VL and c) GM Activity from the Enveloped sEMG Signals



4.4.4 Integrated sEMG

Integrated sEMG signals provide information regarding the activity of the muscle(s) in question over the whole task that is being examined (Richards et al 2008). The integrated sEMG represents the area under the curve of the rectified sEMG signal and therefore allows the sum of the muscle activity during the whole activity to be identified. The end point or maximum value of the integrated signal has been reported to represent the overall work done by the muscle, with the integrated sEMG signal reflecting the level of physiological activity and overall muscle effort during the stance phase of stair descent (Miao et al 2015). Figure 4.6 shows an example of an integrated sEMG signal for VL.

Figure 4.6 An Integrated sEMG Trace for VL



4.4.5 EMG Normalisation

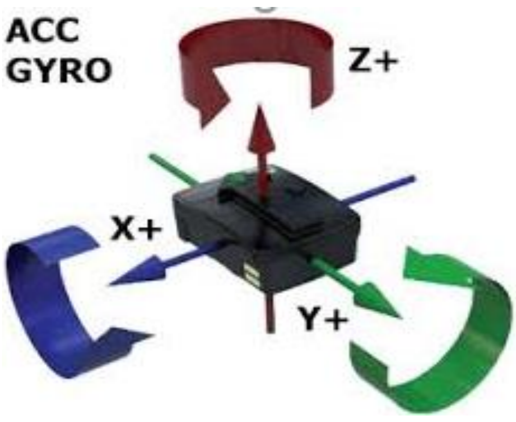
As discussed in section 2.14.7, normalisation of the sEMG data allows data collected from different participants and different muscles to be compared (De Luca 1997). Therefore, normalisation can be said to provide the basis from which a comparison of the differing force capabilities of a given muscle(s) can be made (De Luca 1997). The maximum value within each of the five trials for each of the sEMG signals from each muscle was determined. Then the maximum observed signal across all trials and across all conditions was found. Next, the mean rectified and the maximum enveloped signals for each condition were normalised against the respective maximum observed signal for each muscle, this was achieved by dividing each data point by the respective maximum observed value.

4.5 IMU Processing

4.5.1 Introduction to IMUs

IMUs are small, lightweight and effective devices for collecting biomechanical data. They allow the collection of data in three directions using accelerometery and three planes of rotation using gyroscopes. Figure 4.7 shows a depiction of the rotations and directions of accelerations that may be measured using IMUs. The curved arrows represent the rotations and the straight arrows represent the accelerations. When considering the tibial and patellar accelerometer data, the X channel represented the medial/lateral accelerations, the Y channel represented vertical accelerations, while the Z channel represented anterior/posterior accelerations. With respect to the gyroscope data, the X channel represented flexion/extension in the sagittal plane, the Y channel shows the external/internal rotation in the transverse plane, and the Z channel shows the adduction/abduction in the coronal plane.

Figure 4.7 Movements Captured by the IMU Sensors



4.5.2 Tibial Accelerometer Data

Figure 4.8 depicts an example of the tibial medial-lateral acceleration during the stance phase during stair descent. Negative values for the tibial accelerometer represented medial accelerations and the positive values represented lateral accelerations. With reference to different stages of stair descent considered in

Section 2.13, the greatest acceleration occurs at the start of the step descent, indicating an initial medial acceleration followed by a lateral acceleration during the early phase. This is followed by a smaller medial acceleration during the middle phase, which was identified by McFadyen and Winter (1988) as being the middle 21-50% of the stair descent of the single leg support phase, before a further small medial and then lateral acceleration toward the late stance phase, which corresponds to the last 50-100% of the stair descent. Key measurements during the different phases were; minimum and maximum values during the early phase of (20%) stair descent; the peak minimum and maximum values in the late phase (second half) of the stair descent; and finally, the range of medial and lateral acceleration seen during the whole of the stance phase during step descent.

Figure 4.8 Tibial Medial-Lateral Acceleration

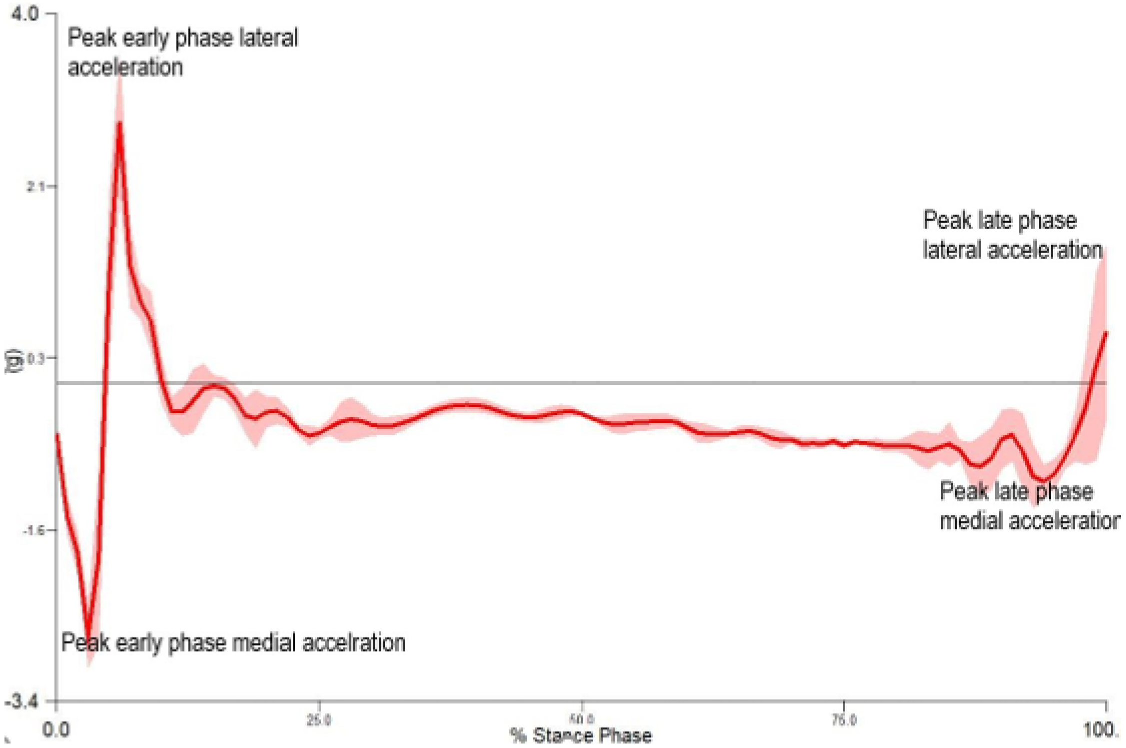
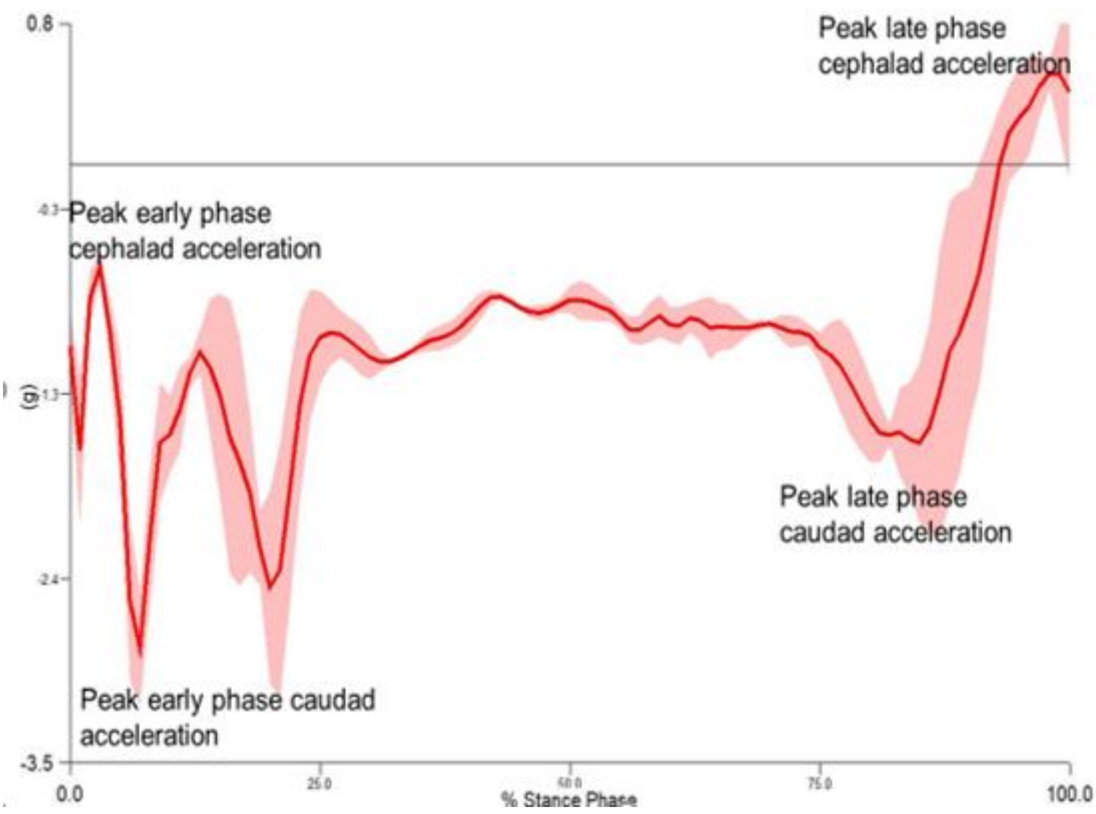


Figure 4.9 illustrates the vertical tibial acceleration with positive values representing acceleration in a cephalad direction. This figure illustrates that there was an initial increase of downwards (caudad) acceleration as the participant moved into double leg support at the start of the stair descent cycle followed by a period of relatively slow downwards acceleration during single leg support,

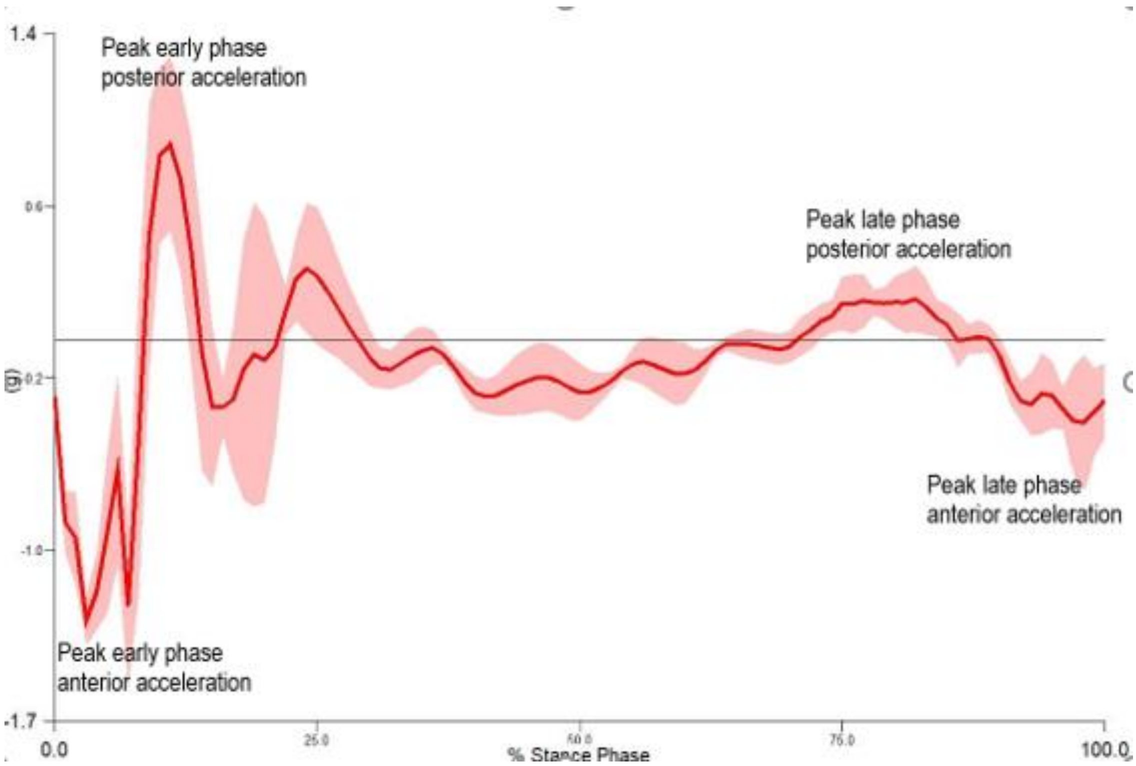
before a final increase in upwards (cephalad) acceleration as the person moved from single leg support into double leg support at the end of stance phase.

Figure 4.9 Tibial Vertical Acceleration



The Z channel describes the anterior-posterior acceleration, with the anterior movements represented by the negative values and the posterior movements being represented by the positive values. Figure 4.10 illustrates the anterior-posterior tibial acceleration, and shows that a large range of anterior acceleration occurred initially followed by a posterior acceleration occurring during the weight acceptance and forward continuance phases. After this, there was a relatively stable phase where there was minimal anterior-posterior acceleration, which corresponds with the controlled lowering phase. Finally, there is more anterior acceleration before a slight move into posterior acceleration during the movement into the second period of double leg support at the end of the stance phase of step descent.

Figure 4.10 Tibial Anterior-Posterior Acceleration.



4.5.3 Tibial Gyroscope Data

The X channel represents the flexion and extension angular velocities of the tibia in the sagittal plane during the step descent, with flexion movements represented by the negative values and extension by the positive values. Figure 4.11 shows that there was an initial quick increase in the flexion angular velocity during the initiation of the movement followed by a more sustained period of flexion during the controlled lowering phase, before an increase in angular extension velocity at the end of the stance phase. It can also be seen that during the early part of the step descent, the range of tibial angular velocity is greatest although this does increase again at the end of stance phase within the step descent. The middle phase, which corresponds with the single leg support phase/controlled lowering phase of the stair descent cycle, shows the tibia moving into more flexion.

Figure 4.11 Tibial Angular Flexion/Extension Velocity in the Sagittal Plane

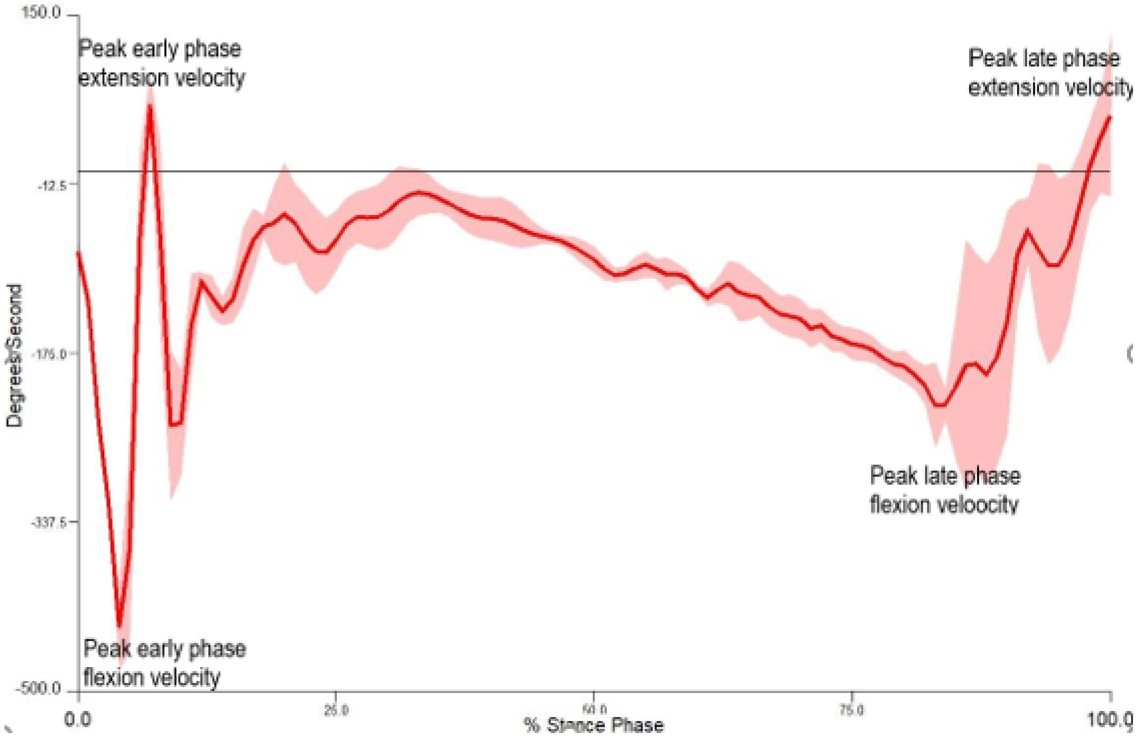


Figure 4.12 illustrates the tibial angular velocity in the transverse plane which represents the internal and external rotational movements of the tibia. Positive values represent external rotation while the negative values represent the internal rotation velocity. The lower the range of these movements, the greater the control and stability that is being shown during the activity. It can be seen that there are two key movements, one initially as the person moves into double leg support at the start of the stair descent cycle, followed by a stable middle phase with little movement while the person is in single leg support, followed by a second movement towards external rotation at the end of the stance phase during the second period of double leg support.

Figure 4.12 Tibial Angular Velocity in the Transverse Plane (Internal/External Rotation)

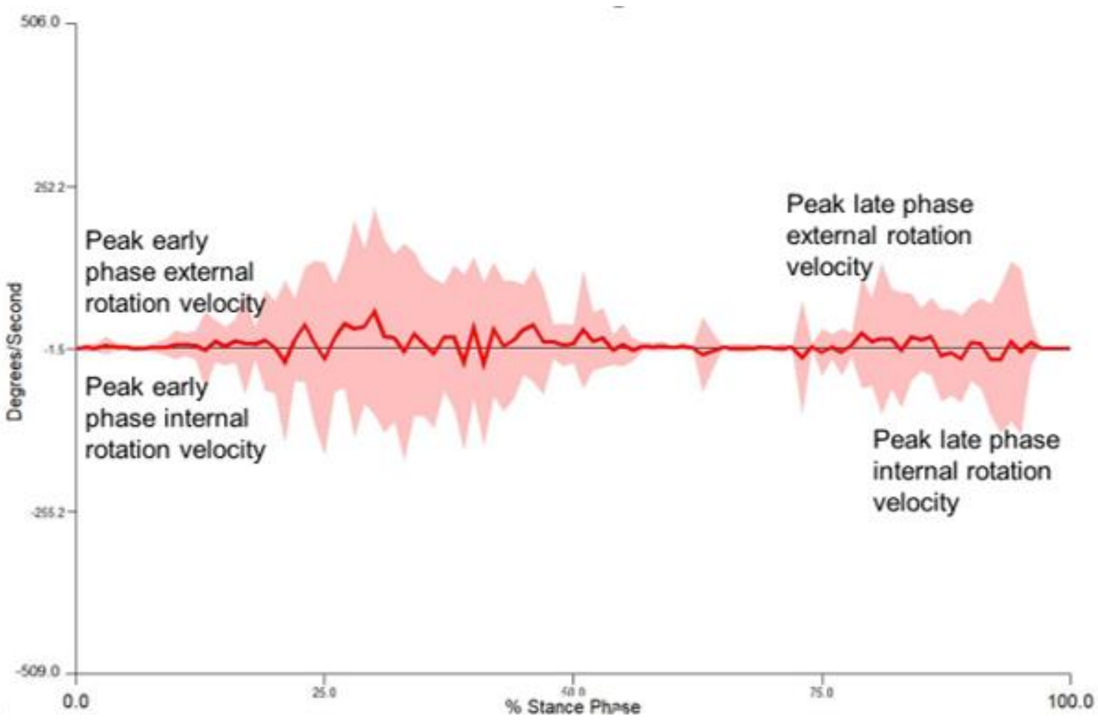
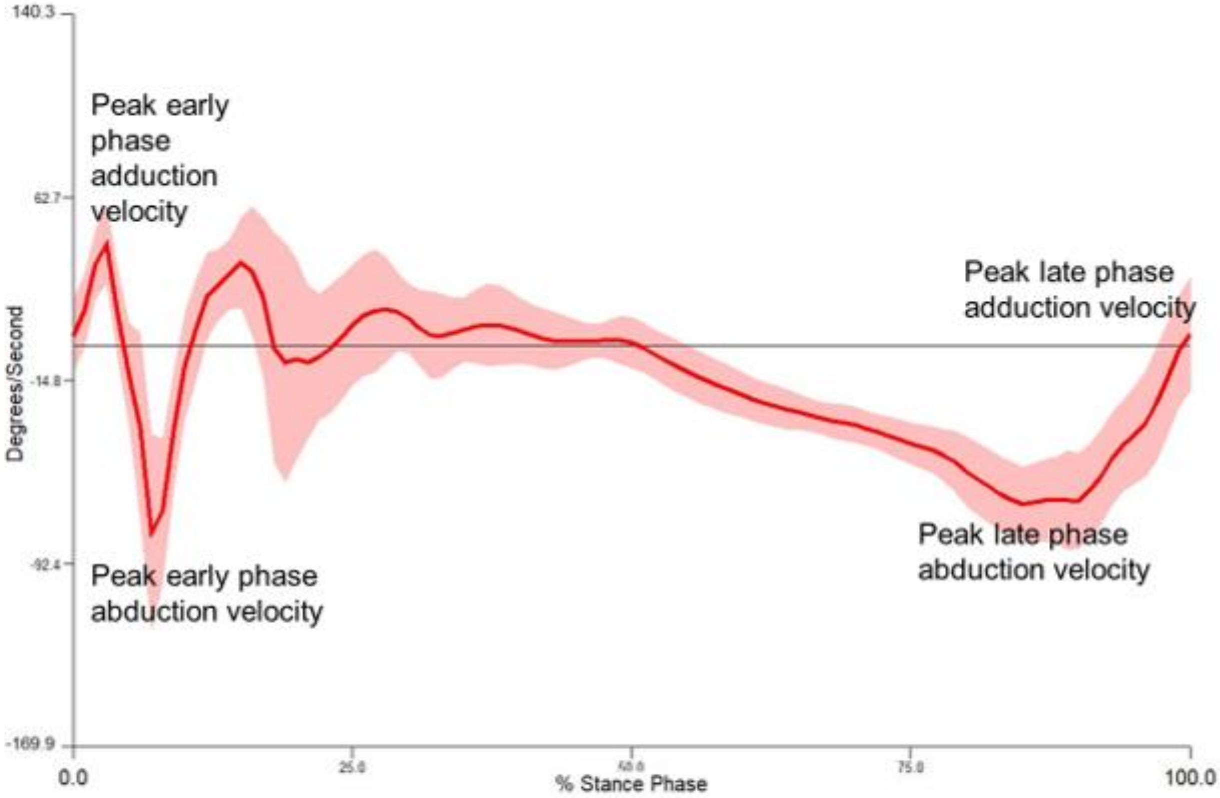


Figure 4.13 illustrates the Z channel which represents the tibial angular velocity in the coronal plane. This reflects the abduction and adduction movement of the tibia with the positive values representing adduction velocity and negative values represent the abduction velocity. Figure 4.13 demonstrates that the tibia moves slightly into adduction before a large abduction movement and a subsequent large movement towards adduction, which corresponds to the weight acceptance phase. There is then a phase where the tibia is not rotating much into either abduction or adduction, although what movement is there is into abduction, during the forward continuance and controlled lowering phases before a final movement into adduction at the end of the stance phase.

Figure 4.13 Tibial Angular Velocity in the Coronal Plane (Abduction/Adduction)



4.5.4 Patellar Accelerometer Data

As with the tibial acceleration discussed above (section 4.3.3.1), the patellar acceleration is considered in the three channels with the X channel showing the medial-lateral acceleration, the Y channel showing the vertical acceleration and the Z channel showing the anterior-posterior acceleration. Figure 4.14 illustrates the medial-lateral acceleration with negative values representing medial accelerations and positive values representing lateral accelerations. Therefore, it can be seen that there is an initial laterally directed acceleration followed by a large medially directed acceleration, which correspond to the weight acceptance and forward continuance phases. These are in turn followed by another lateral acceleration, before a period of reduced acceleration which corresponds with the single leg support phase, before the medial acceleration increases again towards the end of the stance phase of the step descent.

Figure 4.14 Patellar Medial-Lateral Acceleration

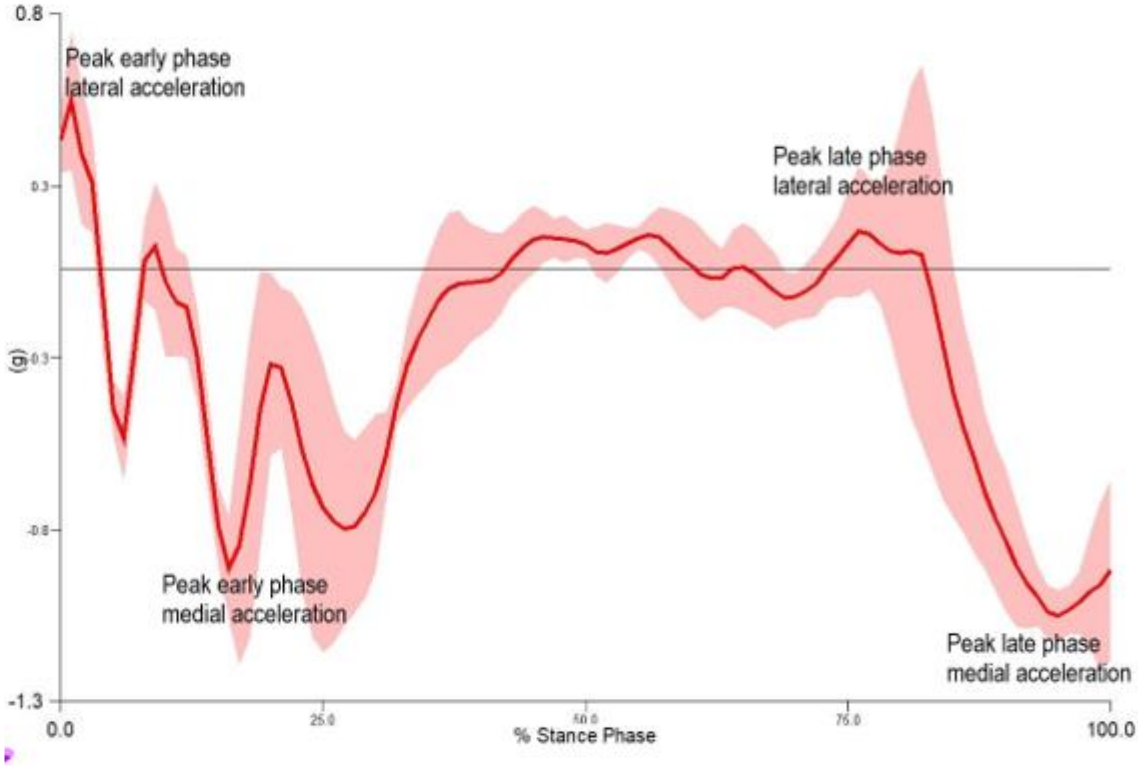


Figure 4.15 illustrates the vertical patellar acceleration, and it can be seen that it follows a similar pattern to that of the medial-lateral patellar acceleration (Figure 4.14). Within both figures, there are distinct areas of greater acceleration at the start and end of the stance phase of the step descent, and a period of slower acceleration in between these two peaks of activity level. This pattern again corresponds with the move from double leg support at the start of the cycle, through the single leg support phase and into double leg support at the end of the cycle. This trace is also similar to the vertical trace for the tibia shown in Figure 4.9.

Figure 4.15 Patellar Vertical Acceleration

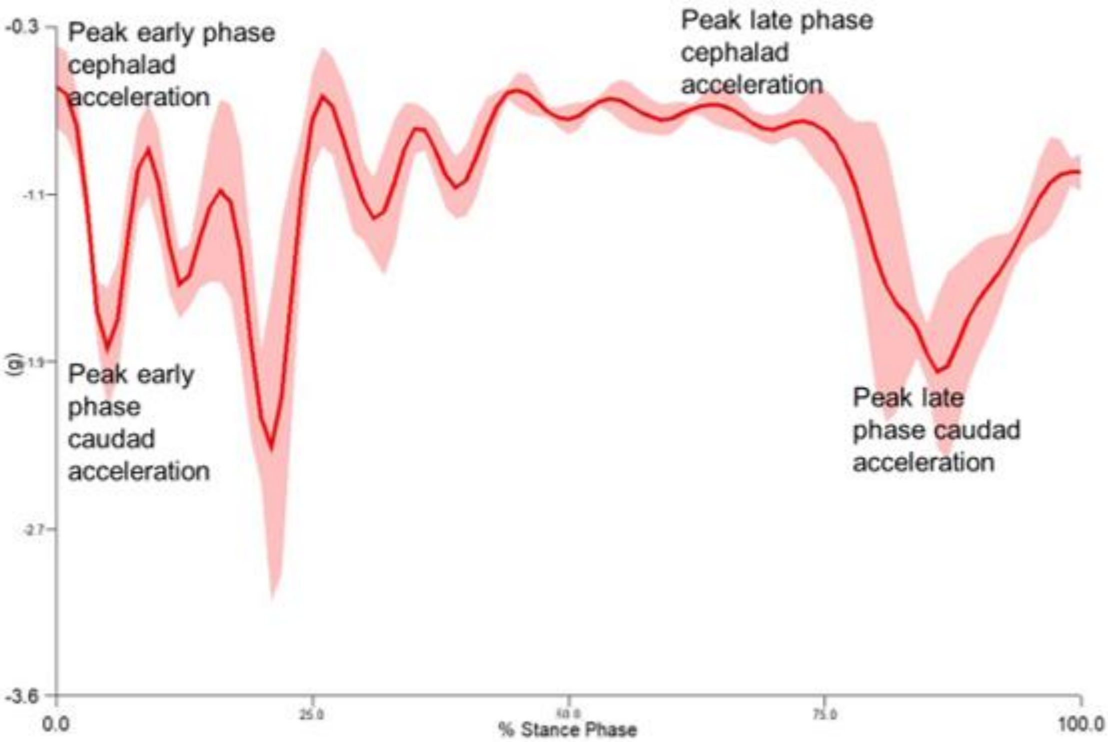
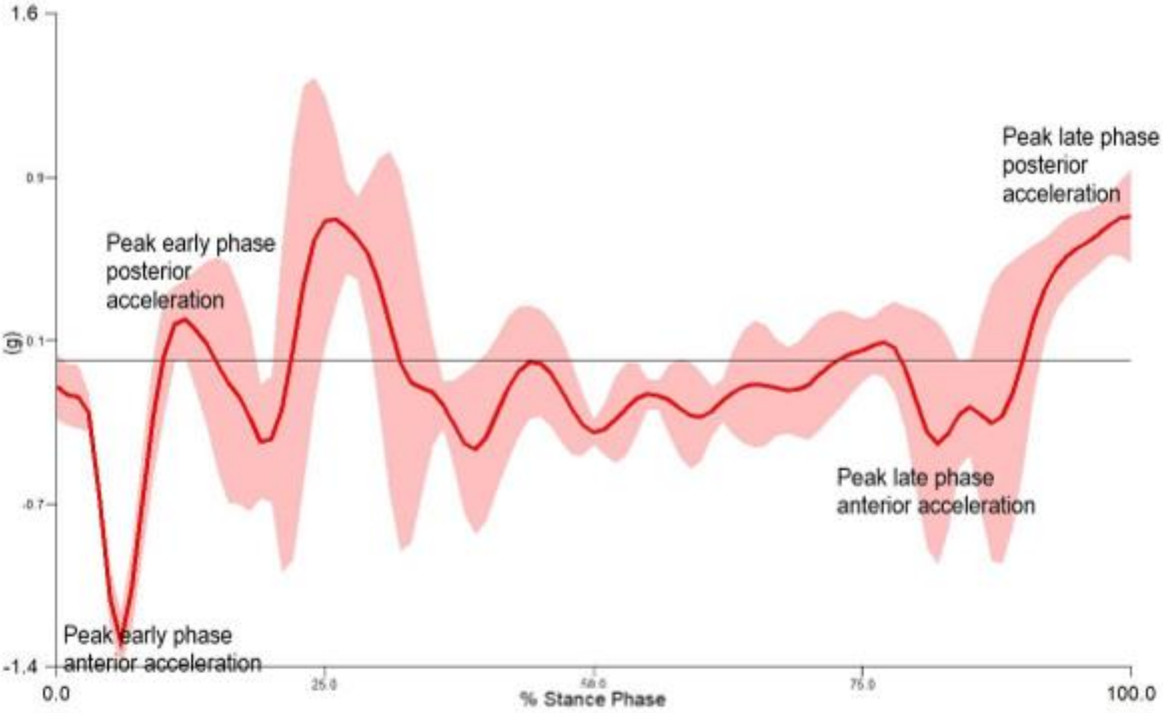


Figure 4.16 illustrates the anterior-posterior patellar acceleration with positive values representing posterior movement and negative values representing anterior movement. Figure 4.16 shows that there is an initial anterior acceleration which is followed by a posterior acceleration and corresponds to the weight acceptance and forward continuance phases. There is then a phase with minimal acceleration in either direction which corresponds with the controlled lowering phase before a final posterior acceleration towards the end of the stance phase.

Figure 4.16 Patellar Anterior-Posterior Acceleration



4.5.5 Patellar Gyroscope Data

With the patellar gyroscope data recorded in the X channel, the negative values represent flexion angular velocity while the positive values represent extension angular velocity. It can be seen in Figure 4.17 that there is a large range of flexion movement initially during the weight acceptance phase which reduces during the middle controlled lowering part of the stance phase, before a movement into extension at the end of the stance phase.

Figure 4.17 Patellar Angular Velocity in the Sagittal Plane (Flexion/Extension)

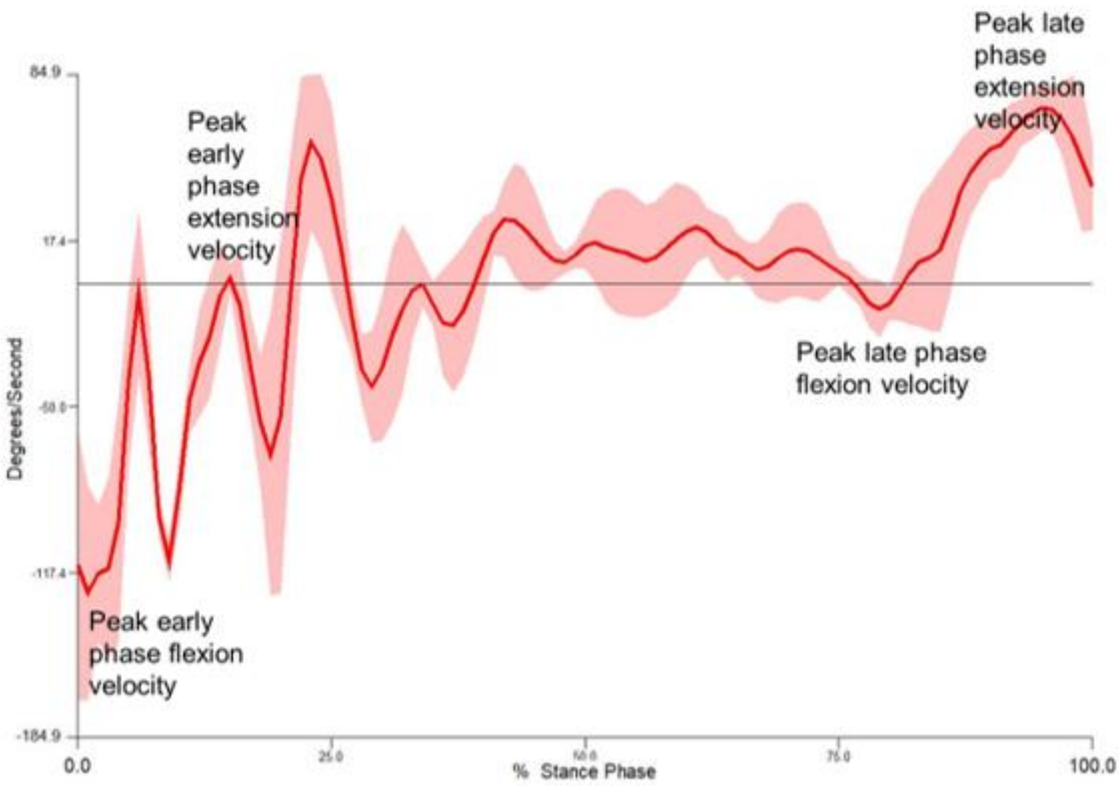


Figure 4.18 illustrates the patellar internal rotation and external rotation angular velocity. The positive values indicate internal rotation whilst the negative values represent external rotation. It can be seen in Figure 4.18 that there is a similar pattern of angular velocity in the tranverse plane as there is in the sagittal plane (Figure 4.17), i.e. there is a large range of movement initially which reduces as the stance phase proceeds into the middle and late phases before an increase in angular velocity towards the end of the stance phase. These phases agai9n correspond to those described by McFadyen and Winter (1988).

Figure 4.18 Patellar Angular Velocity in the Transverse Plane (Internal/External Rotation)

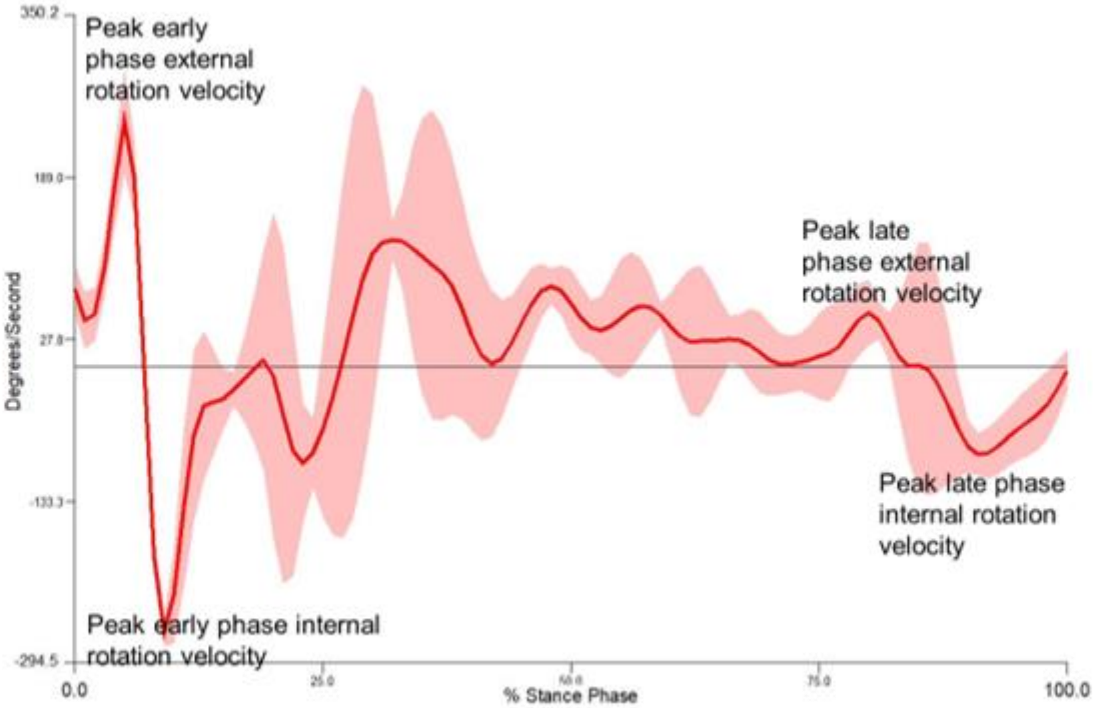
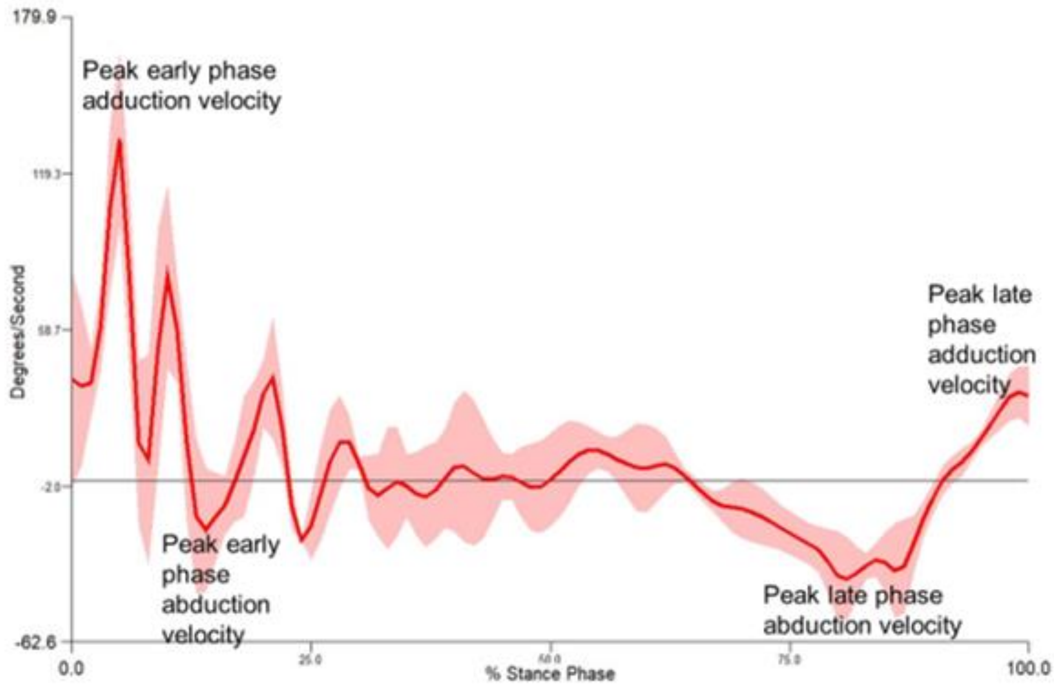


Figure 4.19 illustrates the patellar coronal plane abduction and adduction movements with the positive values representing abduction movement and negative values representing adduction. It can again therefore be seen that there is the greatest range of angular velocity in the early phase which corresponds to weight acceptance, a period of minimal angular velocity in the middle which corresponds to forward continuance and controlled lowering, before the angular velocity increases again at the end of the stance phase.

Figure 4.19 Patellar Angular Velocity in the Coronal Plane (Abduction/Adduction)



4.6 Data Processing in Excel

Once the data had been processed in Visual 3D, which included the calculation of contact time from the start and end points of the selected data for each taping condition on each of the two riser heights, they were exported to Excel for further processing by running the appropriate pipeline(s) in Visual 3D. This created a text file for each taping condition and each riser height for each participant. A separate spreadsheet was created for each participant, in which minimum, maximum and range values were calculated for each variable of interest for each taping condition under each riser height for the first phase (0 - 20%) of the stance phase, the latter half (51 - 100%) of the stance phase, and the whole of the stance phase (0 - 100%).

4.7 Statistical analysis

All data described above were imported from Excel into SPSS (Version 26) for statistical analysis. The distribution of all the data were examined using a Kolmogorov-Smirnov (KS) test and demonstrated that the majority of the data were not normally distributed. Therefore, Wilcoxon signed-rank tests were used to explore the effect of the two riser heights, whilst Friedman tests were used to explore the differences between the three taping conditions. Where significant results were found with the Friedman tests, further post-hoc analysis on those significant results was completed with Wilcoxon signed-rank tests.

Chapter 5 Results for Asymptomatic Participants

5.1 Introduction

This chapter presents the results for the asymptomatic participants. All of the 30 recruited participants met the inclusion criteria set out in section 3.6. Demographic data are used to highlight descriptors of this cohort whilst sEMG and IMU data are presented to explore the differences in muscle activity and movement control of the lower limb, respectively, between three taping conditions and two riser heights. Each section will consider the effects of the tape and then the riser height in each of the sub-phases of the stance phase.

5.2 Demographic Data

The demographic data for the asymptomatic participants are presented in Table 5.1. Of the 30 participants that took part in this study, 13 were female and 17 were male. The participant's age ranged from 18 to 52 years old with a mean age of 29 years old and a standard deviation (SD) of 9.87. For the whole sample, participant height ranged from 162-190cm with a mean of 174cm (SD = 8.93), and a weight range of 50-106kg with a mean of 75kg (SD = 14.25). Mean BMI was 24.8kg/m^2 with a range of 18.6-36.6kg/m^2 (SD = 4.18).

When processing the data, it was identified that the data for participant 22 were confounded by noise and therefore were removed from subsequent inferential statistical analysis.

Table 5.1 Asymptomatic Participant Demographic Data

Participant Number	Sex	Age	Height (cm)	Weight (kg)	BMI (kg/m^2)
01	Male	23	184	86	25.4
02	Male	23	180	87	26.8
03	Female	22	164	59	21.9
04	Male	45	174	68	22.4
05	Female	52	176	80	25.8
06	Male	22	178	64	20.1
07	Female	18	164	56	21.5
08	Female	41	162	63	24.0
09	Female	37	162	50	19.0
10	Female	25	170	63	21.7
11	Female	23	169	90	31.5
12	Male	47	165	77	28.2
13	Male	20	190	83	22.9
14	Male	19	187	73	20.8
15	Male	28	170	106	36.6
16	Male	19	187	78	22.3
17	Male	25	170	82	28.3
18	Male	23	177	74	23.6
19	Male	22	177	81	25.8
20	Male	27	180	86	26.5
21	Male	33	171	100	34.1
22	Female	25	166	63	22.8
23	Male	50	186	83	23.9
24	Female	42	170	54	18.6
25	Male	29	188	90	25.4
26	Female	29	169	57	19.9
27	Male	26	187	99	28.3
28	Female	20	163	67	25.2
29	Female	24	176	70	26.3
30	Female	24	176	71	22.9

5.3 Distribution Testing and Statistical Methods

Firstly, the distribution of the contact time, muscle activity, gyroscope and accelerometer data (n = 29) were examined using the Kolmogorov-Smirnov (KS) test to determine which inferential statistical tests should be subsequently performed. For the contact time, the KS tests revealed that the data were normally distributed, thus a repeated measures ANOVA was used to analyse the effect of taping and riser height. Where significant main effects were seen, post-hoc pairwise comparisons were performed. For the muscle activity data, the KS tests revealed that all the data except for peak VM activity were normally distributed. Therefore, for all normally distributed data, parametric repeated measures ANOVAs were performed, and where significant main effects of taping condition were identified, post-hoc pairwise comparisons were also performed. For the peak VM activity, Friedman tests were used to explore the effect of the three different taping conditions and, where there were significant differences found, Wilcoxon signed-rank tests were used to explore this e differences. Wilcoxon signed-rank tests were also performed to explore the effect of the two different riser heights.

For the movement control data, at least one or more of the parameters for each condition was found to be not normally distributed, therefore non-parametric inferential statistical tests were used as above. Where significant differences between the taping conditions were found ($p < 0.05$), post-hoc Wilcoxon signed-rank tests were performed to determine where the differences lay between the three taping conditions.

The results of the inferential statistical analyses are presented below. For the contact time data and each of the muscle activity and movement control parameters, there is a table to illustrate the effects of the riser height and the effects of the taping conditions with any significant differences that were found being highlighted in bold.

5.4 Effect of Taping Conditions and Riser Height

As stated in section 2.17, one of the objectives of the study involving asymptomatic individuals was to explore the effect of three different taping conditions; namely active tape, neutral tape and no tape, on the activity of VL, VM and GM, and also on the control of the lower limb. The null hypothesis (H_0) was that there would be no differences in muscle activity or lower limb control between the three taping conditions. The alternative hypothesis (H_1) was that there would be significant differences between the three taping conditions, with the active tape showing greater improvement in muscle activity and movement control when compared to the neutral tape and no tape conditions, and with the neutral tape condition showing greater improvement in muscle activity and movement control when compared to the no tape condition.

The second objective of this study was to explore the effect of different stair riser heights on VL, VM and GM activity, and also on the lower limb control parameters determined by the gyroscope and accelerometer data. The rationale for using two riser heights was that this would better facilitate the exploration of potential differences in muscle activity and the control of the lower limb. The null hypothesis (H_0) was that there would be no difference in muscle activity or lower limb control between the two riser heights. The alternative hypothesis (H_1) was that the high riser would show greater muscle activity and reduced lower limb movement control than the low riser.

5.5 Foot Contact Time for the Three Taping Conditions and the Two Riser Heights During the Stance Phase of Stair Descent

The foot contact time, hereafter referred to as the stance phase, represents the duration that the foot of the study limb was in contact with the relevant step during the stair descent. The repeated measures ANOVA revealed no significant interaction between taping condition and riser height, nor a significant main effect for the taping conditions. However, there was a significant main effect for the riser heights, with the high riser demonstrating a significantly longer stance phase time compared to the low riser ($p < 0.001$). Table 5.2 shows the stance phase results for each of the taping conditions on both riser heights.

Table 5.2 Stance Phase Duration (in Seconds) under the Three Taping Conditions for the Two Riser Heights

Contact Time	Mean (Standard Deviation)		Tape Effect p value ($p\eta^2$)
	High Riser	Low Riser	
Active Tape	0.78 (0.19)	0.74 (0.19)	p=0.111 (0.08)
Neutral Tape	0.78 (0.18)	0.73 (0.19)	
No Tape	0.77 (0.16)	0.71 (0.13)	
Riser Height p value ($p\eta^2$)	<0.001 (0.56)		

5.6 Muscle Activity for the Three Taping Conditions on the Two Riser Heights During the Stance Phase of Stair Descent

5.6.1 Average Muscle Activity

The repeated measures ANOVA revealed that there were no significant interactions between taping condition and riser height for the VM, VL or GM average muscle activity. Neither was there a significant main effect seen for the taping conditions. However, for the average VL and VM activity, significant main effects for riser height were seen, with the high riser height producing significantly greater average VL and VM activity compared to the low riser height ($p < 0.001$), Table 5.3. For the average GM muscle activity, no significant main effects for taping condition nor riser height were seen.

Table 5.3 Average Gluteus Medius, Vastus Lateralis and Vastus Medialis Activity for each of the Three Taping Conditions on the Two Riser Heights during the Stance Phase

	Mean (Standard Deviation)		Tape Effect p value ($p\eta^2$)
	High Riser	Low Riser	
Gluteus Medius			
Active Tape	0.41 (0.13)	0.41 (0.14)	
Neutral Tape	0.43 (0.12)	0.41 (0.14)	0.834 (0.01)
No Tape	0.42 (0.11)	0.40 (0.15)	
Riser Height p value ($p\eta^2$)	0.445 (0.02)		
Vastus Lateralis			
Active Tape	0.48 (0.14)	0.37 (0.11)	
Neutral Tape	0.49 (0.16)	0.40 (0.12)	0.131 (0.07)
No Tape	0.47 (0.13)	0.36 (0.13)	
Riser Height p-value ($p\eta^2$)	<0.001 (0.63)		
Vastus Medialis			
Active Tape	0.47 (0.13)	0.38 (0.12)	
Neutral Tape	0.50 (0.13)	0.37 (0.12)	0.755 (0.01)
No Tape	0.47 (0.13)	0.38 (0.11)	
Riser Height p-value ($p\eta^2$)	<0.001 (0.62)		

5.6.2 Peak Muscle Activity

Table 5.4 presents the results of the repeated measures ANOVA for the peak GM and VL activity. There were no significant interactions between the taping conditions and riser heights for GM or VL. For peak muscle activity for both muscles there were no significant main effects between the different taping conditions. There was however a significant main effect of riser height for peak VL muscle activity but not for GM, with the high riser height showing significantly greater peak VL activity compared to the low riser height.

Table 5.4 Peak Gluteus Medius and Vastus Lateralis Activity for each of the Three Taping Conditions on the Two Riser Heights during the Stance Phase

	Mean (Standard Deviation)		Tape Effect p value ($p\eta^2$)
	High Riser	Low Riser	
Gluteus Medius			
Active Tape	0.67 (0.15)	0.68 (0.16)	
Neutral Tape	0.69 (0.15)	0.68 (0.14)	0.516 (0.02)
No Tape	0.68 (0.14)	0.65 (0.17)	
Riser Height p-value ($p\eta^2$)	0.364 (0.03)		
Vastus Lateralis			
Active Tape	0.77 (0.10)	0.63 (0.11)	
Neutral Tape	0.80 (0.12)	0.67 (0.11)	0.072 (0.09)
No Tape	0.78 (0.10)	0.64 (0.12)	
Riser Height p-value ($p\eta^2$)	<0.001 (0.79)		

For the peak VM activity, the Friedman test showed no significant differences in peak VM activity between the taping conditions. However, Wilcoxon signed-rank test showed that riser height did have a significant effect across all the taping conditions, with a greater peak VM activity being demonstrated under the high riser condition compared to the low riser, Table 5.5.

Table 5.5 Peak Vastus Medialis Activity for each of the Three Taping Conditions on the Two Riser Heights during the Stance Phase

	Median ($25^{th}/75^{th}$ Percentile)		Z score	p-value Riser height
	High Riser	Low Riser		
Active Tape	0.80 (0.71/0.86)	0.59 (0.54/0.67)	-4.6	>0.001
Neutral Tape	0.82 (0.74/0.86)	0.62 (0.54/0.70)	-4.4	>0.001
No Tape	0.78 (0.74/0.84)	0.63 (0.55/0.70)	-4.2	>0.001
Chi Square Taping	0.7	0.5		
p-value Taping	0.966	0.786		

5.7 Tibial Angular Velocity for the Three Taping Conditions and the Two Riser Heights During the Stance Phase of Stair Descent

5.7.1 5Tibial Flexion-Extension Angular Velocity

5.7.1.1 (i) Early Stance Phase

The tibial flexion-extension angular velocities for the different conditions are presented in Table 5.6. The Friedman tests showed significant differences between the taping conditions during early stance phase for the peak tibial flexion and the angular velocity range on the high riser. Post-hoc Wilcoxon signed-rank tests revealed significant differences between the active tape and no tape conditions (p = 0.017), and also between the active tape and the neutral tape conditions for the peak tibial flexion angular velocity (p = 0.012), with the active tape showing the greatest value. There was no difference seen between the neutral tape and no tape conditions (p = 0.304). The Wilcoxon signed-rank tests showed active tape significantly increased the angular velocity range compared to the neutral tape conditions (p = 0.013). They also showed a trend towards a significant difference between the active tape and no tape conditions (p = 0.086). However, no difference was seen between the neutral tape and no tape conditions (p = 0.347).

Comparing the riser heights during early stance phase, Wilcoxon signed-rank tests showed a significantly greater tibial flexion angular velocity between the high riser and low riser for the active tape, neutral tape and no tape conditions. Similarly, the high riser showed significantly greater extension tibial angular velocities for the active and neutral tape conditions.

Table 5.6 Tibial Flexion-Extension Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Tibial Flexion-Extension Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Flexion	-163.8 (-207.0/-123.8)	-121.0 (-181.9/-93.7)	-4.2	<0.001
NT Flexion	-145.0 (-188.9/-110.8)	-137.8 (-162.3/-96.1)	-2.3	0.021
NoT Flexion	-147.3 (-192.3/-119.9)	-139.9 (152.5/-119.6)	-2.5	0.014
Chi Square Taping	15.0	0.3		
p-value Taping	0.001 [a, b]	0.871		
AT Extension	-48.7 (-65.0/-20.5)	-27.6 (-55.5/-3.0)	-2.6	0.008
NT Extension	-46.8 (-55.3/-22.4)	-33.8 (-61.0/-11.6)	-2.6	0.009
NoT Extension	-41.8 (-65.8/-22.7)	-37.6 (-56.2/-6.1)	-1.5	0.139
Chi Square Taping	0.5	3.3		
p-value Taping	0.786	0.191		
AT Range	119.9 (66.5/176.1)	93.7 (63.2/163.9)	-1.8	0.068
NT Range	102.4 (67.7/137.8)	91.8 (60.7/141.1)	-0.6	0.538
NoT Range	102.0 (64.3/148.1)	100.0 (71.8/141.0)	-0.3	0.754
Chi Square Taping	6.7	1.3		
p-value Taping	0.035[a]	0.519		

Key: AT = active tape, NT = neutral tape and NoT = no tape, negative values = flexion, positive values = extension, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.7.1.2 (ii) Late Stance Phase

During late stance phase the Friedman tests showed a significant difference between taping conditions for the peak tibial flexion angular velocity on the high riser. Further post-hoc analysis using Wilcoxon signed-rank tests for the peak flexion angular velocity on the high riser revealed a significant difference between the neutral tape and no tape conditions (p = 0.048), with the neutral tape condition showing the greater value. However, no differences were seen between the active and neutral tape conditions (p = 0.222), or between the active tape and the no tape conditions (p = 0.974).

When comparing the two riser heights, significant differences were seen in the peak tibial extension angular velocity under the neutral tape and no tape conditions, with the high riser showing the greatest angular velocities, Table 5.7.

Table 5.7 Tibial Flexion-Extension Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Tibial Flexion-Extension Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Flexion	-152.2 (-174.9/-124.3)	-162.4 (-196.3/-124.3)	-1.2	0.247
NT Flexion	-158.1 (-169.5/-118.7)	-160.0 (-180.3/-122.5)	-1.4	0.170
NoT Flexion	-154.3 (-174.2/-129.0)	-152.4 (-174.2/-143.4)	-1.1	0.265
Chi Square Taping	7.5	2.7		
p-value Taping	0.023[c]	0.261		
AT Extension	26.3 (-29.1/58.0)	7.5 (-36.0/40.1)	-1.9	0.056
NT Extension	15.5 (-25.0/51.1)	-8.0 (-28.7/29.2)	-2.1	0.039
NoT Extension	17.8 (-28.7/52.8)	5.8 (-22.3/21.8)	-2.2	0.031
Chi Square Taping	5.6	0.9		
p-value Taping	0.061	0.639		
AT Range	159.3 (130.7/225.1)	164.8 (125.8/209.2)	-1.0	0.315
NT Range	139.1 (123.0/214.4)	156.9 (119.7/187.2)	-1.5	0.144
NoT Range	156.2 (129.5/220.8)	154.9 (128.7/185.2)	-1.6	0.103
Chi Square Taping	4.2	3.0		
p-value Taping	0.122	0.227		

Key: AT = active tape, NoT = no tape and NT = neutral tape, negative values = flexion, positive values = extension, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.7.1.3 (iii) Whole of Stance Phase

When considering the whole of stance phase, the Friedman tests showed significant differences between the taping conditions for peak tibial flexion angular velocity on the high riser, the peak tibial extension angular velocity on the high riser, the range of angular velocity on the high riser, the peak tibial extension angular velocity on the low riser and the range of angular velocity on the low riser, Table 5.8.

Further post-hoc analysis using Wilcoxon signed-rank tests revealed that for the peak tibial flexion angular velocity on the high riser, there was a significant difference between the active tape and the neutral tape conditions (p = 0.048), with the active tape showing the greater value. The difference between the active tape and the no tape conditions was not significant (p = 0.061), and neither was the difference between the neutral tape and the no tape conditions (p= 0.854). For the peak tibial extension angular velocity on the high riser, despite the Friedman tests revealing a significant difference, the Wilcoxon tests failed to identify any significant differences between the various taping conditions. Although unusual, it may be that this is a reflection of the wide distribution of the data.

For the range of tibial angular velocity on the high riser further post-hoc analysis using Wilcoxon signed-rank tests revealed significant differences between the active tape and the neutral tape conditions (p = 0.014), with the active tape showing the greater value. There were no significant differences between the active tape and the no tape conditions nor between the neutral tape and the no tape conditions (p = 0.058 and p = 0.214), respectively. The peak tibial extension angular velocity on the low riser also showed significant differences between the active tape and the neutral tape conditions (p = 0.013), with the active tape again giving the greater value. There were no significant differences between the active tape and the no tape, and between the neutral tape and the no tape (p = 0.127 and p = 0.596), respectively. Finally, for the range of flexion-extension angular velocities on the low riser, significant differences were seen between the active tape and the neutral tape conditions (p = 0.001), and also between the active tape and the no tape conditions (p = 0.027). In both cases, the active tape condition that showed the greatest values, with the difference between the neutral and no tape conditions showing no significant difference (p = 0.214). In addition, a significant difference was seen in the range of angular velocity between riser heights under the neutral tape condition only, with the high riser showing the greater angular velocity, Table 5.8.

Table 5.8 Tibial Flexion-Extension Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Tibial Flexion-Extension Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Flexion	-170.3 (-225.0/-149.7)	-173.6 (-203.7/-134.1)	-1.9	0.056
NT Flexion	-168.4 (-196.2/-142.6)	-165.2 (-183.7/-147.5)	-0.6	0.524
NoT Flexion	-163.2 (-201.5/-138.7)	-164.0 (-193.1/-149.1)	-0.4	0.705
Chi Square Taping	7.7	1.9		
p-value Taping	0.021[a]	0.381		
AT Extension	27.8 (-13.3/64.90	20.6 (-10.0/46.6)	-1.4	0.163
NT Extension	15.5 (-13.0/51.1)	-3.4 (-13.5/37.4)	-1.7	0.098
NoT Extension	18.3 (-19.1/55.4)	8.9 (-8.7/30.7)	-1.9	0.061
Chi Square Taping	9.2	6.3		
p-value Taping	0.010	0.043[a]		
AT Range	191.5 (150.2/284.7)	178.5 (147.0/254.7)	-1.8	0.068
NT Range	189.4 (138.2/245.4)	164.4 (128.0/221.1)	-2.2	0.027
NoT Range	165.5 (140.8/255.2)	178.8 (145.5/221.6)	-1.9	0.056
Chi Square Taping	8.6	10.8		
p-value Taping	0.014[a]	0.005[a.b]		

Key: AT = active tape, NoT = no tape and NT = neutral tape, negative values = flexion, positive values = extension, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.7.2 Tibial Internal-External Rotation Angular Velocity

5.7.2.1 (i) Early Stance Phase

Table 5.9 shows the values for the tibial internal-external rotation angular velocity for both riser heights and the three taping conditions during early stance phase. The Friedman test showed a significant difference between the taping conditions for the range of tibial internal-external rotation angular velocity on the high riser. Further post-hoc analysis using Wilcoxon signed-rank tests revealed no significant differences between the active tape and no tape (p = 0.294), active tape and neutral tape (p = 0.103), and neutral tape and no tape (p = 0.804). Again, although it is unusual that the Wilcoxon tests failed to find any significant differences when the Friedman test had, it may be that when the individual differences were explored with the Wilcoxon tests, there was inconsistency in the direction of response between the taping conditions within the participants. For the riser heights during early stance phase the Wilcoxon signed-rank tests revealed no significant differences for any of the internal-external rotation angular velocity parameters (p>0.05).

Table 5.9 Tibial Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Tibial Internal-External Rotation Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Internal	-217.1 (-323.0/-148.2)	-171.8 (-244.6/-144.9)	-1.3	0.184
NT Internal	-196.0 (-260.7/-154.7)	-184.4 (-267.2/-141.0)	-0.1	0.922
NoT Internal	-195.6 (-299.2/-148.1)	-197.5 (-265.8/-159.4)	-0.3	0.770
Chi Square Taping	2.5	2.1		
p-value Taping	0.289	0.343		
AT External	159.9 (93.3/228.6)	140.7 (65.7/212.5)	-0.6	0.567
NT External	127.9 (60.5/183.8)	119.6 (73.5/222.8)	-0.1	0.888
NoT External	142.1 (70.9/212.7)	123.9 (85.9/208.3)	-0.3	0.804
Chi Square Taping	1.4	0.5		
p-value Taping	0.485	0.786		
AT Range	382.8 (223.1/544.8)	316.4 (257.2/498.3)	-1.6	0.107
NT Range	304.0 (247.1/485.1)	304.2 (211.5/479.1)	-0.5	0.627
NoT Range	382.9 (209.7/457.0)	321.8 (237.3/427.3)	-0.3	0.974
Chi Square Taping	6.3	3.6		
p-value Taping	0.043	0.166		

Key: AT = active tape, NoT = no tape and NT = neutral tape, negative values = internal rotation, positive values = external rotation,

5.7.2.2 (ii) Late Stance Phase

Table 5.10 shows the values for the tibial internal-external rotation angular velocities for both riser heights and the three taping conditions during late stance phase. The Friedman test showed no significant differences between any of the taping conditions. For the riser heights, the Wilcoxon signed-rank tests also showed no significant differences.

Table 5.10 Tibial Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Tibial Internal-External Rotation Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Internal	-67.8 (-153.1/-24.0)	-78.8 (-141.9/-33.3)	-0.3	0.738
NT Internal	-70.8 (-156.1/-29.0)	-90.4 (-155.3/-33.5)	-0.9	0.370
NoT Internal	-75.0 (-106.4/-29.5)	-73.5 (-109.4/-39.4)	-0.6	0.567
Chi Square Taping	2.5	4.6		
p-value Taping	0.289	0.099		
AT External	70.0 (56.8/96.6)	63.2 (50.2/103.5)	-0.6	0.538
NT External	77.8 (52.3/122.3)	68.7 (42.0/91.3)	-1.1	0.256
NoT External	67.7 (47.7/94.2)	75.8 (45.3/104.6)	-0.9	0.347
Chi Square Taping	3.4	0.6		
p-value Taping	0.185	0.733		
AT Range	193.4 (92.5/252.6)	177.9 (98.8/237.3)	-0.7	0.496
NT Range	172.3 (114.7/249.4)	196.4 (112.2/242.1)	-0.1	0.088
NoT Range	130.7 (97.0/212.6)	155.5 (111.3/240.2)	-0.9	0.347
Chi Square Taping	1.7	1.3		
p-value Taping	0.422	0.519		

Key: AT = active tape, NoT = no tape and NT = neutral tape, negative values = internal rotation, positive values = external rotation,

5.7.2.3 (iii) Whole of Stance Phase

Table 5.11 shows the values for the tibial internal-external rotation angular velocities for both riser heights and the three taping conditions when considering the whole of stance phase. The Friedman test showed a significant difference between taping conditions for the range of tibial internal-external rotation angular velocity on the low riser. However, the post-hoc analysis using Wilcoxon signed-rank tests again, and for the reasons explained previously, revealed no significant differences between the active and neutral tape conditions (p = 0.974), between the active and the no tape conditions (p = 0.127), or between the neutral tape and the no tape conditions (p = 0.284). For the riser heights, the Wilcoxon signed-rank tests showed no significant differences for any of the tibial internal-external rotation angular velocities when considering the whole of stance phase.

Table 5.11 Tibial Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Tibial Internal-External Rotation Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Internal	-218.0 (-342.2/-154.5)	-178.9 (-264.8/-146.0)	-1.1	0.284
NT Internal	-207.0 (-282.5/-159.6)	-184.8 (-267.2/-161.8)	-0.1	0.905
NoT Internal	-195.6 (-313.4/-151.4)	-203.8 (-265.8/-169.1)	-1.2	0.239
Chi Square Taping	1.9	5.0		
p-value Taping	0.394	0.081		
AT External	169.4 (100.1/248.9)	164.1 (118.3/260.1)	-0.3	0.770
NT External	137.5 (122.6/206.1)	167.9 (82.4/250.2)	-0.1	0.940
NoT External	175.0 (90.5/218.0)	160.0 (101.2/247.6)	-0.1	0.991
Chi Square Taping	1.9	0.5		
p-value Taping	0.381	0.786		
AT Range	382.8 (254.5/645.8)	348.8 (267.8/556.1)	-1.1	0.275
NT Range	359.0 (279.8/529.1)	367.4 (254.5/539.8)	-0.6	0.567
NoT Range	387.2 (242.0/490.9)	347.9 (304.2/459.6)	-0.8	0.430
Chi Square Taping	3.0	7.1		
p-value Taping	0.227	0.029		

Key: AT = active tape, NoT = no tape and NT = neutral tape, negative values = internal rotation, positive values = external rotation

5.7.3 Tibial Abduction-Adduction Angular Velocity

5.7.3.1 (i) Early Stance Phase

The tibial abduction-adduction angular velocity data for both riser heights and the three taping conditions during early stance phase are presented in Table 5.12. The Friedman tests revealed a significant difference for the taping conditions for the peak tibial abduction angular velocity on the low riser. Further post-hoc analysis using Wilcoxon signed-rank tests revealed a significantly greater peak tibial abduction angular velocity in the neutral tape compared to the active tape condition (p = 0.010) and the no tape condition (p = 0.033). However, no significant differences were seen between the active tape and the no tape condition (p = 0.370). For the riser heights, the Wilcoxon signed-rank tests revealed a significant difference under the no tape condition, with the high riser producing greater tibial adduction angular velocity compared to the low riser.

Table 5.12 Tibial Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Tibial Abduction-Adduction Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Abduction	5.6 (-24.2/18.1)	6.5 (-28.9/19.3)	-0.3	0.974
NT Abduction	7.7 (-21.8/24.1)	10.2 (-25.8/23.6)	-0.1	0.940
NoT Abduction	4.3 (-28.3/22.3)	1.6 (-35.7/19.0)	-0.3	0.974
Chi Square Taping	4.4	8.6		
p-value Taping	0.110	0.014 [a, c]		
AT Adduction	74.6 (51.1/88.5)	64.5 (44.5/84.6)	-1.4	0.150
NT Adduction	67.0 (41.0/92.6)	66.4 (38.8/87.0)	-0.8	0.443
NoT Adduction	75.1 (55.2/94.3)	66.8 (47.7/84.5)	-2.2	0.025
Chi Square Taping	0.8	0.9		
p-value Taping	0.661	0.639		
AT Range	67.4 (48.1/92.2)	57.1 (44.2/92.3)	-0.8	0.430
NT Range	52.1 (43.1/92.2)	54.1 (37.9/86.3)	-0.9	0.358
NoT Range	64.32 (48.1/87.3)	58.3 (46.5/84.3)	-1.7	0.086
Chi Square Taping	2.5	3.6		
p-value Taping	0.289	0.166		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.7.3.2 (ii) Late Stance Phase

During late stance phase, the Friedman tests showed no significant differences for any of the tibial adduction-abduction angular velocity parameters between the taping conditions. In addition, the Wilcoxon signed-rank tests showed no significant differences between the riser heights, Table 5.13.

Table 5.13 Tibial Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Tibial Abduction-Adduction Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Abduction	-33.4 (-53.1/-18.1)	-33.7 (-49.2/-16.2)	-0.5	0.642
NT Abduction	-29.3 (-44.3/-17.3)	-33.7 (-50.1/-16.2)	-0.9	0.358
NoT Abduction	-25.7 (-56.1/-6.4)	-35.1 (-52.6/-19.5)	-1.3	0.184
Chi Square Taping	0.8	1.3		
p-value Taping	0.661	0.519		
AT Adduction	40.82 (23.6/56.6)	35.1 (22.5/55.7)	-0.6	0.552
NT Adduction	38.2 (26.6/61.9)	34.6 (18.7/55.4)	-1.8	0.078
NoT Adduction	38.8 (20.3/56.3)	32.0 (24.4/55.0)	-0.7	0.510
Chi Square Taping	0.5	0.3		
p-value Taping	0.786	0.871		
AT Range	70.0 (58.9/82.1)	67.8 (52.0/87.2)	-0.1	0.888
NT Range	63.4 (51.7/88.8)	72.8 (49.8/88.8)	-0.1	0.940
NoT Range	70.0 (49.1/86.3)	64.9 (56.1/90.2)	-0.9	0.325
Chi Square Taping	2.1	0.5		
p-value Taping	0.343	0.786		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

5.7.3.3 (iii) Whole of Stance Phase

During the whole of stance phase, the Friedman tests revealed no significant differences between the taping conditions for any of the adduction-abduction tibial angular velocity parameters. However, for the riser heights, the Wilcoxon signed-rank tests showed that the tibial adduction angular velocity on the high riser was significantly greater compared to the low riser under the active tape and no tape conditions, Table 5.14.

Table 5.14 Tibial Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Tibial Abduction-Adduction Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Abduction	-33.4 (-58.1/-18.8)	-36.1 (-62.4/-20.0)	-0.2	0.820
NT Abduction	-31.1 (-52.4/-17.3)	-36.2 (-51.0/-18.0)	-0.6	0.552
NoT Abduction	-31.0 (-63.5/-15.4)	-36.6 (-64.2/-19.6)	-1.3	0.198
Chi Square Taping	0.2	0.9		
p-value Taping	0.902	0.639		
AT Adduction	74.6 (57.8/88.5)	70.5 (47.0/84.9)	-2.0	0.045
NT Adduction	67.8 (45.5/92.6)	68.5 (38.8/91.9)	-1.1	0.256
NoT Adduction	75.1 (57.8/94.3)	71.4 (56.5/89.7)	-2.0	0.041
Chi Square Taping	2.1	0.5		
p-value Taping	0.343	0.786		
AT Range	107.9 (83.9/124.8)	106.5 (81.7/130.2)	-0.9	0.336
NT Range	98.5 (79.6/115.1)	103.4 (76.1/120.1)	-0.4	0.721
NoT Range	97.6 (80.8/135.4)	102.7 (79.3/127,7)	-0.3	0.787
Chi Square Taping	3.0	4.2		
p-value Taping	0.227	0.122		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

5.8 Patellar Angular Velocity Under the Three Taping Conditions and the Two Riser Heights During the Stance Phase of Stair Descent

5.8.1 Patellar Anterior-Posterior Angular Velocity

5.8.1.1 (i) Early Stance Phase

During early stance phase of the stair descent the Friedman tests revealed no significant differences between the taping conditions for the anterior-posterior patellar angular velocity parameters. In addition, with Wilcoxon signed-rank tests showed no significant differences between the two riser heights, Table 5.15.

Table 5.15 Patellar Anterior-Posterior Angular Velocity for each of the Three Taping Conditions on the two Riser Heights during Early Stance Phase

Patellar Anterior-Posterior Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Anterior	-108.4 (-141.7/-84.3)	-105.3 (-131.4/-80.2)	-0.9	0.393
NT Anterior	-113.3 (-139.4/-76.9)	-109.2 (-146.8/-88.2)	-0.8	0.443
NoT Anterior	-103.9 (-139.1/-84.2)	-109.3 (-135.5/-85.8)	-0.7	0.510
Chi Square Taping	0.1	3.4		
p-value Taping	0.191	0.519		
AT Posterior	15.9 (-3.3/47.5)	22.0 (-0.8/50.5)	-0.2	0.837
NT Posterior	22.9 (2.6/67.4)	21.0 (3.2/44.7)	-0.2	0.804
NoT Posterior	14.7 (0.8/46.5)	28.1 (-2.8/45.1)	-0.4	0.673
Chi Square Taping	3.3	1.3		
p-value Taping	0.966	0.185		
AT Range	134.4 (90.4/181.1)	125.6 (81.5/172.2)	-1.1	0.275
NT Range	132.3 (87.3/192.6)	141.4 (99.4/199.9)	-0.6	0.581
NoT Range	117.4 (92.2/167.5)	130.7 (90.0/170.0)	-0.5	0.611
Chi Square Taping	0.8	3.4		
p-value Taping	0.661	0.185		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

5.8.1.2 (ii) Late Stance Phase

During late stance phase the Friedman tests revealed no significant differences between the taping conditions for the anterior-posterior patellar angular velocity parameters. However, for the riser heights, the Wilcoxon signed-rank tests showed significant differences in the posterior and range of anterior-posterior angular velocities under all three taping conditions, with the low riser height showing the greater anterior-posterior patellar angular velocities, Table 5.16.

Table 5.16 Patellar Anterior-Posterior Angular Velocity for each of the Three Taping Conditions on the two Riser Heights during Late Stance Phase

Patellar Anterior-Posterior Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Anterior	-48.7 (-73.3/-33.0)	-51.7 (-67.1/-35.2)	-0.1	0.940
NT Anterior	-47.5 (-75.9/-31.8)	-50.6 (-66.4/-36.0)	-0.2	0.837
NoT Anterior	-46.5 (-78.1/-28.5)	-52.5 (-73.7/-38.4)	-1.2	0.239
Chi Square Taping	0.5	2.7		
p-value Taping	0.786	0.639		
AT Posterior	78.8 (62.0/97.0)	92.8 (64.6/121/6)	-3.1	0.002
NT Posterior	73.4 (58.2/91.6)	98.6 (79.4/125.8)	-3.5	<0.001
NoT Posterior	77.2 (57.7/101.2)	99.6 (69.8/122.0)	-2.9	0.003
Chi Square Taping	0.5	0.9		
p-value Taping	0.786	0.261		
AT Range	131.0 (77.7/155.8)	149.0 (101.5/174.6)	-2.3	0.021
NT Range	132.5 (100.6/156.0)	152.2 (114.0/186.8)	-2.4	0.016
NoT Range	127.8 (95.1/167.8)	158.6 (113.1/195.4)	-2.5	0.012
Chi Square Taping	0.1	3.4		
p-value Taping	0.966	0.185		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

5.8.1.3 (iii) Whole of Stance Phase

During the whole of stance phase for the anterior-posterior patellar angular velocity, the Friedman tests revealed no significant differences between taping conditions. However, for the riser height, the Wilcoxon tests showed significant differences between the riser heights for the posterior patella angular velocity under all three conditions. They also showed a significant difference for the range of anterior-posterior patellar angular velocity under the no tape condition. Across all measures the low riser height showed the greater angular velocities, Table 5.17.

Table 5.17 Patellar Anterior-Posterior Angular Velocity for each of the Three Taping Conditions on the two Riser Heights during the Whole of Stance Phase

Patellar Anterior-Posterior Angular Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Anterior	-119.0 (-161.4/-84.8)	-105.6 (-148.8/-80.2)	-1.4	0.170
NT Anterior	-127.3 (-142.6/-80.6)	-109.2 (-162.7/-88.2)	-0.1	0.888
NoT Anterior	-103.9 (-144.9/-86.9)	-111.8 (-143.4/-88.0)	-0.9	0.370
Chi Square Taping	1.1	0.9		
p-value Taping	0.166	0.786		
AT Posterior	85.2 (67.3/109.6)	99.5 (77.3/131.8)	-2.4	0.016
NT Posterior	85.7 (65.8/110.4)	107.7 (81.6/128.4)	-2.3	0.020
NoT Posterior	81.0 (67.0/103.9)	102.7 (74.8/124.1)	-2.6	0.010
Chi Square Taping	3.6	0.5		
p-value Taping	0.576	0.639		
AT Range	189.7 (167.3/271.9)	212.0 (172.3/265.9)	-1.0	0.294
NT Range	217.53 (155.2/245.5)	218.2 (182.8/292.1)	-1.4	0.177
NoT Range	196.7 (156.0/245.2)	214.0 (189.2/236.2)	-2.6	0.009
Chi Square Taping	0.8	3.0		
p-value Taping	0.661	0.227		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

5.8.2 Patellar Internal-External Rotation Angular Velocity

5.8.2.1 (i) Early Stance Phase

During early stance phase of the stair descent the Friedman tests revealed no significant differences between taping conditions for the patellar internal-external angular velocities. In addition, for the riser heights no significant differences were evident, Table 5.18.

Table 5.18 Patellar Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Int/External Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Internal	-138.6 (-241.1/-80.4)	-126.1 (-186.8/-84.6)	-1.1	0.275
NT Internal	-120.8 (-182.6/-85.2)	-130.3 (-232.2/-85.1)	-1.7	0.098
NoT Internal	-120.8 (-174.9/-95.8)	-139.3 (-229.1/-88.0)	-1.0	0.315
Chi Square Taping	2.7	0.5		
p-value Taping	0.261	0.394		
AT External	97.7 (53.7/178.4)	76.5 (39.9/137.5)	-1.8	0.064
NT External	84.0 (45.4/131.9)	73.2 (41.3/195.7)	-0.5	0.642
NoT External	74.6 (52.1/153.5)	89.0 (45.9/131.2)	-0.4	0.705
Chi Square Taping	2.7	1.9		
p-value Taping	0.261	0.786		
AT Range	245.8 (151.2/417.0)	190.8 (129.9/317.1)	-1.9	0.056
NT Range	243.8 (116.0/323.7)	198.9 (138.6/408.5)	-1.1	0.256
NoT Range	193.5 (160.3/332.5)	236.7 (133.9/356.6)	-0.1	0.974
Chi Square Taping	2.1	0.9		
p-value Taping	0.343	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

5.8.2.2 (ii) Late Stance Phase

During late stance phase of the stair descent the Friedman tests revealed no significant differences between taping conditions for the patellar internal-external angular velocities. For the riser height, a significant difference was seen for the patellar internal rotation angular velocity under the no tape condition, with the high riser showing the greater angular velocity, Table 5.19.

Table 5.19 Patellar Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Int/External Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Internal	-53.0 (-80.4/-24.6)	-50.4 (-74.8/-29.7)	-0.2	0.837
NT Internal	-52.8 (-76.2/-29.0)	-41.4 (/59.0/-25.5)	-0.9	0.325
NoT Internal	-57.6 (-74.2/-30.5)	-44.9 (-57.3/-29.6)	-2.2	0.027
Chi Square Taping	2.1	3.9		
p-value Taping	0.485	0.519		
AT External	50.0 (40.0/67.5)	49.2 (30.2/64.7)	-1.1	0.275
NT External	55.9 (42.8/86.2)	63.9 (36.5/81.6)	-1.1	0.256
NoT External	56.8 (42.3/69.6)	62.8 (34.8/72.7)	-0.3	0.770
Chi Square Taping	1.4	1.3		
p-value Taping	0.343	0.140		
AT Range	98.0 (75.1/145.2)	91.4 (68.6/128.2)	-0.9	0.358
NT Range	103.7 (83.7/155.1)	102.4 (74.7/140.6)	-1.7	0.094
NoT Range	100.4 (84.0/128.5)	106.4 (69.4/128.2)	-1.5	0.127
Chi Square Taping	0.3	0.5		
p-value Taping	0.871	0.786		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

5.8.2.3 (iii) Whole of Stance Phase

During the whole of stance phase, the Friedman tests showed no significant differences between taping conditions for the patellar internal-external angular velocities. In addition, no significant differences were seen between riser heights, Table 5.20.

Table 5.20 Patellar Internal-External Rotation Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Int/External Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
	0-100% stance phase during stair descent			
AT Internal	-144.9 (-241.1/-93.7)	-126.1 (195.3/-88.5)	-1.5	0.133
NT Internal	-127.7 (-201.9/-95.7)	-130.3 (-232.2/-97.6)	-0.8	0.417
NoT Internal	-136.8 (-185.2/-105.7)	-139.3 (-229.1/-90.1)	-0.1	0.991
Chi Square Taping	3.6	3.3		
p-value Taping	0.639	0.661		
AT External	108.8 (78.3/216.9)	98.8 (65.6/186.8)	-1.1	0.284
NT External	101.8 (72.0/174.6)	120.7 (71.4/196.2)	-0.2	0.854
NoT External	101.1 (66.0/168.9)	114.3 (83.2/189.7)	-1.9	0.056
Chi Square Taping	0.9	0.8		
p-value Taping	0.166	0.191		
AT Range	268.5 (166.6/472.1)	229.2 (170.0/392.8)	-1.6	0.107
NT Range	251.2 (163.8/369.1)	250.5 (168.3/417.7)	-0.5	0.596
NoT Range	242.3 (184.6/358.8)	255.5 (190.4/424.9)	-1.2	0.222
Chi Square Taping	1.4	0.9		
p-value Taping	0.485	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

5.8.3 Patellar Abduction-Adduction Angular Velocity

5.8.3.1 (i) Early Stance Phase

For the taping conditions during early stance phase, significant differences were found for the peak abduction and range of abduction-adduction angular velocities on the low riser. Post-hoc analysis using Wilcoxon signed-rank tests revealed a significant difference between the neutral tape and the no tape conditions (p = 0.030) for the peak abduction angular velocity with the neutral tape showing the greater value. For the range of abduction-adduction angular velocity, the post-hoc analyses showed a significant difference between the neutral tape and the no tape conditions (p = 0.006), with the neutral tape showing the greater value. However, no differences were seen between the active tape and no tape conditions or between the active tape and neutral tape conditions (p = 0.198 and p= 0.496), respectively. For the riser heights, the Wilcoxon signed-rank tests revealed significant differences for the patellar abduction angular velocity, the patellar adduction angular velocity, and the range of abduction-adduction angular velocity, all under the no tape condition. In all cases, the high riser showed the greatest angular velocities, Table 5.21.

Table 5.21 Patellar Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights for Early Stance Phase

Ab/Adduction Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Abduction	-29.4 (-48.0/-18.94)	-31.9 (-55.3/-12.3)	-0.3	0.738
NT Abduction	-22.2 (-42.8/-7.7)	-31.0 (-49.1/-15.8)	-0.9	0.381
NoT Abduction	-30.4 (-53.9/-13.9)	-25.5 (-40.1/-12.4)	-2.8	0.005
Chi Square Taping	1.9	9.6		
p-value Taping	0.394	0.008[c]		
AT Adduction	52.2 (28.5/86.8)	42.9 (29.5/67.7)	-1.9	0.061
NT Adduction	47.5 (34.6/74.6)	44.3 (31.4/72.1)	-0.2	0.820
NoT Adduction	51.6 (36.4/71.8)	40.9 (29.4/59.9)	-2.7	0.009
Chi Square Taping	1.3	3.4		
p-value Taping	0.519	0.185		
AT Range	86.7 (62.0/117.2)	69.0 (50.7/115.7)	-1.0	0.315
NT Range	71.4 (56.5/105.5)	77.6 (55.3/103.8)	-0.6	0.567
NoT Range	85.7 (60.4/116.7)	68.2 (51.3/90.4)	-2.8	0.005
Chi Square Taping	0.1	7.1		
p-value Taping	0.966	0.029[c]		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.8.3.2 (ii) Late Stance Phase

During late stance phase, the Friedman tests showed no significant differences between taping conditions for the patellar abduction-adduction angular velocity. In addition, no significant differences were seen between riser heights, Table 5.22.

Table 5.22 Patellar Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Ab/Adduction Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Abduction	-32.1 (-37.8/-25.6)	-31.1 (-38.2/-20.0)	-1.1	0.284
NT Abduction	-36.1 (-43.1/-20.6)	-31.5 (-38.8/-21.9)	-1.9	0.061
NoT Abduction	-32.2 (-43.1/-24.0)	-30.0 (-38.5/-18.5)	-1.8	0.078
Chi Square Taping	0.1	0.2		
p-value Taping	0.966	0.902		
AT Adduction	15.0 (10.8/24.3)	21.5 (9.5/26.7)	-0.7	0.482
NT Adduction	18.5 (8.9/27.0)	22.6 (10.8/30.3)	-1.6	0.107
NoT Adduction	22.3 (6.7/27.9)	18.1 (7.9/25.8)	-0.4	0.721
Chi Square Taping	0.2	1.4		
p-value Taping	0.902	0.485		
AT Range	49.4 (39.1/55.9)	46.4 (31.5/60.8)	-0.3	0.770
NT Range	47.4 (41.5/57.6)	50.0 (36.3/60.2)	-0.6	0.552
NoT Range	52.2 (37.5/58.5)	43.7 (36.2/58.1)	-1.6	0.112
Chi Square Taping	2.6	0.8		
p-value Taping	0.279	0.661		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

5.8.3.3 (iii) Whole of Stance Phase

During all stance phase, the Friedman tests showed no significant differences between taping conditions for the patellar abduction-adduction angular velocity. For the riser heights the Wilcoxon signed-rank tests showed significant differences in the abduction, adduction and range of angular velocity under the no tape condition, and the abduction angular velocity under the active tape condition, all of which showed greater angular velocities on the high riser, Table 5.23.

Table 5.23 Patellar Abduction-Adduction Angular Velocity for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Ab/Adduction Patellar Velocity	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Abduction	-41.8 (-55.5/-35.5)	-45.9 (-61.5/-33.8)	-0.7	0.496
NT Abduction	-43.3 (-51.4/-36.3)	-40.3 (-57.9/-31.9)	-1.1	0.265
NoT Abduction	-48.8 (-59.4/-33.9)	-40.3 (-49.3/-32.6)	-2.8	0.006
Chi Square Taping	2.1	2.1		
p-value Taping	0.343	0.343		
AT Adduction	55.6 (39.4/88.4)	50.0 (33.5/69.5)	-2.2	0.031
NT Adduction	50.7 (38.0/81.3)	52.8 (33.3/75.9)	-0.1	0.940
NoT Adduction	57.1 (41.3/74.3)	52.1 (36.9/68.1)	-3.1	0.002
Chi Square Taping	0.8	0.2		
p-value Taping	0.661	0.902		
AT Range	103.4 (75.0/131.0)	95.9 (68.2/131.8)	-1.3	0.206
NT Range	96.1 (77.9/133.6)	98.4 (73.1/132.5)	-0.8	0.430
NoT Range	113.1 (78.0/133.3)	95.3 (71.3/114.6)	-3.1	0.002
Chi Square Taping	0.3	1.3		
p-value Taping	0.871	0.519		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

5.9 Tibial Acceleration for the Three Taping Conditions and the Two Riser Heights During the Stance Phase of Stair Descent

5.9.1 Medial-Lateral Tibial Accelerations

5.9.1.1 (i) Early Stance Phase

During early stance phase, the Friedman tests showed no significant differences due to taping in any of the medial-lateral tibial acceleration parameters. For the riser heights, the Wilcoxon signed-rank tests also showed no significant differences ($p > 0.05$), Table 5.24.

Table 5.24 Tibial Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Medial	-0.91 (-1.10/-0.59)	-0.86 (-1.24/-0.61)	-0.9	0.347
NT Medial	-0.88 (-1.16/-0.62)	-0.82 (-1.11/-0.54)	-0.1	0.922
NoT Medial	-0.84 (-1.09/-0.67)	-0.89 (-1.10/-0.60)	-0.3	0.974
Chi Square Taping	1.9	0.8		
p-value Taping	0.381	0.661		
AT Lateral	0.56 (0.40/0;89)	0.62 (0.37/0.84)	-0.7	0.510
NT Lateral	0.52 (0.38/0.79)	0.56 (0.40/0.82)	-1.1	0.315
NoT Lateral	0.60 (0.34/0.91)	0.69 (0.46/0.89)	-1.2	0.239
Chi Square Taping	2.7	3.4		
p-value Taping	0.261	0.185		
AT Range	1.34 (1.01/2.17)	1.39 (1.05/2.05)	-0.1	0.905
NT Range	1.30 (1.01/1.93)	1.43 (1.03/1.77)	-0.4	0.721
NoT Range	1.36 (1,01/1.86)	1.60 (1.15/1.91)	-1.1	0.256
Chi Square Taping	0.6	1.3		
p-value Taping	0.733	0.519		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.9.1.2 (ii) Late Stance Phase

During late stance phase, the Friedman tests showed no significant differences due to taping in any of the medial-lateral tibial acceleration parameters. For the riser heights, the Wilcoxon signed-rank tests revealed a significant difference in the peak medial tibial accelerations under all taping conditions, with the greater accelerations seen on the high riser. In addition, the range of medial-lateral tibial acceleration was also significantly greater when descending on the high riser compared to the low riser under the no tape condition, Table 5.25.

Table 5.25 Tibial Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Medial	-0.52 (-0.75/-0.31)	-0.39 (-0.54/-0.25)	-2.4	0.015
NT Medial	-0.57 (-0.73/-0.31)	-0.41 (-0.55/-0.28)	-3.2	0.001
NoT Medial	-0.52 (-0.70/-0.36)	-0.34 (-0.49/-0.23)	-3.2	0.001
Chi Square Taping	4.6	2.7		
p-value Taping	0.099	0.261		
AT Lateral	0.19 (-0.05/0.34)	0.11 (0.03/0.32)	-0.3	0.804
NT Lateral	0.19 (-0.05/0.34)	0.16 (0.03/0.35)	-0.4	0.658
NoT Lateral	0.19 (-0.07/0.41)	0.15 (-0.00/0.36)	-0.6	0.581
Chi Square Taping	2.7	2.7		
p-value Taping	0.261	0.261		
AT Range	0.60 (0.47/0.77)	0.52 (0.39/0.69)	-1.6	0.107
NT Range	0.67 (0.53/0.86)	0.59 (0.38/0.71)	-1.7	0.082
NoT Range	0.65 (0.48/0.85)	0.56 (0.41/0.68)	-2.0	0.043
Chi Square Taping	4.3	1.3		
p-value Taping	0.114	0.519		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.9.1.3 (iii) Whole of Stance Phase

During the whole of stance phase, the Friedman tests showed no significant differences due to taping in any of the medial-lateral tibial acceleration parameters, and no significant differences were seen for riser height, Table 5.26.

Table 5.26 Tibial Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Medial	-0.92 (-1.10/-0.60)	-0.86 (-1.24/-0.61)	-0.8	0.430
NT Medial	-0.91 (-1.16/-0.65)	-0.83 (-1.24/-0.60)	-0.3	0.754
NoT Medial	-0.88 (-1.09/-0.73)	-0.89 (-1.10/-0.67)	-0.5	0.642
Chi Square Taping	0.1	0.5		
p-value Taping	0.966	0.786		
AT Lateral	0.68 (0.42/0.97)	0.62 (0.41/0.89)	-0.4	0.689
NT Lateral	0.57 (0.44/0.86)	0.60 (0.43/0.85)	-0.3	0.738
NoT Lateral	0.64 (0.34/0.91)	0.69 (0.48/0.91)	-1.2	0.214
Chi Square Taping	0.8	2.5		
p-value Taping	0.661	0.289		
AT Range	1.34 (1.08/2.17)	1.39 (1.06/2.05)	-0.2	0.871
NT Range	1.45 (1.06/2.18)	1.49 (1.06/1.92)	-0.4	0.721
NoT Range	1.41 (1.17/1.86)	1.60 (1.18/1.94)	-1.1	0.275
Chi Square Taping	0.2	2.1		
p-value Taping	0.902	0.343		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.9.2 Vertical Tibial Accelerations

5.9.2.1 (i) Early Stance Phase

During early stance phase, the Friedman tests showed no significant differences due to taping in any of the vertical tibial acceleration parameters. For the riser height data, Wilcoxon signed-rank test demonstrated a significant difference in the caudad (downwards) acceleration during early stance phase, with significantly greater downward accelerations when descending the high riser height under the active tape and the no tape conditions compared to the low riser height. In addition, the cephalad (upwards) tibial acceleration was significantly greater for the low riser compared to the high riser under the active tape condition. The range of vertical tibial acceleration was also significantly greater for the high riser compared to the low riser under the active tape condition, Table 5.27.

Table 5.27 Tibial Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Vertical Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Caudad	-2.12 (-2.89/-1.82)	-1.93 (-2.41/-1.67)	-3.4	0.001
NT Caudad	-2.02 (-2.43/-1.81)	-1.94 (-2.24/-1.79)	-1.6	0.112
NoT Caudad	-2.00 (-2.54/-1.83)	-1.87 (-2.31/-1.74)	-2.7	0.006
Chi Square Taping	5.6	0.9		
p-value Taping	0.061	0.639		
AT Cephalad	-0.93 (-1.05/-0.65)	-0.99 (-1.11/-0.83)	-1.9	0.048
NT Cephalad	-1.01 (-1.08/-0.86)	-0.98 (-1.09/-0.88)	-0.4	0.689
NoT Cephalad	-0.98 (-1.06/-0.86)	-0.97 (-1.06/-0.80)	-0.1	0.905
Chi Square Taping	1.7	0.9		
p-value Taping	0.422	0.639		
AT Range	1.17 (0.86/1.92)	0.99 (0.68/1.35)	-3.4	0.001
NT Range	1.01 (0.76/1.54)	1.05 (0.64/1.38)	-1.2	0.214
NoT Range	1.09 (0.77/1.57)	0.90 (0.74/1.32)	-1.9	0.053
Chi Square Taping	1.9	0.3		
p-value Taping	0.381	0.871		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.9.2.2 (ii) Late Stance Phase

During late stance phase, Friedman tests revealed a significant difference with the taping condition on peak tibial cephalad acceleration on the low riser. Although the active tape value was lower than that of the neutral tape, and the neutral tape was lower than the no tape, post-hoc Wilcoxon signed-rank tests revealed no significant differences between taping conditions; active tape compared to no tape (p = 0.090), active tape compared to neutral tape (p = 0.098), and no tape compared to neutral tape (p = 0.574). For the riser heights, the Wilcoxon signed-rank tests showed significant differences in the peak caudad tibial acceleration for all taping conditions, and the peak cephalad tibial acceleration in the active and neutral taping conditions. Interestingly, for all these results, the low riser showed the greater accelerations, Table 5.28.

Table 5.28 Tibial Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Vertical Tibial Acceleration	Median ($25^{th}/75^{th}$ Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Caudad	-1.60 (-1.82/-1.26)	-1.81 (-2.03/-1.63)	-3.9	>0.001
NT Caudad	-1.66 (-1.80/-1.35)	-1.87 (-2.05/-1,57)	-3.3	0.001
NoT Caudad	-1.52 (-1.80/-1.29)	-1.84 (-2.08/-1.64)	-3.6	>0.001
Chi Square Taping	0.5	0.1		
p-value Taping	0.786	0.966		
AT Cephalad	0.07 (-0.18/0.34)	-0.09 (-0.30/0.15)	-3.3	0.001
NT Cephalad	0.02 (-0.11/0.35)	-0.03 (-0.39/0.32)	-2.3	0.021
NoT Cephalad	0.02 (-0.15/0.32)	0.06 (-0.27/0.21)	-1.9	0.058
Chi Square Taping	3.0	6.4		
p-value Taping	0.227	0.040		
AT Range	1.71 (1.21/2.00)	1.78 (1.28/2.07)	-1.6	0.107
NT Range	1.76 (1.20/2.07)	1.75 (1.08/2.39)	-0.6	0.581
NoT Range	1.52 (1.5/2.02)	1.90 (1.15/2.28)	-1.6	0.117
Chi Square Taping	3.4	0.5		
p-value Taping	0.185	0.786		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.9.2.3 (iii) Whole of Stance Phase

Over the whole of stance phase, Friedman test revealed significant differences for the taping conditions for the peak tibial caudad acceleration on the high riser. Post-hoc Wilcoxon signed-rank tests revealed no differences between the active tape and the neutral tape conditions (p = 0.094), between the active tape and the no tape conditions (p = 0.482), and between the neutral tape and the no tape conditions (p = 0.139). For the riser heights, the Wilcoxon signed-rank tests showed significant differences in the peak cephalad tibial acceleration between the riser heights under the active tape and the neutral tape conditions, with the greater accelerations were found on the low riser. However, for the range of caudad-cephalad tibial accelerations, significantly greater values were seen under both the active tape and the neutral tape conditions on the high riser, Table 5.29.

Table 5.29 Tibial Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Vertical Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Caudad	-2.12 (-2.92/-1.86)	-2.00 (-2.54/-1.83)	-1.4	0.163
NT Caudad	-2.02 (-2.52/-1.84)	-2.00 (-2.49/-1.91)	-0.1	0.991
NoT Caudad	-2.15 (-2.62/-1.84)	-2.13 (-2.39/-1.90)	-1.4	0.150
Chi Square Taping	6.4	0.1		
p-value Taping	0.040	0.966		
AT Cephalad	0.07 (-0.18/0.34)	-0.09 (-0.30/0.15)	-3.0	0.002
NT Cephalad	0.02 (-0.07/-0.35)	-0.03 (-0.29/0.32)	-2.3	0.020
NoT Cephalad	0.02 (-0.15/0.32)	0.06 (-0.28/0.21)	-1.9	0.058
Chi Square Taping	3.6	5.8		
p-value Taping	0.166	0.055		
AT Range	2.17 (1.90/3.08)	1.91 (1.67/2.57)	-2.7	0.007
NT Range	2.19 (1.82/2.76)	2.07 (1.61/2.73)	-2.8	0.006
NoT Range	2.25 (1.82/2.73)	2.07 (1.63/2.55)	-1.9	0.058
Chi Square Taping	1.4	0.9		
p-value Taping	0.485	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.9.3 Anterior-Posterior Tibial Accelerations

5.9.3.1 (i) Early Stance Phase

During early stance phase, Friedman tests revealed significant differences for the taping conditions for the posterior tibial acceleration and range of anterior-posterior tibial acceleration on the high riser height but not for the low riser. Post-hoc Wilcoxon signed-rank tests revealed greater accelerations for the posterior tibial acceleration under the active tape condition compared to the neutral tape condition (p = 0.006) and also between the active tape condition and the no tape condition (p = 0.016). There was no significant difference seen between the neutral and no tape conditions (p = 0.721). For the range of anterior-posterior tibial acceleration the post-hoc Wilcoxon tests showed a significant difference between the active and neutral tape conditions (p = 0.031), with the active tape showing the greater value. The results between the active tape condition and the no tape condition, and between the neutral tape condition and the no tape condition were not significant; p = 0.071 and p=0.787 respectively. For the riser heights, the Wilcoxon signed-rank tests showed that the peak anterior tibial acceleration was significantly greater on the high riser under the active tape condition, Table 5.30.

Table 5.30 Tibial Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Anterior Posterior Tibial Acceleration	Median ($25^{th}/75^{th}$ Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Anterior	-0.78 (-1.25/-0.64)	-0.65 (-1.06/-0.40)	-2.3	0.024
NT Anterior	-0.79 (-1.39/-0.49)	-0.74 (-1.07/-0.36)	-1.6	0.103
NoT Anterior	-0.90 (-1.30/-0.53)	-0.91 (-1.11/-0.54)	-0.8	0.430
Chi Square Taping	2.1	3.0		
p-value Taping	0.343	0.227		
AT Posterior	1.30 (0.83/1.66)	1.07 (0.74/1.64)	-1.9	0.056
NT Posterior	1.01 (0.73/1.65)	1.03 (0.70/1.56)	-0.6	0.552
NoT Posterior	1.14 (0.67/1.54)	1.06 (0.85/1.45)	-0.3	0.738
Chi Square Taping	7.7	0.5		
p-value Taping	0.021[a, b]	0.786		
AT Range	2.26 (1.61/2.91)	1.85 (1.21/2.56)	-1.9	0.058
NT Range	1.87 (1.39/3.03)	1.70 (1.05/2.71)	-1.3	0.198
NoT Range	2.08 (1.19/2.67)	1.94 (1.30/2.66)	-0.6	0.553
Chi Square Taping	9.2	0.9		
p-value Taping	0.010[a]	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.9.3.2 (ii) Late Stance Phase

During late stance phase, Friedman test revealed no significant differences in anterior-posterior tibial acceleration. However, for the riser heights the Wilcoxon signed-rank tests showed significant differences for the anterior and posterior accelerations under all taping conditions, and for the range of anterior-posterior tibial acceleration under the active tape condition. For all the peak anterior tibial accelerations and the range of anterior-posterior tibial accelerations, the greatest significant accelerations were seen under the high riser, Table 5.31. However, the significant peak posterior tibial accelerations showed the greatest accelerations on the low riser.

Table 5.31 Tibial Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Anterior Posterior Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Anterior	-0.88 (-1.11/-0.74)	-0.68 (-0.81/-0.54)	-4.7	>0.001
NT Anterior	-0.91 (-1.04/-0.77)	-0.71 (-0.81/-0.56)	-3.9	>0.001
NoT Anterior	-0.88 (-0.99/0.78)	-0.71 (-0.78/-0.57)	-4.5	>0.001
Chi Square Taping	1.4	2.1		
p-value Taping	0.485	0.343		
AT Posterior	-0.06 (-0.19/-0.29)	0.04 (-0.07/0.62)	-3.2	0.001
NT Posterior	-0.12 (-0.20/-0.23)	0.34 (-0.11/0.70)	-3.5	0.001
NoT Posterior	-0.08 (-0.19/-0.17)	0.17 (-0.07/0.67)	-3.8	>0.001
Chi Square Taping	0.8	0.9		
p-value Taping	0.661	0.639		
AT Range	0.85 (0.65/1.23)	0.76 (0.55/1.19)	-2.1	0.039
NT Range	0.89 (0.61/1.16)	0.79 (0.59/1.43)	-1.0	0.304
NoT Range	0.78 (0.69/1.15)	0.89 (0.61/1.38)	-0.1	0.991
Chi Square Taping	0.5	1.3		
p-value Taping	0.786	0.519		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior.

5.9.3.3 (iii) Whole of Stance Phase

During the whole of stance phase, Friedman tests revealed significant differences for taping for the peak posterior tibial acceleration and the range of anterior-posterior tibial acceleration on the high riser. The post-hoc Wilcoxon signed-rank tests showed significant differences in the posterior tibial acceleration between the active and neutral tape conditions (p = 0.006) and between the active and no tape conditions (p = 0.016). In both cases, the active tape showed the greater value. However, no significant differences were seen between the neutral and no tape conditions (p = 0.721). For the range of anterior-posterior acceleration significant differences were seen between the active tape and the neutral tape conditions (p = 0.019) and between the active tape and the no tape conditions (p = 0.045), and no differences between the neutral tape and the no tape conditions (p = 0.820). For the riser heights the Wilcoxon signed-rank tests showed significant differences for the peak anterior tibial acceleration under all taping conditions, and for the range of anterior-posterior tibial accelerations under the active tape condition. All of the significant differences demonstrated greater accelerations on the high riser, see Table 5.32.

Table 5.32 Tibial Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Anterior Posterior Tibial Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Anterior	-1.07 (-1.35/-0.85)	-0.85 (-1.14/-0.60)	-2.5	0.013
NT Anterior	-0.96 (-1.40/-0.80)	-0.92 (-1.26/-0.65)	-2.0	0.041
NoT Anterior	-1.07 (-1.40/-0.80)	-0.94 (-1.11/-0.67)	-2.8	0.004
Chi Square Taping	2.1	0.9		
p-value Taping	0.343	0.639		
AT Posterior	1.30 (0.83/1.66)	1.07 (0.74/1.64)	-1.7	0.094
NT Posterior	1.01 (0.73/1.65)	1.03 (0.70/1.56)	-0.6	0.552
NoT Posterior	1.14 (0.67/1.54)	1.06 (0.86/1.50)	-0.2	0.820
Chi Square Taping	7.7	0.9		
p-value Taping	0.021[a, b]	0.639		
AT Range	2.36 (1.75/3.12)	2.10 (1.43/2.57)	-2.3	0.023
NT Range	2.05 (1.58/3.03)	1.96 (1.38/2.71)	-1.6	0.112
NoT Range	2.29 (1.59/2.87)	2.00 (1.60/2.66)	-1.6	0.107
Chi Square Taping	7.7	0.1		
p-value Taping	0.021 [a, b]	0.966		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.10 Patellar Acceleration for the Three Taping Conditions and the Two Riser Heights During the Stance Phase of Stair Descent

5.10.1 Medial-Lateral Patellar Accelerations

5.10.1.1 (i) Early Stance Phase

The Friedman test revealed no significant differences between taping conditions for any of the patellar acceleration parameters in the early stance phase. For the riser heights the Wilcoxon signed-rank tests showed significant differences in the peak lateral patellar acceleration under the neutral tape condition which was greater on the low riser. During late stance phase and the whole of stance phase, there were no significant effects for riser height for any medial-lateral patellar acceleration parameters, Table 5.33.

Table 5.33 Patellar Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Medial-Lateral Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Medial	-0.54 (-0.99/-0.41)	-0.47 (-0.74/-0.35)	-1.7	0.098
NT Medial	-0.54 (-0.70/-0.39)	-0.44 (-0.84/-0.30)	-0.4	0.705
NoT Medial	-0.54 (-0.87/-0.36)	-0.58 (-0.83/-0.35)	-0.2	0.820
Chi Square Taping	0.6	5.0		
p-value Taping	0.733	0.081		
AT Lateral	0.47 (0.32/0.95)	0.51 (0.32/0.88)	-0.1	0.991
NT Lateral	0.41 (0.26/0.64)	0.56 (0.35/0.83)	-2.2	0.031
NoT Lateral	0.52 (0.32/0.63)	0.55 (0.30/0.76)	-0.6	0.538
Chi Square Taping	1.3	0.6		
p-value Taping	0.519	0.733		
AT Range	1.16 (0.77/1.79)	0.97 (0.82/1.59)	-0.8	0.430
NT Range	0.97 (0.71/1.43)	1.11 (0.72/1.54)	-0.7	0.496
NoT Range	0.94 (0.76/1.36)	1.11 (0.73/1.54)	-0.7	0.510
Chi Square Taping	3.4	0.6		
p-value Taping	0.185	0.733		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.10.1.2 (ii) Late Stance Phase

The Friedman test revealed no significant differences between taping conditions for any of the patellar acceleration parameters in late stance phase. For the riser heights, Wilcoxon signed rank tests revealed there were also no significant differences in late stance phase, Table 5.34.

Table 5.34 Patellar Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Medial-Lateral Patellar Acceleration	Median (25th/75th Percentile) High Riser	Low Riser	Z score	p-value
	51-100% stance phase during stair descent			
AT Medial	-0.31 (-0.46/-0.23)	-0.35 (-0.43/-0.18)	-0.8	0.417
NT Medial	-0.33 (-0.45/-0.27)	-0.31 (-0.45/-0.19)	-1.3	0.191
NoT Medial	-0.35 (-0.44/-0.29)	-0.27 (-0.47/-0.17)	-1.7	0.090
Chi Square Taping	0.5	1.9		
p-value Taping	0.786	0.381		
AT Lateral	0.31 (0.19/0.38)	0.23 (0.19/0.39)	-1.2	0.222
NT Lateral	0.31 (0.21/0.36)	0.27 (0.19/0.40)	-0.6	0.538
NoT Lateral	0.27 (0.17/0.49)	0.31 (0.20/0.42)	-0.5	0.627
Chi Square Taping	0.3	2.7		
p-value Taping	0.871	0.261		
AT Range	0.66 (0.50/0.80)	0.56 (0.44/0.69)	-0.9	0.336
NT Range	0.65 (0.48/0.82)	0.56 (0.48/0.83)	-1.0	0.304
NoT Range	0.59 (0.49/0.87)	0.59 (0.41/0.85)	-1.2	0.239
Chi Square Taping	0.5	0.2		
p-value Taping	0.786	0.902		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.10.1.3 (iii) Whole of Stance Phase

There were no significant differences found between taping conditions for any of the patellar acceleration parameters over the whole of stance phase. There were also no significant differences between the two riser heights, Table 5.35.

Table 5.35 Patellar Medial-Lateral Acceleration for each of the Three Taping Conditions on the Two Riser Heights during All Stance Phase

Medial-Lateral Patellar Acceleration	Median (25th/75th Percentile) High Riser	Low Riser	Z score	p-value
0-100% stance phase during stair descent				
AT Medial	-0.70 (-1.08/-0.49)	-0.66 (-0.91/-0.44)	-1.3	0.198
NT Medial	-0.58 (-0.90/-0.44)	-0.63 (-1.06/-0.46)	-0.7	0.496
NoT Medial	-0.62 (-0.97/-0.41)	-0.61 (-0.91/-0.52)	-0.8	0.430
Chi Square Taping	2.1	1.3		
p-value Taping	0.343	0.519		
AT Lateral	0.74 (0.40/1.06)	0.63 (0.41/0.96)	-1.4	0.177
NT Lateral	0.57 (0.39/0.90)	0.63 (0.41/1.00)	-1.2	0.239
NoT Lateral	0.59 (0.47/0.89)	0.64 (0.49/0.91)	-0.1	0.905
Chi Square Taping	2.1	3.4		
p-value Taping	0.343	0.185		
AT Range	1.43 (1.01/2.08)	1.15 (0.88/1.87)	-1.4	0.163
NT Range	1.14 90.80/1.66)	1.26 (0.81/2.13)	-0.9	0.370
NoT Range	1.19 (0.95/1.88)	1.28 (1.04/1.89)	-0.5	0.596
Chi Square Taping	2.7	2.5		
p-value Taping	0.261	0.289		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

5.10.2 Vertical Patellar Accelerations

5.10.2.1 (i) Early Stance Phase

The Friedman test revealed no significant differences between taping conditions for any of the vertical patellar acceleration parameters in early stance phase. For the riser heights the Wilcoxon signed-rank tests showed no significant differences under the different taping conditions for any parameter during early stance phase, Table 5.36.

Table 5.36 Patellar Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Vertical Patellar Acceleration	Median ($25^{th}/75^{th}$ Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Caudad	-1.93 (-2.22/-1.62)	-1.84 (-1.98/-1.56)	-0.9	0.325
NT Caudad	-1.78 (-2.23/-1.66)	-1.83 (-2.11/-1.60)	-0.6	0.552
NoT Caudad	-1.75 (-2.28/-1.62)	-1.82 (-1.90/-1.66)	-1.8	0.078
Chi Square Taping	0.1	0.2		
p-value Taping	0.966	0.902		
AT Cephalad	-0.77 (-0.94/-0.58)	-0.82 (-0.91/-0.70)	-1.1	0.265
NT Cephalad	-0.83 (-097/-0.71)	-0.75 (-0.90/-0.58)	-1.9	0.061
NoT Cephalad	-0.80 (-0.93/-0.72)	-0.85 (-0.93/-0.73)	-0.7	0.482
Chi Square Taping	2.5	5.4		
p-value Taping	0.279	0.066		
AT Range	1.14 (0.82/1.60)	0.95 (0.68/1.28)	-1.9	0.064
NT Range	1.06 (0.72/1.41)	1.09 (0.77/1.54)	-0.4	0.673
NoT Range	0.94 (0.81/1.46)	0.93 (0.81/1.24)	-1.2	0.214
Chi Square Taping	1.1	0.9		
p-value Taping	0.576	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.10.2.2 (ii) Late Stance Phase

As with the early stance phase, the Friedman test revealed no significant differences between taping conditions for any of the vertical patellar acceleration parameters during late stance phase, Table 5.36. For the riser heights the Wilcoxon signed-rank tests again showed no significant differences under the different taping conditions for any parameter during late stance phase, Table 5.37.

Table 5.37 Patellar Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
	51-100% stance phase during stair descent			
AT Caudad	-1.77 (-1.92/-1.50)	-1.75 (-1.96/-1.61)	-1.0	0.294
NT Caudad	-1.74 (-1.88/-1.57)	-1.81 (-1.99/-1.58)	-1.1	0.275
NoT Caudad	-1.74 (-1.90/-1.53)	-1.81 (-2.03/-1.65)	-1.2	0.239
Chi Square Taping	1.3	0.6		
p-value Taping	0.519	0.733		
AT Cephalad	-0.67 (-0.72/-0.58)	-0.69 (-0.73/-0.63)	-1.5	0.139
NT Cephalad	-0.62 (-0.71/-0.51)	-0.67 (-0.72/-0.59)	-1.5	0.139
NoT Cephalad	-0.66 (-0.71/-0.54)	-0.67 (-0.71/-0.63)	-1.4	0.163
Chi Square Taping	4.2	3.4		
p-value Taping	0.122	0.185		
AT Range	1.14 (0.81/1.33)	1.08 (0.95/1.35)	-0.1	0.991
NT Range	1.07 (0.94/1.37)	1.18 (0.87/1.45)	-0.6	0.567
NoT Range	1.14 (0.85/1.30)	1.12 (0.92/1.34)	-0.7	0.456
Chi Square Taping	3.4	1.3		
p-value Taping	0.185	0.519		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.10.2.3 (iii) Whole of Stance Phase

Friedman tests revealed that there were no significant differences found between the taping conditions over the whole of stance phase. Wilcoxon signed ranks tests revealed that there were no significant differences between the two riser heights during all stance phase, Table 5.38.

Table 5.38 Patellar Vertical Acceleration for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Caudad	-2.01 (-2.27/-1.68)	-1.91 (-2.20/-1.72)	-1.0	0.294
NT Caudad	-1.89 (-2.33/-1.74)	-1.97 (-2.14/-1.80)	-0.3	0.754
NoT Caudad	-1.87 (-2.40/-1.72)	-1.98 (-2.14/-1.74)	-1.5	0.139
Chi Square Taping	0.2	2.7		
p-value Taping	0.902	0.261		
AT Cephalad	-0.58 (-0.71/-0.50)	-0.59 (-0.68/-0.51)	-0.2	0.871
NT Cephalad	-0.60 (-0.64/-0.47)	-0.58 (-0.69/-0.46)	-0.1	0.957
NoT Cephalad	-0.60 (-0.68/-0.47)	-0.63 (-0.67/-0.55)	-0.7	0.496
Chi Square Taping	1.3	4.2		
p-value Taping	0.519	0.122		
AT Range	1.38 (1.16/1.74)	1.23 (1.12/1.67)	-0.5	0.596
NT Range	1.38 (1.09/1.87)	1.45 (1.15/1.71)	-0.2	0.820
NoT Range	1.44 (1.03/1.79)	1.35 (1.12/1.62)	-1.1	0.256
Chi Square Taping	2.1	1.3		
p-value Taping	0.343	0.519		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

5.10.3 Anterior-Posterior Patellar Accelerations

5.10.3.1 (i) Early Stance Phase

The Friedman tests revealed significant differences between taping conditions for peak anterior acceleration and the range of anterior-posterior acceleration on the high riser in the early stance phase. For the peak anterior acceleration post-hoc Wilcoxon signed-rank tests showed a significant difference between the active tape and the neutral tape conditions (p = 0.002) with the active tape creating the greater value, and between the neutral tape and no tape conditions (p = 0.014) with the no tape condition providing the greater value, but no significant difference between the active tape and the no tape conditions (p = 0.596). For the range of anterior-posterior acceleration significant differences were seen between the active tape and the neutral tape conditions (p = 0.003), and between the active tape and the no tape conditions (p = 0.024) on the high riser. In both cases, the active tape condition showed the greater values. The result between the neutral tape condition and the no tape condition was not significant (p = 0.127).

For the riser heights the Wilcoxon signed-rank tests showed significant differences for the anterior-posterior patellar acceleration for; the anterior angular velocity, posterior angular velocity and range of angular velocity, all under the active tape condition. In addition, a significant difference for the range of angular velocity was seen under the no tape condition. For all results the high riser showed the greatest accelerations, Table 5.39.

Table 5.39 Patellar Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Early Stance Phase

Anterior-posterior Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-20% stance phase during stair descent				
AT Anterior	-0.62 (-1.02/-0.41)	-0.52 (-0.75/-0.24)	-2.5	0.013
NT Anterior	-0.48 (-0.74/-0.21)	-0.50 (-0.74/-0.18)	-0.8	0.443
NoT Anterior	-0.64 (-0.82/-0.36)	-0.54 (-0.73/-0.31)	-1.6	0.103
Chi Square Taping	7.5	0.2		
p-value Taping	0.023 [a, c]	0.902		
AT Posterior	0.77 (0.41/0.94)	0.53 (0.32/1.00)	-2.0	0.048
NT Posterior	0.68 (0.37/0.95)	0.70 (0.36/0.89)	-0.3	0.738
NoT Posterior	0.58 (0.36/0.83)	0.51 (0.34/0.83)	-1.5	0.139
Chi Square Taping	1.7	1.9		
p-value Taping	0.422	0.394		
AT Range	1.36 (0.84/1.72)	0.95 (0.64/1.49)	-2.7	0.007
NT Range	0.98 (0.70/1.55)	0.94 (0.65/1.42)	-0.4	0.673
NoT Range	1.15 (0.89/1.50)	0.98 (0.77/1.31)	-2.3	0.019
Chi Square Taping	9.6	0.2		
p-value Taping	0.008 [a, b]	0.902		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

5.10.3.2 (ii) Late Stance Phase

The Friedman tests revealed no significant differences between the taping conditions for the anterior-posterior patellar acceleration during late stance phase. For the riser heights the Wilcoxon signed-rank tests showed significant differences in peak posterior acceleration for all taping conditions, all showing greater accelerations on the low riser. In addition, a significant difference was seen in the range of anterior-posterior acceleration under the active tape condition, with the high riser showing the greater accelerations, Table 5.40.

Table 5.40 Patellar Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during Late Stance Phase

Anterior-posterior Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
51-100% stance phase during stair descent				
AT Anterior	-1.08 (-1.31/-0.79)	-1.06 (-1.21/-0.81)	-1.6	0.117
NT Anterior	-1.06 (-1.28/-0.89)	-1.12 (-1.25/-0.71)	-1.4	0.150
NoT Anterior	-1.06 (-1.31/-0.80)	-1.10 (-1.21/-0.84)	-0.9	0.347
Chi Square Taping	0.9	0.2		
p-value Taping	0.639	0.902		
AT Posterior	0.16 (0.07/0.31)	0.32 (0.18/0.46)	-3.7	<0.001
NT Posterior	0.24 (0.10/0.38)	0.34 (0.16/0.43)	-2.5	0.013
NoT Posterior	0.20 (0.11/0.35)	0.37 (0.19/0.51)	-2.7	0.007
Chi Square Taping	4.2	0.3		
p-value Taping	0.122	0.871		
AT Range	1.31 (1.05/1.52)	1.28 (1.08/1.61	-2.4	0.015
NT Range	1.39 (1.04/1.58)	1.48 (0.87/1.64)	-0.7	0.482
NoT Range	1.23 (0.97/1.56)	1.44 (1.12/1.58)	-1.4	0.177
Chi Square Taping	3.0	0.9		
p-value Taping	0.227	0.639		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

5.10.3.3 (iii) Whole of Stance Phase

The Friedman tests revealed no significant differences between the taping conditions during the whole of stance phase. For the riser heights the Wilcoxon signed-rank tests showed a significant difference in the peak anterior acceleration under the active tape condition with the high riser showed the greatest accelerations, Table 5.41.

Table 5.41 Patellar Anterior-Posterior Acceleration for each of the Three Taping Conditions on the Two Riser Heights during the Whole of Stance Phase

Anterior-posterior Patellar Acceleration	Median (25th/75th Percentile)		Z score	p-value
	High Riser	Low Riser		
0-100% stance phase during stair descent				
AT Anterior	-1.19 (-1.36/-0.99)	-1.10 (-1.31/-0.99)	-2.1	0.037
NT Anterior	-1.23 (-1.37/-0.94)	-1.20 (-1.38/-0.98)	-0.8	0.430
NoT Anterior	-1.24 (-1.40/-0.86)	-1.15 (-1.23/-1.06)	-1.3	0.184
Chi Square Taping	1.9	0.5		
p-value Taping	0.381	0.786		
AT Posterior	0.77 (0.41/0.94)	0.59 (0.36/1.01	-1.2	0.230
NT Posterior	0.68 (0.41/0.95)	0.70 (0.40/0.89)	-0.2	0.820
NoT Posterior	0.58 (0.43/0.83)	0.63 (0.39/0.83)	-1.0	0.304
Chi Square Taping	0.3	0.5		
p-value Taping	0.871	0.786		
AT Range	1.85 (1.36/2.15)	1.61 (1.29/2.37)	-1.8	0.078
NT Range	1.86 (1.36/2.31)	1.80 (1.38/2.30)	-0.5	0.596
NoT Range	1.68 (1.38/2.15)	1.69 (1.40/2.03)	-1.5	0.139
Chi Square Taping	0.5	1.1		
p-value Taping	0.786	0.576		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

5.11 Chapter Summary

This chapter presented the results from asymptomatic participants. It is interesting to note that for the taping data, there were significant differences found in the movement control parameters but not in the stance phase or any of the muscle activity parameters. Meanwhile, the riser heights affected variables in all of these domains.

The movement control data revealed differences due to the active taping condition which increased the peak tibial flexion angular velocity and the range of tibial flexion-extension angular velocity when compared to the neutral tape and the no tape conditions during the early phase and the whole stance phase. However, only minimal significant differences in the transverse and coronal plane tibial angular velocities were seen.

For the tibial accelerations, significant differences were found during the early stance phase and when the whole of stance phase was considered for the anterior-posterior accelerations. These differences were increases in the peak posterior tibial acceleration and the range of anterior-posterior tibial accelerations due to the active tape condition with respect to both the neutral and no tape conditions. For the vertical tibial accelerations, there were significant differences found during the late phase and over the whole of stance phase, although the subsequent Wilcoxon tests were unable to reveal in which direction these differences lay. There were no differences seen in the medial-lateral tibial accelerations in any of the phases.

The patellar angular velocity data revealed that the coronal plane produced significant main effects in early stance phase. These were an increase in the peak abduction patellar angular velocity and in the range on abduction-adduction patellar angular velocity, with both increases being due to the neutral tape condition with respect to the no tape condition. However, there were no differences due to the taping conditions in the late stance phase or when the whole of stance phase was considered. Furthermore, there were no differences due to the taping conditions found in either the sagittal or the transverse plane patellar angular velocities.

For the taping effects on the anterior-posterior patellar accelerations, early stance phase revealed significant differences due to the active tape condition on the peak anterior acceleration and range of anterior-posterior acceleration with respect to the neutral tape condition. There was also a significant difference between the no tape and neutral tape conditions, again in the early phase. There were no significant differences in late stance phase or over the whole of the stance phase. Furthermore, there were also no significant differences for the medial-lateral or vertical patellar accelerations in any of the phases.

For the riser height data, it was revealed that the high riser produced greater stance phase duration than the low riser. There were also increases in the both the average and the peak muscle activity of VL and VM seen on the high riser. Therefore, the test limb was on the stair with the high riser for a longer time and produced greater VL and VM muscle activity while it was there than when compared to the low riser.

Significant differences were also seen in the sagittal plane tibial angular velocity where the high riser increased both the peak flexion and the peak extension angular velocities in the early phase, and also increased the peak extension angular velocity in the late phase. Although there were no significant differences seen in the transverse plane tibial angular velocities, the coronal plane data revealed that the high riser increased the peak adduction in both the early phase and over the whole of the stance phase.

Viewing the riser height influence on the tibial accelerations, there were significant differences seen in the medial-lateral tibial acceleration during the late stance phase, with the high riser increasing both the peak medial acceleration and the range of medial-lateral accelerations. Further significant differences were also found in both the vertical tibial acceleration and the anterior-posterior tibial acceleration. For the vertical tibial accelerations, the high riser increased the peak caudad, peak cephalad and range of caudad-cephalad accelerations in the early phase. However, interestingly it was the low riser that produced increases in the peak caudad and peak cephalad in the late phase, and again in the peak cephalad acceleration over the whole of stance phase. For the anterior-posterior tibial acceleration, the high riser produced significant differences across each of the sub-phases and over the whole of the stance phase. In the early phase, there were increases in the peak posterior acceleration and the range of anterior-posterior acceleration, while in the late phase and over the whole of the stance phase there were increases in the peak anterior acceleration and the range of anterior-posterior tibial acceleration.

The riser height data for the patellar angular velocities revealed significant differences in many of the parameters. For the anterior-posterior angular velocities, it was the low riser that increased both the posterior and the range of anterior-posterior during the late phase and over the whole of the stance phase. However, for the transverse and coronal planes it was the high riser that produced the significant differences, increasing the internal rotation during the late phase, and the abduction, adduction and ranges during the early phase and over the whole of the stance phase.

Finally, when considering the patellar accelerations, the low riser increased the lateral acceleration in in the early phase, the posterior acceleration in the late phase and the range of anterior-posterior accelerations in the late phase. Meanwhile, the high riser was responsible for increases in the anterior and range of anterior-posterior in the early phase, and the anterior accelerations when viewed over the whole of the stance phase.

When reviewing the taping data, it is interesting to note that the early phase and whole of the stance phase seemed to be more challenging than the late phase. However, for the riser height data, there was a more even spread of significant results over the phases of the stair descent, meaning that no one phase was more challenging than another. This will be further explored in the study with a symptomatic cohort where a second FSR will be utilised to further break down the sub-phases.

In summary, the key findings from the current study were:

- the taping technique(s) used in the current study influenced both the tibial and patellar kinematics during stair descent
- the taping techniques did not change VL, VM or GM muscle activity
- the taping techniques had no effect on stance phase duration
- riser height influences tibial and patellar kinematics during stair descent
- riser height influences muscle activity during stair descent, with the high riser being associated with increased VL and VM activity
- riser height influences stance phase duration, with increased stance phase being associated with the high riser
- both the different taping conditions and the different riser heights led to detected kinematic changes which indicates that IMUs can be used to collect kinematic data which has historically required laboratory-based camera systems

Chapter 6 Discussion: Efficacy of Taping and Effect of Riser Height in an Asymptomatic Cohort

6.1 Introduction

The aim of this study was to explore the efficacy of a taping technique reported to inhibit VL muscle activity in an asymptomatic cohort. This chapter will discuss the effect of three different taping conditions; active tape (applied with tension), neutral tape (applied without tension) and a no tape control condition on different parameters including stance phase duration, lower limb control and muscle activity. The effect of the taping and of the riser heights on the kinematic variables will be presented and discussed with respect to the early stance subphase (0-20%), late stance subphase (51-100%) and the whole of the stance phase (0-100%). The analysis of the separate sub-phases is to facilitate a fuller exploration of the taping and riser height variables than would be possible if only the whole stance phase was examined, and these sub-phases align with those described by McFadyen and Winter (1988). There is a precedence for only studying VL when exploring the effects of taping on the kinematics of stair descent in individuals with PFP (Salsich et al 2002). However, although the tape was applied to the skin over VL only, and was designed to have a direct effect on that muscle, VM and GM are also analysed as they are frequently investigated alongside VL in the PFP literature and have been reported as key muscles in the control of the lower limb in people with PFP (De Oliveira Silva et al 2016, Bolgla et al 2011b). In addition to the taping effects, this study also explored the effect of riser height on the same parameters using a stair unit with two different riser heights; one of 18cm which is referred to as the high riser, and one of 13cm which is referred to as the low riser (see figure 3.7).

The implications of the results for clinical practice and future research are discussed. This will be explored through statistical significance and clinical importance. Statistical significance in clinical research is used to demonstrate that any findings are not simply due to chance (Bhardwaj et al 2004). As defined by Sedgwick (2014), statistical significance provides an inference that the change seen in the sample will also be seen in the population, whereas clinical significance implies that the difference in effectiveness of a given treatment technique is clinically important. Clinical importance then implies that any difference(s) found may be sufficient to provide a meaningful change to patients. Terms such as minimally important change (MIC), minimal clinically important change (MCIC) and minimal clinically important difference (MCID) are often used interchangeably, with MICs often being attached to an outcome measure and used to interpret the size of any treatment effects (Kamper 2019c), and MCIDs being a patient-centred concept capturing both the objective improvements and the feelings or emotions that the patient puts on these changes (Fan et al 2021). It has been identified that interpreting an outcome score involves making a judgement about what a change or difference in that score really means, i.e., is it statistically significant, clinically meaningful or both? (Kamper 2019a). Determining whether something is clinically meaningful involves defining a threshold for an outcome measure, for example a change of two points in a numerical pain rating scale or a percentage improvement from a baseline score and then assessing whether the difference found is larger than the identified threshold (Kamper 2019b). This is important as clinicians who wish to apply research findings to their clinical practice need to be able to assess and interpret the size of any treatment effects (Kamper 2019c). However, to the author's knowledge, no thresholds have been found in the literature for establishing or determining what may be a MCID when evaluating magnitudes of difference in the parameters explored in the current study. Although these magnitudes of difference are expressed as a percentage change, it is unknown where the cut-off is for asserting whether there has been a MCID found. Therefore, a pragmatic decision regarding the threshold for demonstrating clinical importance is required (Kim et al 2018). For the purposes of the current study, research papers were sought where there was a statistically significant change in pain, which has an accepted MCID of two points on an 11-point VAS/NPRS (Fukuda et al 2010, Salaffi et al 2004), and also a statistically significant change in a given kinematic variable. The percentage change of the pain measurement can then be compared with the percentage change in the kinematic variable and used as a reference by which to imply a MCID.

6.2 Taping Effects

6.2.1 Taping Effects on Stance Phase Duration

The results of this study revealed that the different taping conditions had no significant effect on the stance phase duration during stair descent in an asymptomatic cohort, which suggests that asymptomatic participants descended the stairs at similar speeds regardless of taping condition. This finding is in agreement with Roy et al (2016) who found no significant difference in the duration of stance phase during step descent (with or without patellar tape) in individuals with meniscal injuries, thereby ruling out any potential effects due to the speed of descent on other parameters explored. Similarly, Smith et al (2016) found that there was no difference in stance time between pre-operative and post-operative knee arthroplasty patients, although there was a difference between their patient group and a group of matched controls. However, Salsich et al (2002) had contradictory results, as they found that stair descent cadence actually increased with the application of patellar taping. Although cadence and stance phase duration are not the same, and are not used inter-changeably, stance phase duration can give a gross indication of stair descent speed and hence the contrast with the work of Salsich et al (2002) is valid. Salsich et al (2002) attributed their findings to the significant pain reduction (92.6%) created by their patellar taping intervention, and then suggested that their participants, who all had PFP, were able to move more freely with the tape in situ, were better able to tolerate the PF joint loading associated with stair descent and therefore that they moved with significantly greater cadence. As the cohort of the current study were asymptomatic, pain reduction would not have been a factor which is a plausible explanation for why no change in stance phase duration was found.

6.2.2 Taping Effects on Lower Limb Control

In the current study, two IMUs were used to measure the participant's lower limb control, one positioned over the distal tibia of the test limb and one over the patella of the test limb. As can be seen in Chapter 5, each of these sensors produced some interesting results and these are discussed below. Although the sagittal plane angular velocity is a clearly interesting area to explore when considering knee movement and control (Aliberti et al 2019, Carruthers et al 2018, Schwane et al 2015), other authors have also recognised the importance of the rotations of the knee in the coronal and transverse planes (Selfe et al 2011). In the present study, these were recorded using the internal and external rotation angular velocities, which have been reported as having a key influence to patellar tracking (Selfe et al 2011, 2008), with patellar tracking also having been identified as a key factor in PFP (Grant et al 2020, Lack et al 2018). Additionally, past research conducted by Selfe et al (2008) has suggested that examining the transverse plane, and indeed the coronal plane as well, are just as important in assessing the potential impact of clinical interventions. Therefore, this study explored all three planes, and these results are discussed below.

6.2.2.1 (i) Kinematics during Early Stance Phase

With regard to the tibial flexion-extension angular velocity data, the active tape significantly increased the peak tibial flexion angular velocity with respect to the neutral tape condition by 13% and with respect to the no tape condition by 11% during early stance phase. These results represent an increase in the rate at which the tibia moved into a flexed position. Using the results of Salsich et al (2002), a MCID for knee flexion of 8% was calculated. Therefore, as the sizes of the changes reported here are exceed the value calculated from Salsich et al (2002), it can be argued that they are large enough to be considered clinically important as well. During the early phase, the active tape also increased the range of tibial flexion-extension angular velocity with respect to the neutral tape by 17% and with respect to the no tape by 18%, which again are likely to be clinically important differences.

With respect to the anterior-posterior tibial accelerations, during the early stance phase the active tape significantly increased the posterior tibial acceleration when compared to the neutral tape and no tape conditions when stepping down on the high riser. This was also the case for the range of anterior-posterior tibial accelerations. These results can be explored in combination with the early phase patellar accelerations, where the active tape significantly increased both the peak anterior acceleration and the range of anterior-posterior accelerations.

There are several possible explanations for the tibial flexion-extension angular velocity and the anterior-posterior tibial and patellar acceleration results during the early stance phase. Firstly, the tension that the active tape was applied with could have resulted in increased control of the knee meaning that the participants were better able/more confident to flex more quickly. This explanation could combine with the possibility that the active taping technique could have created increased proprioceptive input, which could in turn mean that the participant(s) had greater control of the tibial flexion-extension and therefore could move with a greater flexion angular velocity. Proprioception is essential for movement control (Riemann and Lephart 2002a and b), but requires sensory input into the central nervous system, which can then be used to modify motor commands to co-ordinate muscle activation patterns (Rőijezon et al 2015). Although there is some evidence to the contrary (Keenan et al 2017), it is generally accepted that proprioceptive input can be enhanced by the application of tape (Alahmari et al 2020, Callaghan et al 2012), and therefore, it is reasonable to speculate that increased confidence and/or proprioception during the early stance phase following the application of the tape is a plausible explanation for the effect of the active tape condition on the sagittal plane angular velocity.

Conversely, reduced control of the knee as a result of the tension in the tape is another potential explanation for the findings of the current study. If the asymptomatic participants in the current study were less able to control the flexion angular velocity as they descended the stairs, and hence did so more quickly, a decrease in the stance phase duration could be expected. However, there was no difference in stance phase duration time due to the taping conditions seen in the current study and therefore reduced control is an unlikely explanation for these findings.

There is good evidence from previous research into other pathologies and injuries besides PFP that suggest that interventions that increase confidence and decrease psychosocial factors such as kinesiophobia/fear avoidance and catastrophising, can lead to improved performance of functional tasks such as stair descent. For example, Harput et al (2016) found that bracing and taping the knee of patients who had undergone anterior cruciate ligament (ACL) reconstruction led to increased confidence in the affected knee and therefore improved performance. Although it should be acknowledged that the present study involved an asymptomatic sample and therefore that kinesiophobia is unlikely to have been a factor, it may still be reasonable to extrapolate from the cited research and attribute the change in flexion angular velocity to the increased confidence that can result from the application of tape (Harput et al 2016, Hug et al 2014). It could also be that the proprioceptive input from the active tape made the task of stair descent seem easier and therefore participants were happy to flex faster. This phenomenon of taping making a task feel easier was proposed by Callaghan et al (2008) to explain their findings which involved patellar taping on asymptomatic participants. If participants did feel more stable/had more control with the tape in the early phase of the step descent then this would indeed be an interesting finding as the early phase is a complex one to manage since it is where the loading of the PF joint increases and stability decreases as the person transitions from double leg support to single leg support, and from forward continuance to controlled lowering (McFadyen and Winter 1988). Although perceived stability was not measured in the current study, it was introduced for the second study comprising this thesis which involved a cohort of individuals with symptomatic PFP.

When considering the transverse plane knee control in the current study, the neutral tape significantly reduced the range of the tibial internal-external rotation angular velocity in early stance phase of the stair descent on the high riser with a 23% difference being found between the neutral tape condition and the active tape condition. Functionally, these results could indicate an increase in control/stability, with the neutral tape appearing to improve the dynamic stability of the taped leg although the post-hoc Wilcoxon test failed to find a significant difference between the two taping conditions. However, Table 5.6a reveals that the neutral tape value was considerably lower than that of either the active or no tape conditions, thereby suggesting that the neutral tape reduced the range of internal-external rotation angular velocity. Extrapolating from the results of Kwaees et al (2019), a MCID of 4% was calculated as the benchmark for establishing clinical importance for the range of transverse plane angular velocity. Therefore, the reduction in the angular velocity reported above exceeds this and the results of the current study for this parameter can be said to be clinically important. The finding of the neutral tape technique improving torsional control is consistent with the findings of Selfe et al (2008), who demonstrated an increase in transverse plane tibial control with patellar taping applied with no tension and concluded that the taping had at least some effect due to cutaneous sensory stimulation and feedback in asymptomatic individuals. This view was further reinforced by Selfe et al (2011) who reported large transverse plane movements in a no tape condition that were not replicated in their neutral patellar taping condition in individuals with PFP. The transverse plane results of the current study also compare with the findings of Tsai et al (2020) who found a reduction in transverse plane joint angles during a single leg squat task, albeit that this was a non-significant reduction. Finally, Kwaees et al (2019) also found that proprioceptive knee bracing in a cohort of asymptomatic participants reduced the transverse plane angular velocities during a step-down task, further supporting the results of the current study.

When exploring tibial angular velocity in the coronal plane, the only significant result in the early phase showed the neutral tape significantly increasing the peak tibial abduction angular velocity compared to both the no tape condition and the active tape condition when stepping down from the low riser. However, an increase in the abduction angular velocity may not be a desirable outcome, especially if it is associated with the dynamic knee valgus that is accepted to be an abnormal movement pattern often seen in PFP patients (Di Staulo et al 2019). The percentage change between the neutral tape condition and the no tape condition was 146%, and 44% between the neutral tape and active tape conditions. Extrapolating from the results of Baldon et al (2014), who explored the effect of functional stabilisation training with the knee abduction angle being one of the parameters studied, a MCID of 10% for knee abduction was calculated. Therefore, with the results of the current study exceeding this threshold by a considerable amount, it is reasonable to suggest that these changes are clinically important. Possible mechanisms for these findings include that the results are a response to the lack of tension with the neutral tape and/or that they are as a result of the proprioceptive effect of the tape. The proprioceptive theory is supported by Selfe et al (2008) who investigated both patellofemoral bracing and patellar taping, and found that both interventions had a significant effect on the torsional (transverse) and coronal mechanics of the knee in an asymptomatic cohort during an eccentric step-down task. However, they found that their interventions improved the control, whereas it appears that the neutral tape in the current study has decreased it. Coronal plane kinematics were also explored by

Richards et al (2019) who found that their PFP group had larger coronal plane movements with respect to an asymptomatic control group, and attributed this to altered motor control or increased knee instability. Both Selfe et al (2008) and Richards et al (2019) concluded that it was important not to overlook the transverse and coronal planes when investigating activities involving the knee, especially as increased movements in these planes may induce greater or excessive loading of the patellofemoral joint which could ultimately cause or exacerbate PFP. Given the increase in coronal plane kinematics found in the current study, which may increase dynamic knee valgus and loading of the patellofemoral joint, this therefore will be an area to examine closely with the symptomatic participants to assess if the neutral tape has a similar effect.

With respect to the patellar angular velocity data, the neutral tape condition significantly increased both the peak abduction and the range of abduction-adduction angular velocity compared to the no tape condition when stepping down from a low riser. The magnitude of the difference between the two taping conditions for these variables was 19% for the peak abduction angular velocity and 13% for the range of abduction-adduction angular velocity, with both of these values arguably representing important clinical changes according to the 10% threshold calculated and extrapolated from Baldon et al (2014). The results of the current study suggest that, due to there being an increase in the movement of the patella, the neutral tape may actually have made the patellar less stable in terms of its abduction-adduction rotations. A possible mechanism for this finding is that during the early stance phase of stair descent, the forefoot makes contact with the stair below and then involves the knee moving from a relatively stable extended position to an increasingly unstable more flexed position through the weight acceptance phase and the transition into the controlled lowering phase (Bonifácio et al 2018, McFadyen and Winter 1988). Therefore, the increase in the patellar abduction-adduction angular velocity seen in the early phase may be a representation of the increasing demands associated with this increasingly challenging phase of the stair descent. However, it could also be a reflection that in the early phase, as the knee starts in an extended position, the patella is not yet engaged in the femoral trochlear groove. Therefore, the patellar angular velocity in the coronal plane results may be a function of the patella having the potential to move more, particularly on the low riser which involves less knee flexion than the high riser and therefore less patellar engagement with the femoral trochlear (Norris 2017).

6.2.2.2 (ii) Kinematics during Late Stance Phase

The functional importance of the late stance phase is that it appears to include the transition from single leg stance to a double support phase (Zachazewski et al 1993, McFadyen and Winter 1988). Therefore, it would be reasonable to expect an increase in angular velocities here. Examining the late stance phase sagittal plane data revealed that the tibial flexion angular velocity did indeed increase. It did so under the neutral taping condition when compared with no tape, albeit with only a 2% difference between the two conditions. Accepting the extrapolated value for a flexion angular velocity MCID which was 8% from Salsich et al (2002), it can be seen that this result is not clinically important. There were no other significant results for the taping effects on the tibial angular velocities in any of the planes. There were also no significant differences in any of the patellar angular velocities during the late phase. For the vertical tibial accelerations, there was a significant difference in the late phase cephalad acceleration when stepping down on the low riser. However, it was one of the results where the post-hoc Wilcoxon tests failed to indicate a direction for this difference. For all other tibial acceleration measures and all the patellar acceleration measures, there were no significant differences due to the taping conditions found in the late phase.

It can be seen from the above that there were not many significant findings in the late phase resulting from the different taping conditions. Also, the findings that were statistically significant were of a magnitude of difference that were not clinically important. As it appears to contain elements of the single leg stance phase and the transition from this to a double leg support phase (Zachazewski et al 1993, McFadyen and Winter 1988), it could be argued that the late phase would be a challenging phase of stair descent and therefore likely to highlight any differences there may have been. However, the results of the current study do not support this, which may have been simply because, as the participants were asymptomatic, they didn't find the stair descent to be a challenging task. Although there have been other studies that have reported on the sub-phases of the stance phase, for example Burston et al (2018), these studies have compared effects between groups not within groups, and therefore it is difficult to draw comparative conclusions from them. A possible reason for the current study not finding many significant differences in the late phase may be in part due to the current methodology which did not allow for a definitive timing of the late stance phase due to the use of only a single FSR on the study limb. Therefore, future work should include the use of a second FSR on the contralateral limb to identify the sub-phases of the stance phase more accurately and allow a fuller exploration of the sub-phases of the stance phase of stair descent.

6.2.2.3 (iii) Kinematics during the Whole of Stance Phase

It is evident that there were several significant results found when viewing the whole of stance phase. These include the active tape increasing the peak tibial extension angular velocity by 57% compared to the neutral tape condition when descending the high riser. The active tape condition increasing the peak tibial extension angular velocity by such a large margin demonstrates that the whole of stance phase observations reveal differences during the task that were not observed within the sub-phases. This may be because the consideration of the whole of stance phase provides an assessment of the entire stair descent task as examined in the current study. For example, the active tape significantly increased peak tibial extension angular velocity by 279% compared to the neutral tape condition when descending the low riser. These results reveal large magnitudes of difference which, in keeping with the extrapolated figure of 8% from Salsich et al (2002), indicates that this represents a clinically important change. Findings from the current study also revealed that the active tape significantly increased the peak posterior tibial acceleration with a magnitude of difference of 25% when compared to the neutral tape condition, and of 13% when compared to the no tape condition. No significant differences were seen between the neutral and no tape conditions. The active tape also significantly increased the range of anterior-posterior acceleration with respect to the neutral tape condition where the magnitude of the difference was 14%, and with respect to the no tape condition where the magnitude of the difference was 3%. There was no difference between the neutral tape and the no tape conditions. With the exception of the 3% value for the increased range under the active tape condition compared to the no tape condition, these values are likely to be clinically important (Salsich et al 2002).

When considering the patellar accelerations, there were no significant effects seen for the medial-lateral patellar accelerations suggesting that there was no significant impact on the sideways control of the patella. This was reinforced by there also being no significant differences in the abduction–adduction patellar angular velocity over the whole of the stance phase. These results indicate that there was minimal, if any, change in the sideways movement at the patella. This may not be a surprising finding for three reasons. Firstly, it was unlikely that there would have been a big change in the medial-lateral accelerations as this was an asymptomatic sample so their medial-lateral control could reasonably have been expected to be good. Secondly, the activity of all three muscles under investigation was unchanged by the tape which could be argued as indicating that there was then no necessity to change the dynamic medial-lateral control mechanisms. Thirdly, it is possible that, as it lies on the skin over the patella, the IMU cannot accurately track the patella as the patella will move independently of the skin. Therefore, this IMU will only give an idea about how the patella is moving. Although there were some sideways patellar movements in the early phase as detected by the patellar angular velocity results described above in section 6.2.2(i), it could be argued that the lack of taping effect on the medial-lateral patellar acceleration over the whole of stance phase supports these suggestions. However, a contrasting view is that the lack of effect on the sideways movement of the patella is surprising given that there is an expectation that the taping conditions would have influenced the proprioceptive feedback and thereby enhanced dynamic stability. This view is supported by Roy et al (2016) who used patellar taping with and without tension in a step descent task and found that both their taping conditions reduced the frontal plane kinematics which they attributed to the cutaneous stimulation and proprioceptive input from the tape.

In the transverse plane, there was a significant difference in the range of the internal-external rotation tibial angular velocity, when participants descended the low riser. However, the post-hoc Wilcoxon tests were unable to establish a direction for this difference, although Table 5.6c reveals that the neutral tape created values considerably higher than both the active tape and no tape conditions. This is a noteworthy finding as it suggests that the neutral tape may have made the knee less stable in the transverse plane when viewed over the whole of the stance phase. However, these results contrast with those of Roy et al (2016) who found that their taping techniques improved the transverse plane kinematics of their participants.

It can be seen from section 6.2.2(i-iii) that there is a suggestion that the early phase and the whole of stance phase were more demanding than the late phase. This agrees with McFadyen and Winter (1988) who found that the early stance phase was associated with greater joint moments than the late stance phase, which suggests that the early phase was more challenging than the late phase. This is further supported by Igawa and Katsuhra (2014) who found that the main kinematic difficulty their OA knee participants had with stair descent was in the early stance phase. Burston et al (2018) also looked at sub-phases of stair descent, dividing their stair descent data into forward continuum (which would correspond approximately to the early phase in the current study) and controlled lowering phases (which would correspond to the late phase in the current study). They hypothesized that their PFP patients would have different biomechanics with respect to their healthy participants evidenced by the PFP patients demonstrating greater peak knee flexion which occurred during the lowering phase and greater knee adduction moments and greater transverse plane rotations which occurred in the forward continuum phase. This suggests that the most demanding phase for the sagittal plane movements was the late phase while for the coronal and transverse planes it was the early phase. This contrasts with the current study where the most demanding phase was the early one for all planes as well as the whole of the stance phase. A possible explanation for this is that the participants in the current study were asymptomatic whilst the Burston et al (2018) study involved participants with PFP. Furthermore, with the current study revealing much activity over the whole stance phase, a plausible explanation for this is that the whole of the stance phase involves greater total knee loading than the individual sub-phases, with Sole et al (2016) postulating that differences for kinematic variables are likely to be more obvious where knee loading is greater.

6.2.3 Taping Effects on Muscle Activity

Previous systematic reviews have suggested that patellar taping can have a significant effect on muscle activity, for example, Chang et al (2015), Barton et al (2014), and Aminaka and Gribble (2005). However, contrastingly, Cowan et al (2006) reported that their patellar taping technique did not alter the EMG of the vasti muscles. The Cowan et al (2006) study notwithstanding, it appears to be reasonable to hypothesize that the taping techniques used in this current study would also have had a significant proprioceptive input which, according to motor control theory, should have had an effect on motor output and therefore muscle activity.

One of the main findings from the current study was that neither of the taping techniques had a significant effect on the VL muscle activity. Furthermore, there were also no significant differences found in the muscle activity of VM and GM between any of the taping conditions. These findings therefore do not support the hypotheses that the active and neutral tape would decrease VL muscle activity compared to the no tape control condition, and the active and neutral tape condition would increase VM and GM muscle activity compared to the no tape control condition. The lack of any significant effects with the taping techniques is in contrast with the findings of both McCarthy Persson (2009) and Tobin and Robinson (2000). The active tape in the current study was applied in such a way that every participant had a furrow created in their VL as recommended by McConnell (McConnell 1995). It is therefore reasonable to expect that the depth of pressure required to create this furrow in the over-lying skin and in the muscle beneath could indeed have stimulated the type IV nociceptors as proposed in section 2.11. This then could have led to the consequential stimulation of the inhibitory inter-neurones in the dorsal horn of the spinal cord leading to reduced alpha motor neurone output and a decreased sEMG signal, again as proposed in section 2.11. Muscle inhibition resulting from the application of tape was confirmed by Smith et al (2009a), who found that a rigid taping technique inhibited the upper fibres of the trapezius muscle, and by Alexander et al (2008) who found that taping along the muscle fibres of the triceps surae muscles inhibited their reflex excitability. Alexander et al (2008) also found that taping across the muscle bellies had no effect. The current study taped across the belly of VL and therefore the findings from Alexander et al (2008) support those of the current study. Serrao et al (2016) assert in their paper investigating the effect of kinesio tape that the direction of the tape application is very important, while Alexander et al (2003) stated that taping along muscle fibres will have a facilitatory effect while taping across them will have an inhibitory effect, although this actually contrasts with their subsequent findings. The conflicting results of these studies demonstrate that the mechanisms by which taping has its effects are, as yet, poorly understood.

Even though the active tape technique used in the current study did not inhibit VL, it is still surprising that there was no effect at all as it would remain reasonable to have expected some form of proprioceptive effect from the application of tape onto the skin. Both inhibition and facilitation have been identified as possible effects of taping (Hug et al 2014), with each outcome depending on the technique applied. Callaghan et al (2012) found that patellar taping led to an increase in activity in the primary sensorimotor cortex which they attributed to the increased sensory input from the tape. They also found that their patellar taping technique reduced the activity in the anterior cingulate and cerebellum, which they proposed was due to the increased proprioception from the tape making the task they studied easier to perform and which therefore needed less activity from these areas. This would suggest that the VL taping techniques used in the current study should have influenced the sensory/proprioceptive input into the higher centres in the cerebral cortex which would have resulted in some change in the motor output, with Kakar et al (2020) identifying this process as a driving factor in sensorimotor function. Indeed, Selfe et al (2011 and 2008), in explaining their findings that PF bracing had more of an effect than patellar taping, albeit that they did not use EMG in their studies, suggested that the bracing had the larger effect as it covered a greater surface area of the skin than the tape did and therefore had a much larger proprioceptive impact and hence enhanced motor control. Furthermore, Edin (2001) identified that mechanoreceptors in the skin play an important role in proprioception. As both of the taping techniques in the current study covered a considerable area of the skin over the anterolateral thigh, that they would activate these mechanoreceptors and thereby induce increased proprioception is a reasonable theory. However, the findings of the current study do not support this, but do show agreement with Serrao et al (2016) who found no difference in any EMG activity under any of their four taping conditions; facilitation tape, inhibition tape, placebo tape and a no tape control condition. These authors attributed this lack of effect(s) to the isolated effects of their kinesio tape being unable to change the magnitude of the EMG activity. The results of the current study also compare with Janwantanakul and Gaogasigam (2005) who found no effect with either inhibition tape or facilitation tape when applied to VL, which they attributed to differences in EMG sampling frequency when compared to the Tobin and Robinson (2000) study.

Another possible explanation for the lack of taping effects found in the current study is that the sEMG may not have been sensitive enough to detect any changes that occurred in the activity of the studied muscles, especially given that there were kinematic changes detected. Using average and peak sEMG is a gross method of looking at muscle activity and motor control, and it may be that exploring onset timings and muscle activity ratios would have led to the detection of changes. It may also be the case that techniques such as decomposition sEMG, which decomposes the sEMG signal into its constituent motor unit action potentials, would be better able to detect subtle changes in muscle activity (De Luca et al 2015). However, this technique is still in its infancy and has, until recently, been confined to isometric muscle contractions (Martinez-Valdes et al 2016) rather than the dynamic activity that was used in the current study. Furthermore, although there has been some recent development with using decomposition sEMG to explore dynamic activities, these developments came too late to be utilised in this thesis. However, it may be that future research utilising decomposition sEMG techniques will be used to increase our understanding of the muscular demands of dynamic activities such as stair descent and the possible effects of taping.

Another plausible explanation for the lack of effect of the taping conditions on the muscle activity is that as the cohort for the current study were asymptomatic, the chosen activity, i.e., stair descent on a maximum riser height of 18cm, may not have been demanding enough. Trinler et al (2016) found that there were increased mechanical demands created by increasing riser heights, from 17cm to 21cm. As the high riser height in Trinler et al’s study was greater than the one used in the current study, which was 18cm, it could be argued that the 21cm riser height stair was more likely to elicit changes in muscle activity than the riser heights used in the current study. The task not being demanding enough could explain the lack of differences in muscle activity. However, it should also be noted that patients with PFP report stair descent as a common symptom aggravating activity, and therefore, given that it equates with the standard stair height in public places (Spanjaard et al 2008), a riser height of 18cm may be sufficiently demanding to elicit differences in the studied parameters when explored with a symptomatic cohort.

Finally, it is also possible that a five-minute washout period between taping conditions may have been insufficient for the tissues to return to their pre-intervention condition. This being the case, it may be that the distinction between the taping conditions was not clear enough to detect and assign changes that may actually have been present.

6.3 The Effect of Riser Height

6.3.1 Riser Height Effects on Lower Limb Control

An additional aim of the current study was to explore the effects of riser height on the control of the lower limb during stair descent and on the muscle activity. Taking the lower limb control data first, the current study found that the riser height had a profound effect on the tibial kinematics.

6.3.2 Riser Height Effects on Stance Phase Duration

The current study found that the high riser height resulted in a significantly longer stance phase duration compared to the low riser. This is potentially due to the stance leg needing to move through a larger range of flexion and the contralateral leg, which is in the swing phase, needing to travel a greater distance when descending the high riser. This compares to the reduced flexion and less distance to travel when negotiating a lower riser height. This finding concurs with Foster et al (2014) who showed increased stance durations with increasing riser heights. Foster et al (2014) also identified that analysing the stance phase is an important part of understanding the influence of clinical conditions and the effects of stepping dynamics. However, Spanjaard et al (2008) reported contrasting, shorter contact times on the higher riser heights, which they attributed to differences in ankle moments and ankle function strategies during stair descent on different riser heights. However, their lowest riser height was only 85mm which they identified as being approximately half that of the most common riser height found in public places (Spanjaard et al 2008). It could also be the height at which stance phase initiation strategies change. During level walking, in the absence of pathology, the stance phase begins with heel strike whereas for step descent, especially on higher riser heights, the initial contact of the foot signifying the start of the stance phase is with the toes/forefoot (Gerstle et al 2018). This transition from heel strike to toe/forefoot strike with increasing riser height is likely to have consequences for the stance phase duration, as demonstrated in the current study by the high riser stance durations compared to the low riser stance durations.

6.3.2.1 (i) Kinematics during the Early Phase

The tibial flexion-extension angular velocity produced several significant findings. The high riser significantly increased the peak tibial flexion angular velocity under all the taping conditions, and significantly increased the peak tibial extension under the active and neutral tape conditions compared to the low riser height. For these results, the magnitude of differences ranged from 5.1% to 55.6%. The clinical importance attached to these differences is again extrapolated MCID from Salsich et al (2002), with the threshold for determining clinical importance being 8%. Using this threshold, all these results except the tibial flexion on the high riser under the neutral and no tape conditions can be considered as clinically important and worthy of further discussion. It is plausible that the findings may be due to the early phase starting with the test limb in a relatively extended position and then beginning to flex rapidly as the person moves through weight acceptance, forward continuance and then controlled lowering (McFadyen and Winter 1988). These findings may be linked with the anterior-posterior patellar accelerations in the early phase, where the high riser significantly increased the peak anterior and posterior accelerations under the active tape condition, and the range of anterior-posterior accelerations under both the active tape and no tape conditions. The magnitudes of these differences were; 18% for the peak anterior acceleration, 37% for the peak posterior acceleration, 36% for the range under the active tape and 16% for the range under the no tape condition. Again, the implication of this is that during the early phase, the stance leg starts from an extended position and moves towards increasing flexion. Thus, during the early phase, as the knee is relatively extended, the patella will not yet be engaged with the femoral trochlear (Norris 2017) meaning that it has more freedom to move which is reflected in the anterior-posterior patellar acceleration results.

The tibial flexion-extension angular velocity findings of the current study are broadly in agreement with those of Trinler et al (2016) who looked at both asymptomatic participants and patients post-knee arthroplasty descending stairs with different riser heights. They found that although there were no significant differences between their study groups, there were significant differences in the knee kinematics and kinetic patterns due to different riser heights. Specifically, they found that there were significantly greater knee flexion moments on the high riser for both their asymptomatic participants and their post-arthroplasty patients, and therefore concluded that the high riser created greater mechanical demands. The implication of this finding for a PFP cohort is that a greater demand created by a high riser could help to explain why stair descent is an activity that PFP patients find challenging.

For the abduction-adduction tibial angular velocity during early stance, the high riser significantly increased peak adduction by 12% compared to the low riser under the no tape condition. This increase in magnitude is potentially a clinically important finding when the 12% value is compared to the 10% benchmark extrapolated from the work of Baldon et al (2014). The high riser increasing the peak adduction in the early phase could suggest that as the participant moved into the forward continuance and potentially also the controlled lowering phases of the stair descent, so there could have been an element of dynamic knee valgus which could increase the loading of the knee (Kowalk et al 1996). The accepted importance of the sagittal plane angular velocities aside, it can be argued that the abduction-adduction moments in the coronal plane are equally as important as they represent the medial-lateral stability of the knee (Kowalk et al 1996), and the medial-lateral stability of the knee is an inherent component of the dynamic knee valgus often seen in PFP patients (Rabelo and Lucareli 2018). This is supported by Richards et al (2019) who identified the clinical importance of the coronal plane movements being indicative of the stability of the knee. Crucially, Richards et al

(2019) also identified these movements as “modifiable factors”, with the modality of choice being either bracing or taping which highlights the importance of these interventions.

When considering the vertical tibial accelerations in the early phase, there were several significant differences found. These include the high riser increasing the peak caudad acceleration for the active and no tape conditions where the magnitudes of the differences between the riser heights were 9% and 7% respectively, the low riser increasing the peak cephalad acceleration for the active tape condition where the magnitude of the difference was 6%, and the high riser increasing the range for the active tape condition where the magnitude of the difference was 17%. Functionally, these results suggest that the high riser increased the downwards acceleration and the vertical range of acceleration of the tibia, which means that the participant(s) were descending the stairs at a greater speed on the high riser than they did on the low riser.

When considering the coronal plane and the patellar abduction-adduction angular velocity, there were noteworthy significant findings in the early phase. The high riser significantly increased the peak patellar abduction angular velocity, the peak patellar adduction angular velocity, and also the range of patellar abduction-adduction angular velocity under the no tape condition. The magnitude of difference between the riser heights for the peak abduction was 18%, for the peak adduction was 23% and for the range of abduction-adduction was 23%. Extrapolating again from the results of Baldon et al (2014), a calculation of their change in knee valgus angle revealed that a difference of 10% suggests clinical importance. Therefore, as they exceed these levels, the magnitudes of difference found in the current study for the peak adduction and the range of abduction-adduction are of a level that are likely to be clinically important. Furthermore, the increase in these parameters on the high riser with respect to the low riser indicates that the high riser created greater demands on the sideways stability and control of the knee. Regarding the medial-lateral patellar acceleration, the only significant finding came during the early phase, and this was the increase in the peak lateral acceleration under the neutral tape condition on the low riser. The magnitude of this difference was 31% which again exceeds the threshold for clinical importance. However, it should be put into the context of there being no other significant findings for this parameter; there being no differences between the riser heights found in the late phase or over the whole of stance. These results compare with those found by Stone et al (2017) who explored a squatting activity in females who had had ACL reconstructions and in non-injured controls, and found that abnormal frontal/coronal plane kinematics were greater in their control group. They attributed this finding to the ACL reconstruction group having undergone proprioceptive re-education and movement control re-education as part of their rehabilitation and therefore had developed greater skills in these areas, while their control group were functioning without this enhanced neuromotor activity. It may therefore be plausible to suggest that this could also be an explanation for the apparent difficulty that the asymptomatic participants in the current study had with the sideways control of their patella.

6.3.2.2 (ii) Kinematics during the Late Phase

When considering the tibial acceleration data, the medial-lateral tibial acceleration produced several significant differences between the riser heights during the late phase, although there were no significant differences found in the early phase or over the whole of the stance phase. The high riser significantly increased the peak medial tibial acceleration for all the taping conditions. The magnitudes of these differences ranged between 29% and 42%, but their clinical importance is unknown. There was also a significant difference in the range of medial-lateral tibial acceleration for the no tape condition, again on the high riser with the magnitude of this difference being 15%, and again, the clinical importance is unknown However, the functional implication of this is that the tibia accelerating medially in the late phase could represent a sub-clinical movement towards the dynamic knee valgus which has been reported to be a feature of PFP (Capin and Snyder-Mackler 2018). However, dynamic knee valgus would also induce differences in the coronal plane tibial angular velocity which, as highlighted above, produced no significant findings in the late phase.

For the anterior-posterior tibial acceleration, there were several significant findings in the late phase. The high riser significantly increased the peak anterior tibial accelerations for all taping conditions, and also increased the range of anterior-posterior tibial acceleration for the active tape condition. Additionally, the low riser increased the peak posterior tibial acceleration under all of the taping conditions. The number of significant differences found in the late phase contrasts with only one in the early phase and four when the whole stance was considered. This could imply that for this parameter, the late phase was more challenging than the early phase or even the whole of the stance phase. The potential functional implications of these findings have been discussed in section 6.3.3(i).

For the acceleration data, the medial-lateral tibial acceleration, the vertical tibial acceleration and the anterior-posterior tibial acceleration all had significant findings during the late phase with high magnitudes of difference. Therefore, for the tibial accelerations, it can be argued that the late phase was the most demanding. However, these results may contrast with Mohr et al (2003) who found that it was the mid stance phase that was actually the most demanding. However, their sub-phases do not correlate with those of the current study as they used loading response, midstance, terminal swing (of the contralateral limb) and pre-swing. Mohr et al (2003) hypothesized that the rationale behind midstance being identified as the most demanding phase was that this was the sub-phase when the person is in single leg standing and is lowering their body weight onto the stair below which requires considerable eccentric muscle control. Mohr et al's (2003) findings compare with those of Baldon et al (2013) who also identified the single leg stance phase as being the most challenging for the hip muscles. The late phase of the current study was from 51-100% of the stance phase, and therefore, it may well have included at least part of the single leg stance phase within it. Although this cannot be stated with absolute certainty, the activity in the various sub-phases of the stance phase is an area worthy of further investigation, and the addition of a second footswitch on the contralateral side would help with the exploration of these sub-phases of the stance phase of stair descent. However, the results of the current study highlight that there were several parameters where it was the early phase that appeared to be the most challenging. These include the tibial flexion-extension, the tibial and patellar abduction-adduction angular velocities and the patellar medial-lateral acceleration.

Considering the patellar angular velocities, the sagittal plane representing anterior-posterior patellar angular velocity produced several significant results with respect to the different riser heights. Although there were none in the early phase, the late phase showed significant differences between the riser heights, with the low riser creating greater peak posterior patellar angular velocity and a greater range of anterior-posterior angular velocity under all taping conditions. These results may be due to the low riser being associated with lower patellofemoral loading due to the reduced knee flexion, with respect to that found on the high riser. Greater knee flexion is associated with greater patellofemoral loading as the patella is pulled tighter into the trochlear groove by the quadriceps creating less freedom of patellar movements (Greenwald et al 1996), which is associated with lower angular velocities. Conversely, the patella has greater freedom of movement when the knee flexion is reduced to the extent that it is no longer in contact with the trochlear surface, with a range of between 0 and 20 - 30 degrees of knee flexion often being quoted (Wheatley 2020, Loudon 2016). The greater freedom of movement that the patellar has in this range facilitates the greater angular velocities associated with the low riser height that have been seen in the current study. In terms of the magnitude of the differences, the peak posterior patellar angular velocity between the two riser heights under the active tape condition was 16%, the peak posterior patellar angular velocity between the two riser heights under the neutral tape condition was 29% and the peak posterior patellar angular velocity between the two riser heights under the no tape condition was 25%. For the range of the anterior-posterior patellar angular velocity, which was again increased on the low riser, the magnitudes of the differences were 13% between the two riser heights under the active tape condition, 14% between the two riser heights under the neutral tape condition, and 22% between the two riser heights under the no tape condition. It is interesting to note that for the tibial flexion-extension angular velocities, it was the early phase that produced the most significant results whereas with the patellar anterior-posterior angular velocity, it was the late phase that was responsible. A possible explanation for this is that the early phase, which coincides with the forward continuance and controlled lowering phases as described by McFadyen and Winter (1988), is associated with the tibia flexing rapidly as the stair descent started.

In the late phase, there were also several significant differences found in the anterior-posterior patellar accelerations between the riser heights. This compares with the findings in the early phase but this time the differences were found in the low riser which increased the peak posterior acceleration under each of the three taping conditions and also for high riser which increased the range of anterior-posterior accelerations under the active tape condition. The magnitudes of the differences found were 67% for the peak posterior acceleration on the low riser under the active tape condition, 35% for the peak posterior acceleration on the low riser under the neutral tape condition, 60% for the peak posterior acceleration on the low riser under the no tape condition, and 2% for the range of accelerations on the high riser under the active tape condition. With the exception of the value for the range of accelerations (2%), all the other magnitudes are of a level which could be considered as clinically important if the extrapolated MCID of 8% from Salsich et al 2002 is accepted.

Examining the transverse plane, the high riser significantly increased the peak patellar internal rotation by 25% on the high riser compared to the low riser under the no tape condition during the late phase. Although this was the only significant result for this parameter, if an extrapolated value for an MCID of 4% from Kwaees et al (2019) is accepted, the magnitude of the difference in the current study was clinically important. Thus, although it may appear that the differing riser heights did not have much influence on the internal or external rotation of the patella, the finding that the high riser increased the internal rotation of the patella is important to consider and undermines the sentiment that for the asymptomatic cohort, this variable does not seem to play a big role in their stair descent kinematics.

6.3.2.3 (iii) Kinematics during the Whole of Stance Phase

The high riser significantly increased the range of flexion-extension tibial angular velocity under the neutral tape condition by 14% during the whole stance phase. Additionally, the high riser also significantly increased the peak adduction angular velocity by 6% under the active tape condition and by 5% under the no tape condition. Using the thresholds calculated previously in this chapter; i.e., the 8% from Salsich et al (2002), it can be seen that neither of these results are therefore clinically meaningful. However, it can still be seen that the higher values were seen on the high riser which indicates that the high riser was more challenging for the sideways control of the knee than the low riser. Although this is a logical finding, it is an important one nonetheless since it establishes the differing demands from the two riser heights (Foster et al 2019).

The whole stance produced similar results to the early phase, with the high riser significantly increasing the peak patellar abduction under the no tape condition, significantly increasing the peak patellar adduction under the no tape condition and significantly increasing the range of patellar abduction-adduction under the no tape condition. In addition, there was also a significant difference between the riser heights for the peak patellar adduction under the active tape condition, with the high riser again being responsible for that difference. The magnitudes of these differences were; 19% for the peak abduction under the no tape condition, 11% for the peak adduction under the active tape condition, 9% for the peak adduction under the no tape condition and 17% for the range under the no tape condition. Using the calculated and extrapolated MCID of 10% for the knee abduction degree from Baldon et al (2014), with the possible exception of the peak abduction under the no tape condition, these magnitudes are likely to be clinically important. The results of the coronal plane patellar angular velocities from the current study compare with those of Trinler et al (2016) who found greater adduction moments at the knee on the high riser in their study, and with Kowalk et al (1996) who found greater peak abduction in the early phase of stair descent. The functional implications of this are that in the early phase particularly, but also over the whole of the stance phase, the mediolateral movement control in this asymptomatic cohort appears to have been more affected on the high riser when compared to the low riser. This could possibly indicate that although these participants were asymptomatic, they may be at risk of developing PFP or other lower limb mechanical-related pathologies such as osteoarthritis, with Richards et al (2019) being among those to propose a link between reduced coronal plane control and excessive patellofemoral joint loading and the possible onset of PFP symptoms. Given the results of Trinler et al (2016) and those of the current study, it would be reasonable to accept that higher riser heights create greater physical demands than lower riser heights, particularly in the coronal plane, which is clearly relevant from a functional perspective. These physical demands in the coronal plane will challenge the lateral and medial stabilising structures involved in knee joint control, for example the collateral ligaments of the knee and the iliotibial band (Kowalk et al 1996), and muscles such as VM (Melo et al 2020). If challenged sufficiently, and over a long enough period of time, there is the potential for tissue and joint overloading and the consequential development of pathology (Dye 2005).

6.3.3 The Effects of Riser Height on Muscle Activity

The current study found significantly greater average and peak VL and VM muscle activity on the higher riser under all taping conditions. There was however, no significant difference in the muscle activity of GM. The magnitudes of the average differences for VL were; active tape between the riser heights was 26%, neutral tape between the riser heights was 20% and no tape between the riser heights was 27%. For all these findings, it was the high riser that increased the muscle activity with respect to that found on the low riser. For the average VM activity, the magnitudes of the differences were; active tape between the riser heights was 21%, neutral tape between the riser heights was 30% and no tape between the riser heights was 21%. Again, as for VL, it was the high riser that increased the muscle activity when compared to the low riser. The magnitudes of the differences in the peak muscle activity were similar to these average values, with the results for VL revealing a difference of 20% with the active tape between the riser heights, 18% with the neutral tape between the riser heights and 20% with the no tape between the riser heights. Finally, for the peak VM activity, the difference with the active tape was 30% between the riser heights, with the neutral tape it was 28% between the riser heights, and with the no tape it was 21% between the riser heights. All these magnitudes are of a value to be clinically important, and are therefore worthy of further consideration. The finding of greater VL and VM activity on the high riser would again seem to be a logical one since the higher riser heights have been shown to be associated with greater task demands than the lower riser heights (Gavin et al 2019). This view is supported by Foster et al (2019) who found that stair descent became more challenging as stair riser height increased. Descending stairs has also been identified as an activity that requires the generation of greater joint moments in the lower limbs (King et al 2018), and joint moments are in part generated by muscle activity. Therefore, it would be expected that the high riser would generate greater demand than the low riser which would be reflected by increased muscle activity, which is what was seen in VL and VM in the current study.

The results with respect to there being no difference in the muscle activity of GM are less easy to explain. It would be reasonable to expect that there would have been a difference in the muscle activity of GM between the two riser heights since this would reflect a response to the changing mechanical demands created by the different riser heights. However, the current study did not find a significant difference in GM activity, thereby suggesting that the different riser heights placed similar demands on this muscle. Furthermore, when reviewing the sEMG data from the current study, although the activation patterns of VL and VM were largely very similar with a biphasic pattern being evident, the traces for GM were very different. For VL and VM, there was usually an initial burst of activity between 0 and 25% of stance phase followed by another activity burst between approximately 60 and 80%, see Figures 6.1 and 6.2. However, for GM, the sEMG pattern revealed an initial burst of activity between 0 and 20% with a monophasic pattern for the rest of the trace. Figure 6.3 clearly illustrates this difference with respect to Figures 6.1 and 6.2.

Figure 6.1 Sample VM sEMG signal

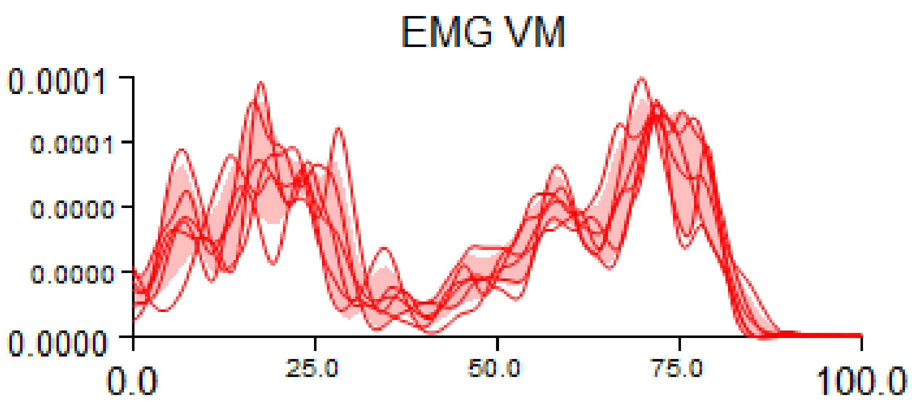


Figure 6.2 Sample VL sEMG signal

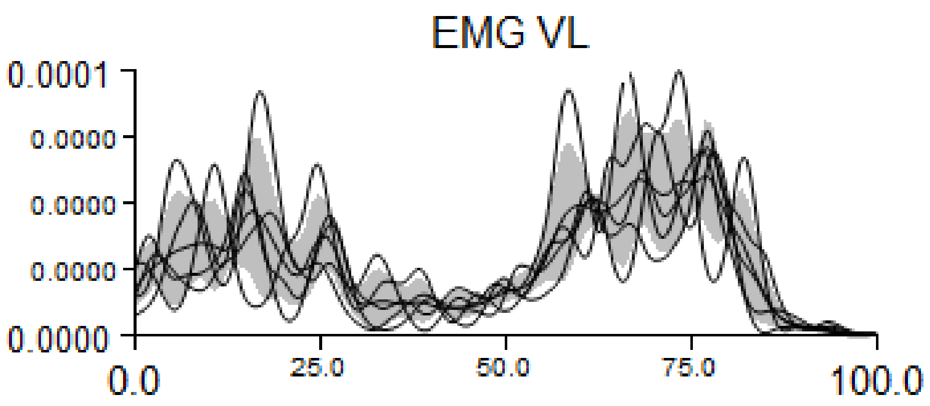
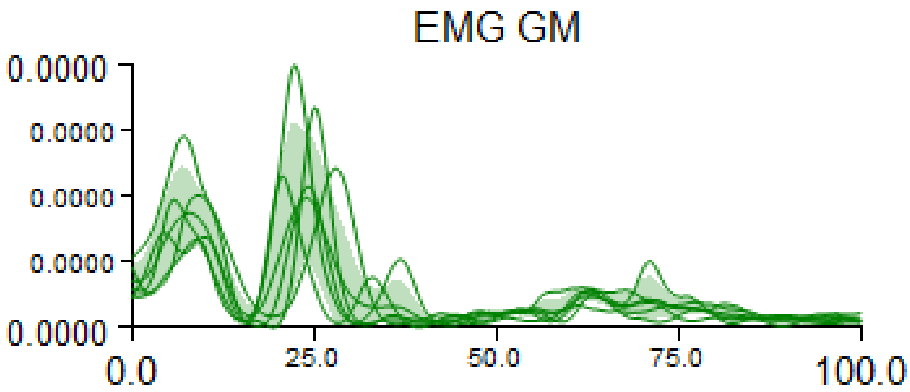


Figure 6.3 Sample GM sEMG signal



6.4 Study Limitations

This study has limitations that should be acknowledged. The first is that it only involved asymptomatic participants which limits its relevance to PFP, which has been recognised by Brabants et al (2018). Brabants et al also recognised the limitations in applicability of both exploring only one task and of having a relatively small sample size. The sample being a convenience one from the same university source could also reduce the generalisability of the findings (Clifford et al 2020). The lack of blinding to the taping condition should also be noted as it is possible that bias could have been unintentionally introduced during the data collection and analysis stages (Bolgla et al 2011b). The order of the tape conditions was randomised but the riser height was not randomised as every participant descended the low riser height first. The speed with which the participants descended the stairs was not regulated to create a more real-life study protocol, but it is recognised that this does make the study less repeatable. As all the data was collected in one session, only the immediate effect(s) of the tape can be insinuated and any long-term effects are unknown (Hickey et al 2016). This is an important point as it has been reported that taping effects can differ between those that are seen immediately after application and those that are seen after a prolonged period of time (Alahmari et al 2020, Keenan et al 2017).

6.5 Implications for Clinical Practice and Future Research

One of the key findings from the current study was that both the active tape and the neutral tape techniques affected several key kinematic parameters, particularly in the early stance phase and over the whole of the stance phase. In most cases, they actually increased the variable of interest, for example the peak sagittal plane tibial flexion and the peak coronal plane patellar abduction, suggesting that there was either increased freedom of movement or reduced movement control with the tape(s) applied.

Another major finding of the current study was the lack of taping effect on muscle activity. Neither the active taping technique nor the neutral taping technique influenced the activity of GM, VL or VM. However, the effect of the taping techniques on other clinically relevant variables such as pain and perceived stability is as yet unknown. The second study of this thesis, which involved a symptomatic cohort and measured participant's pain and perceived stability, may therefore provide important information as to the effect(s) of the tape.

The increased stance phase contact time that was seen on the high riser may have implications for exercise prescription. Eccentric loading, which can be achieved with step-down tasks, has been identified as a key part of an exercise programme for PFP patients. If it is desired for the patient to work within their envelope of function (Dye et al 1999), or with as little pain as possible with taping reducing the pain during a provocative activity by at least 50% (McConnell 1986), then it may be wise in the initial stages of PFP rehabilitation to use a low riser height so as not to provoke symptoms and look to increase riser height as the rehabilitation process progresses (Brindle et al 2003).

Conversely, if maximum quadriceps muscle recruitment with increased duration and demand is desired, then working on a higher riser height should be considered. The results from the current study indicate that there was a significant difference found with the high riser increasing sEMG activity of both VL and VM. However, it would appear that this was not the case for GM. Although this was an asymptomatic cohort, meaning that the implications for clinical practice are therefore limited, it may be that, as discussed above, there is cause to consider riser height when setting step descent as an element of a home exercise programme, with the greater recruitment of the vasti muscles coming from greater riser heights, but possibly with higher riser heights being associated with greater pain levels (McClinton et al 2007). However, as discussed previously, this is an issue that needs to be determined by the levels of pain reported during this activity, and therefore it will be discussed further with the results from the next study of this thesis involving a symptomatic cohort where reported pain was recorded.

Another of the main implications from the current study is that the IMUs are an effective way of collecting biomechanical data and offer an alternative to the more traditional camera-based methods. The current study used just two light-weight, easily transported and simple to use sensors to gather information on the lower limb kinematics. That they produced significant information on these kinematics opens up the possibility of using them in clinical settings rather than being laboratory-based with a potentially significant impact on musculoskeletal assessments and outcome measures used clinically.

Further research involving a symptomatic cohort is needed to put the results of the current study into the context of PFP. It will be important to use the results of the current study to inform and influence the methodology used with a symptomatic cohort, including the addition of collecting data on patient reported pain and perceived stability during the stair descent.

It would also be useful to explore the various sub-phases of the stance phase more fully, and to this end the methodology for the next study in this thesis was altered to include a second footswitch, which was not available for the current study, on the opposite/contralateral limb.

6.6 Chapter Summary

In summary, this study has explored the effects of a specific VL inhibition therapeutic taping technique on various neuromuscular and biomechanical/kinematic parameters in an asymptomatic cohort. Although the participants being asymptomatic limits the clinical implications and application of the findings, there are still contributions to knowledge to be taken from this study. These include the exploration of the impact of applying a rigid therapeutic taping technique with and without tension, the exploration of the impact of different riser heights on the lower limb control (kinematics) and muscle activity (sEMG), and exploring the potential to recommend using IMUs in a clinical setting.

Chapter 7 Methods - Symptomatic Participants

7.1 Introduction

The second study in this thesis involved the collection of data from symptomatic participants and in this chapter, only methodological differences from the asymptomatic methods (Chapter 3) will be described in detail. The taping conditions and the instructions given to the participants regarding non-use of the handrails, the descent at their own speed and the leading with the test limb remained the same.

7.2 Ethical Considerations and Approval

For ethical approval for the second study in this thesis, an ethics amended application was submitted and subsequently approved by the University of Central Lancashire's Science, Technology, Engineering, Medicine, Health Ethics Committee (STEMH 283_amendment), see appendix 5. All participants gave their written informed consent and each participant was assigned a participant code number so their data/ identifying information was fully anonymised. All information gathered for each participant, including their informed consent, was stored in a locked cabinet at UCLan. Furthermore, the muscle activity (sEMG) and movement control (IMU) data were collected on a password-protected laptop and stored on OneDrive. All participants were informed of their right to withdraw at any time during the data collection session and without any reason.

7.3 Participant Recruitment and Demographics

Symptomatic participants were recruited from the local Parkrun community with the backing of the Parkrun Research Committee, and also from the UCLan staff and students. Prior to participating, all potential participants were given the amended Participant Information Sheet – Version 3 (04/08/18) to read (see appendix 6). If potential participants were still interested in participating, several screening questions were asked over the phone to assess their eligibility for the study. These questions included having had pain at the front of the knee(s) for more than three months, aged between 18 and 40 years old, willing to attend an assessment session at UCLan, having no known allergy to tape, having no other medical conditions, not currently having treatment for lower limb or back conditions, having no previous history of lower limb problems, having no history of knee locking or giving way, having no history of lower limb surgery, and not currently waiting for lower limb surgery (see appendix 7). Suitable participants were then invited to attend the UCLan Movement Analysis Laboratory where a single data collection session was performed. Prior to data collection commencement, informed consent was obtained and demographic data and further PFP assessment screening was acquired (see appendices 8-12). Seventeen potential participants were excluded for the following reasons; outside the age ranges (n=8), experiencing patellar tendinopathy (n=3), had Osgood-Schlatter's disease (n=2), had a popliteal injury (n=1), unable to attend the testing session (n=1), symptoms resolved prior to testing (n=1) and declined to be taped (n=1).

7.4 Methodological Changes from the First Study

The equipment (section 3.2), skin preparation (section 3.3.1), footwear criteria (section 3.3.3), taping conditions (section 3.4), handrail instructions (section 3.8.3) and stair descent speed (section 3.8.4) were the same as the asymptomatic study (see Chapter 3). However, based on the outcomes of the asymptomatic study, some methodological changes were warranted which are now described below.

7.4.1 Pre-Testing Screening

When the participants attended for their data collection session, after consent was obtained (see Appendix 8) and their demographic data recorded (see Appendix 9), participants were asked a series of screening questions regarding their experiences with pain during functional activities including squatting, prolonged sitting, stair ascent/descent, running, kneeling and hopping/jumping. Participants were also screened for pain on palpation of their patella and pain during/after resisted isometric quadriceps contraction (see Appendix 10). This was done to help with the process of assessment and confirming that their pain was PFP and therefore that they were appropriate for the study.

7.4.2 Sensor Placement and Addition of a Second FSR

The results of the asymptomatic study revealed that distinct sub-phases within the stance phase during stair descent were evident despite only recording the stance phase of the study limb. As a result, a second FSR was positioned under the first metatarsal head of the unaffected limb with the aim of increasing the accuracy of identifying these sub-phases within the stance phase. This allowed the stance phase to be analysed in four separate sub-phases: the first double leg support phase, the single leg support phase, the second double leg support phase and the whole of the stance phase (see Figures 2.8a and 2.8b).

7.4.3 Stair Riser Height

As reported in Chapter 5 and discussed in Chapter 6, analysis of the data from the asymptomatic participants highlighted that the high riser height was the more challenging condition when examining the knee stability kinematics. Given that stair descent is an activity known to be provocative for people with PFP symptoms (Leibbrandt and Louw 2017, Crossley et al 2016a), and it was believed that the symptomatic participants would therefore be likely to experience pain during stair descent, it was decided to only include the high riser height within this study. This decision was further informed by the desire to choose the high riser height (18cm) which more closely matched the average 17cm riser of stairs found in public places (Spanjaard et al 2008) and was deemed more relevant to real life situations.

7.4.4 Washout Period

In seeking explanations for the lack of inhibition of VL found in the asymptomatic sample, on reflection the five-minute washout period between taping conditions may have been inadequate. It is possible that the five minutes was not sufficient for the skin, and more importantly the muscle, to return to its normal pre-testing state. Whilst past research utilised a five-minute rest/wash out period between conditions (Selfe et al 2011, Aminaka and Gribble 2008, and Cowan et al 2006), other studies used a ten-minute wash out period (Choi and Lee 2018 and McCarthy Persson et al 2009). Whilst acknowledging that there is an argument for keeping the testing conditions the same to allow direct comparisons to be made between the two studies, it was felt that changing the washout period to ten minutes would give the skin and muscle more time to recover and would therefore make any differences between the taping conditions more likely to be detected. Therefore, the decision was made to change the washout period to ten minutes.

7.4.5 Knee Injury and Osteoarthritis Outcome Score

Patient reported outcome measures (PROMs) are used to gather information from patients about their condition status and to evaluate their perspective of the efficacy of interventions given (Crossley et al 2018). As they are completed by patients, they reduce the potential for the observer bias that is inherent with clinician-led outcome measures. However, Crossley et al (2018) identified that, due to the array of PROMs currently available, there is no gold-standard specific PROM for PFP or PFP OA to be found in the literature. In their systematic review, Howe et al (2012) identified 47 studies relating to 37 outcome measures for the knee. However, these were not all PFP specific as they included, for example, the Anterior Cruciate Ligament – Quality of Life outcome measure and the generic SF-36. Subsequently, Green et al (2014) in their systematic review identified 7 studies which included 12 PROMs relating to assessing/measuring pain, daily activities and the PF joint. However, they were unable to identify one that was superior to the others or that could be recommended as the gold standard. This left the field of PFP open for the development of a new PROM.

The patellofemoral pain and osteoarthritis subscale of the KOOS (KOOS-PF), (see appendix 11) was developed to address both the lack of a gold standard PFP outcome measure and also the specificities of patellofemoral joint pathologies. The KOOS-PF was developed in three phases: firstly, input was generated not only from expert clinicians and researchers in the field of PFP and/or PF OA, but also from patients with these conditions. The second phase involved the generation of 80 items for consideration of inclusion, with these being reduced down to 11 in the final outcome measure. The third and final phase was the evaluation of the outcome measure in line with the **co**nsensus-based **s**tandards for the selection of health **m**easurements **in**struments (COSMIN) guidelines. These guidelines evaluate the reliability, validity, responsiveness and interpretability of an outcome measure, with the KOOS-PF being found to be reliable, valid and responsive for patients with PFP and/or patellofemoral osteoarthritis (OA) (Crossley et al 2018). Each item in the KOOS-PF has a five-point Likert scale which ranges from zero to four and is scored with the aggregate score for each domain being transformed to a 0-100 scale by the formula:

$$100 - \frac{\text{mean raw score}}{\text{possible raw score range}} \times 100$$

The higher the score, the less problematic the condition is whilst lower scores represent increasing difficulties.

Although it is a relatively new outcome measure, the KOOS-PF is already being used in the PFP literature, for example MacLachlan et al (2020), Tayfur et al (2020) and Sinclair et al (2018). Barton et al (2019) used both the KOOS-PF and the anterior knee pain scale (AKPS) in their study. They found that the 13-item AKPS and the 11-item KOOS-PF scores were very similar for their groups, with the AKPS scores being 76 out of 100 pre-intervention and 90 out of 100 post intervention while the pre and post intervention scores of the KOOS-PF were 74 out of 100 and 89 out of 100 respectively. Nunes et al (2019) also found similar responses in their participants with these two outcome measures, with the mean AKPS pre and post intervention scores being 76.3 and 99.5 respectively and the mean KOOS-PF scores being 67.3 and 98.9 respectively. Nunes et al (2019) also identified that the KOOS-PF encompasses items related to stiffness, pain and quality of life whereas the AKPS is more focused on difficulties with functional activities. Given all the above, it can therefore be argued that the KOOS-PF is a robust outcome measure and was an appropriate one to use in the current study.

7.4.6 TIPPS Assessment

In order to further inform the description of the symptomatic participants, each participant was assessed with the TIPPS assessment battery (see Appendix 14). The TIPPS assessment battery was developed by Selfe and colleagues to provide a comprehensive clinical assessment of the factors that are known to influence PFP with a view to identifying clinical sub-groups (Selfe et al 2013 and 2016). These factors were identified as lower limb biarticular muscle tightness, hip abductor weakness, quadriceps weakness, patellar hypomobility, patellar hypermobility, and a pronated foot posture (Selfe et al 2013). Originally the TIPPS assessment consisted of six clinical tests (see Section 2.12 for more details), but, as hamstring length was found not to be informative with respect to forming the subgroups, this test was discarded (Selfe et al 2016). Therefore, the TIPPS assessment now includes the five remaining measurements plus the full foot posture index (FPI) assessment. The five remaining TIPPS assessment tests are; passive prone knee flexion to measure rectus femoris length, calf flexibility in standing to measure gastrocnemius length, hip abductor strength, Quadriceps strength, total patellar mobility. The FPI meanwhile consists of six separate tests including talar head position, supra and infra lateral malleolar curvature, calcaneal frontal plane position, prominence in the region of the talonavicular joint, congruence of the medial longitudinal arch and abduction/adduction of the forefoot on the rearfoot (Redmond et al 2008 and 2006). The results of these eleven tests are then used to assign patients to one of three subgroups; strong, weak and tighter, and weak with pronated feet which is calculated using the Appatella application. The theory is that if patients can be assigned to one of these sub-groups, then their interventions can be tailored, or targeted, to meet their specific needs and therefore enhance rehabilitation outcomes (Selfe et al 2018).

7.4.7 Measures of Pain and Perceived Stability

As the participants in this study were symptomatic for PFP, it was deemed necessary to capture self-reported pain data at rest and during the step descent task under each taping conditions. Self-reported pain is undoubtedly an important marker for any assessment and/or treatment programme, with Kaya et al (2012) identifying it as the most important guide in the treatment process. Numerical pain rating scales (NPRS) are quick and easy ways of quantifying pain levels, and have been recommended for research purposes (Matthews et al 2017). They can be administered verbally or graphically to provide a unidimensional measure of pain intensity. There have been attempts to categorise the data gleaned from NPRS's, for example zero being no pain, one-three being indicative of mild pain, four-six reflecting moderate pain and seven-ten representing severe pain. However, these categories are arbitrary and may not truly capture the patients intended meaning. Therefore, it is difficult to categorise individual pain scores rated at a single point in time and thus changes in pain scores are generally reported with both Matthews et al (2017) and Collins et al (2018) reporting that a change in score of two points or more on a NPRS represents the minimal change necessary to indicate clinically important change. Prior to undergoing the testing conditions, each participant was asked to rate their average pain in the previous week using a NPRS of zero-ten where zero represented no pain and ten represented the worst pain imaginable (see appendix 10). Participants were also asked to complete an NPRS after they had completed the five trials under each of the taping conditions.

Perceived stability is another patient reported outcome measure. Perceived stability can be closely linked to function, with increased stability leading to improved functional performance. Function often goes hand in hand with pain, with increased pain often resulting in decreased function and vice versa. Function is often seen as being as important as pain, with a reduction in pain not necessarily result in functional improvement (Leibbrandt and Louw 2019), Therefore it is important to utilise other outcome measures besides just the pain levels in order to capture information about variables relating to function, such as perceived stability. This is important as being able to address issues relies on being able to identify and measure them, hence the recording of pain and perceived stability outcome measures in this study. All participants were asked to complete a five-point Likert scale to measure their perception of knee stability after each taping condition, with the points on the scale being very unstable, unstable, neither stable nor unstable, stable and very stable, see appendix 13.

7.4.8 Randomisation

The order of the three different taping conditions were randomised using computer generated permutations (using www.randomization.com).

7.4.9 Selection of the Test Limb

The participants' painful knee was selected for testing, however if they experienced bilateral symptoms, the most severe side was chosen for testing (Powers et al 1996).

Chapter 8 Results for Symptomatic Participants

8.1 Introduction

This chapter will present the results for the symptomatic participants. Unfortunately, Covid-19 restrictions meant that recruitment of participants for this study was limited, with only sixteen participants being recruited. This means that the conclusions that can be derived from these results and the inferential statistics must be tempered due to the small sample size. The possible effects of a small sample size can be seen in the TIPPS classifications of the current study's sample. Although all three of the TIPPs subgroups were represented in the symptomatic sample recruited for this study, the relative proportions differed from those found by Selfe et al (2018) who had a much larger sample of 130 participants. The larger sample size means that individual classifications have a smaller relative effective on the overall proportion or percentage of participants in each subgroup. This is discussed further in section 9.2. However, it is an indication that the small size of the current sample may not therefore be truly representative of these subgroups. All sixteen participants met the inclusion criteria set out in section 7.3, and attended UCLan for further data collection. Firstly, demographic data and descriptive data highlighting the PFP screening results, including KOOS-PF scores and TIPPS assessment data to describe the symptomatic cohort were collected. The results of these descriptive data are presented in this chapter, and are followed by the results of the inferential statistical analysis of the muscle activity (sEMG) data, the movement control (IMU) data, and the self-reported pain and perceived stability data. These results will be presented to facilitate the exploration the effect of the three taping conditions and the sub-phases of the stance phase.

8.2 Pre-screening Data

Thirty-three potential symptomatic participants were screened for their eligibility to participate. However, unfortunately seventeen of these potential participants were ineligible. Eight potential participants were excluded because they were outside of the specified age range, two because they were diagnosed with Osgood-Schlatter's disease, two because they had patellar tendinopathy, one because they had a popliteal tendon injury, two because they found that they were unable to commit to the data collection, one whose symptoms resolved prior to testing and one because they were unwilling to have the tape applied to their skin. The remaining sixteen participants all met the inclusion criteria, see Appendix 7. They were then asked a series of PFP screening questions, the results of which are presented in Table 8.1 below.

Table 8.1 Results of the Symptomatic Participant PFP Screening Questions

Participant number	Squat	Sit	Stairs up	Stairs down	Run	Kneel	Hop	Patellar Palpation	Isometric quads
01	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
02	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No
03	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
04	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes
05	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
06	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes
07	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
08	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
09	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
13	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
14	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
15	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No
16	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Yes answers	16	12	13	16	15	12	13	14	14

8.3 Demographic Data

Table 8.2 displays the demographic data of the sixteen eligible symptomatic participants. There were nine females and seven males, with an age range of 22 - 39 and a mean age of 31.5 years (SD = 6.74). The participants' height ranged from 156 - 191cm with a mean height of 176cm (SD = 12.32). Their weights ranged from 53 - 120kg with a mean weight of 86kg (SD = 21.28). The range of BMI scores was 19.9 - 33.5kg/m^2 with a mean of 27.4kg/m^2 (SD = 4.20).

Table 8.2 Symptomatic Participant Demographic Data

Participant Number	Sex	Age	Height (cm)	Weight (kg)	BMI (kg/m^2)
01	Female	22	170	92	31.8
02	Male	30	191	100	27.4
03	Female	24	156	65	26.7
04	Female	22	162	53	20.3
05	Female	20	164	60	22.3
06	Female	39	170	66	22.8
07	Female	39	181	87	26.5
08	Male	35	178	86	27.1
09	Female	27	179	64	19.9
10	Male	32	189	120	33.5
11	Female	38	170	89	30.7
12	Male	36	189	113	31.6
13	Male	38	187	109	31.1
14	Male	39	185	104	30.3
15	Male	33	191	106	29.0
16	Female	30	156	68	27.9

When processing the data, it was identified that the data for two participants (participants 8 and 9) were confounded by noise and therefore they were removed from subsequent inferential statistical analysis. However, the reported pain and perceived knee stability data from both participants was retained for the inferential statistical analysis of these variables. Therefore, for the stance duration, muscle activity and movement control data, the sample size analysed was n=14 while for the reported pain and perceived stability data, the sample size analysed was n=16.

8.4 Descriptive Data and Patient Reported Outcome Measures

All sixteen symptomatic participants provided descriptive and outcome measure data from the KOOS-PF and the TIPPS assessments, as well as that from a numerical pain rating scale, see Table 8.3 below. For the KOOS-PF, the highest possible score is 100 which represents no dysfunction, with low KOOS-PF scores therefore reflecting greater dysfunction. The KOOS-PF scores ranged from 21 to 65 with the mean KOOS-PF score for this cohort being 45 (SD = 12.21) which represents considerable dysfunction. Following the TIPPS assessments, there were three possible sub-groups to which each participant could be assigned and these were strong, weak and tight, and weak and pronated. It can be seen from Table 8.3 that there were three participants classified as strong, five who were classified as weak and tight, and eight who were classified as weak and pronated. Finally, participants also rated their average pain over the last week on an 11-

point numerical pain rating scale where 0 was no pain and 10 was the worst pain imaginable. The pain scores ranged from 4 to 7 with a mean pain score for the cohort being 6 (SD = 0.89) which represents a moderate pain intensity, see Table 8.3.

Table 8.3 Patient Reported Variables – KOOS-PF, TIPPS and Average Pain

Participant Number	KOOS-PF Score	TIPPS Group	Average pain
01	41	Weak and Pronated	7
02	59	Strong	4
03	21	Weak and Tight	5
04	55	Weak and Tight	7
05	63	Weak and Pronated	6
06	48	Weak and Tight	6
07	39	Weak and Tight	6
08	45	Strong	6
09	45	Weak and Pronated	6
10	45	Strong	5
11	34	Weak and Pronated	6
12	45	Weak and Pronated	6
13	52	Weak and Tight	5
14	28	Weak and Pronated	4
15	65	Weak and Pronated	5
16	34	Weak and Pronated	6

8.5 Effect of the Taping Conditions on the Stance Phase Duration

Table 8.4 shows the effect of the taping conditions on the stance phase duration. The repeated measures ANOVA revealed that there was no significant main effect for stance phase duration from the taping conditions ($p = 0.389$).

Table 8.4 Stance Phase Duration (in Seconds) under the Three Taping Conditions

Contact Time	**Mean (Standard Deviation)**	**Tape Effect p value (pη^2)**
Active Tape	0.96 (0.23)	$p = 0.389$ (0.07)
Neutral Tape	0.96 (0.25)	
No Tape	0.93 (0.18)	

8.6 Muscle Activity for the Three Taping Conditions During the Stance Phase of Stair Descent

8.6.1 Average Muscle Activity

The average muscle activity data for VL and VM during the stair descent were found to be normally distributed and suitable for parametric testing. Tables 8.5, 8.7, 8.9 and 8.11 show the mean and standard deviation and main effects from the repeated measures ANOVA tests for the various phases of the stair descent. The GM muscle activity was found to be not normally distributed and therefore a non-parametric Friedman test was performed on these data, the results of which are presented in Tables 8.6, 8.8, 8.10 and 8.12.

The repeated measures ANOVA revealed that there were no significant main effects of taping condition on the average muscle activity of either VL or VM during the first double support phase, Table 8.5.

Table 8.5 Average Muscle Activity for Vastus Lateralis and Vastus Medialis for the Three Taping Conditions during the First Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	First Double Support Phase	
Vastus Lateralis		
Active Tape	0.34 (0.13)	p = 0.834 (0.01)
Neutral Tape	0.35 (0.13)	
No Tape	0.35 (0.11)	
Vastus Medialis		
Active Tape	0.27 (0.12)	p = 0.315 (0.09)
Neutral Tape	0.30 (0.16)	
No Tape	0.28 (0.12)	

For the non-normally distributed GM data, Friedman tests revealed no significant effect of tape on the average GM muscle activity during the first double support phase of the stair descent, Table 8.6.

Table 8.6 Average Muscle Activity for Gluteus Medius Activity for the Three Taping Conditions during the First Double Support Phase

	Median (25^{th}/75^{th} Percentile)	Chi Square	p value
	First Double Support Phase		
Gluteus Medius			
Active Tape	0.52 (0.40 / 0.59)	3.00	p = 0.223
Neutral Tape	0.50 (0.46 / 0.56)		
No Tape	0.52 (0.48 / 0.59)		

For VL, there was a significant main effect of tape on average muscle activity during the single leg stance phase of the stair descent ($p = 0.026$). Post-hoc pairwise comparisons showed that the active tape significantly decreased the average VL muscle activity compared to the no tape condition ($p = 0.023$). The post-hoc pairwise comparisons also revealed that there were no significant differences found between the active tape and neutral tape conditions ($p = 0.213$) or between the no tape and neutral tape conditions ($p = 0.112$), Table 8.7.

Table 8.7 Average Muscle Activity for Vastus Lateralis and Vastus Medialis for the Three Taping Conditions during the Single Leg Stance Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Single Leg Stance Phase	
Vastus Lateralis		
Active Tape	0.47 (0.10)	
Neutral Tape	0.50 (0.10)	$p = 0.026^{b}$ (0.25)
No Tape	0.55 (0.14)	
Vastus Medialis		
Active Tape	0.49 (0.18)	
Neutral Tape	0.51 (0.15)	$p = 0.802$ (0.02)
No Tape	0.48 (0.17)	

Key: a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

Friedman tests revealed that there were no significant differences in GM activity during the single leg stance phase of the stair descent, Table 8.8.

Table 8.8 Average Muscle Activity for Gluteus Medius Activity for the Three Taping Conditions during the Single Leg Stance Phase

	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p value
	Single Leg Stance Phase		
Gluteus Medius			
Active Tape	0.49 (0.39 / 0.53)		
Neutral Tape	0.47 (0.39 / 0.54)	0.14	$p = 0.931$
No Tape	0.49 (0.41 / 0.53)		

Repeated measures ANOVA revealed that there were no significant main effects on the average muscle activity of either VL or VM during the second double support phase, see Table 8.9

Table 8.9 Average Muscle Activity for Vastus Lateralis and Vastus Medialis for the Three Taping Conditions during the Second Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value (pη^2)
	Second Double Support Phase	
Vastus Lateralis		
Active Tape	0.33 (0.14)	p = 0.393 (0.07)
Neutral Tape	0.30 (0.15)	
No Tape	0.33 (0.17)	
Vastus Medialis		
Active Tape	0.31 (0.17)	p = 0.689 (0.03)
Neutral Tape	0.29 (0.17)	
No Tape	0.32 (0.15)	

Friedman tests revealed that there were no significant differences in GM muscle activity due to the taping conditions during the second double support phase of the stair descent, Table 8.10.

Table 8.10 Average Muscle Activity for Gluteus Medius Activity for the Three Taping Conditions during the Second Double Support Phase

	Median (25th/75th Percentile)	Chi Square	p value
	Second Double Support Phase		
Gluteus Medius			
Active Tape	0.34 (0.22 / 0.42)	3.53	p = 0.171
Neutral Tape	0.33 (0.20 / 0.41)		
No Tape	0.33 (0.20 / 0.39)		

During the whole of the stance phase, repeated measures ANOVA revealed that there were no significant main effects on VL and VM average muscle activity, see Table 8.11.

Table 8.11 Average Muscle Activity for Vastus Lateralis and Vastus Medialis for the Three Taping Conditions during the Whole of Stance Phase

	Mean (Standard Deviation)	Tape Effect p value (pη^2)
	Whole of Stance Phase	
Vastus Lateralis		
Active Tape	0.49 (0.11)	p = 0.203 (0.12)
Neutral Tape	0.52 (0.08)	
No Tape	0.55 (0.12)	
Vastus Medialis		
Active Tape	0.48 (0.16)	p = 0.452 (0.06)
Neutral Tape	0.52 (0.16)	
No Tape	0.49 (0.13)	

Friedman tests revealed that there were no significant differences in GM muscle activity over the whole of stance phase of the stair descent, Table 8.12.

Table 8.12 Average Muscle Activity for Gluteus Medius Activity for the Three Taping Conditions during the Whole of Stance Phase

	Median (25th/75th Percentile)	Chi Square	p value
	Whole of Stance Phase		
Gluteus Medius			
Active Tape	0.52 (0.49 / 0.59)	4.43	p = 0.109
Neutral Tape	0.51 (0.48 / 0.55)		
No Tape	0.54 (0.49 / 0.61)		

8.6.2 Integrated Muscle Activity

The integrated muscle activity for VL was found to be normally distributed and therefore, repeated measures ANOVA were performed. The integrated VM and GM muscle activity were found to be not normally distributed and as a result, Friedman tests were used to explore the effect of taping on integrated muscle activity.

For the integrated VL activity, there were no significant main effects between the taping conditions in the first double support phase and these data are presented in Table 8.13.

Table 8.13 Integrated Muscle Activity for Vastus Lateralis for the Three Taping Conditions during the First Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value (pη^2)
	First Double Support Phase	
Vastus Lateralis		
Active Tape	0.18 (0.06)	p = 0.884 (0.01)
Neutral Tape	0.18 (0.06)	
No Tape	0.18 (0.05)	

Friedman tests revealed that there were no significant differences between the taping conditions for either GM or VM in the first double support phase, Table 8.14.

Table 8.14 Integrated Muscle Activity for Gluteus Medius and Vastus Medialis Activity for the Three Taping Conditions During the First Double Support Phase

	Median (25th/75th Percentile)	Chi Square	p value
	First Double Support Phase		
Gluteus Medius			
Active Tape	0.22 (0.20 / 0.26)	0.26	p = 0.880
Neutral Tape	0.20 (0.19 / 0.25)		
No Tape	0.22 (0.19 / 0.25)		
Vastus Medialis			
Active Tape	0.17 (0.12 / 0.20)	0.26	p = 0.878
Neutral Tape	0.16 (0.13 / 0.18)		
No Tape	0.16 (0.14 / 0.21)		

For the integrated VL muscle activity data during the single leg stance phase, the repeated measures ANOVA revealed that there were no significant main effects between the taping conditions seen, Table 8.15.

Table 8.15 Integrated Muscle Activity for Vastus Lateralis for the Three Taping Conditions during the Single Leg Stance Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Single Leg Stance Phase	
Vastus Lateralis		
Active Tape	0.65 (0.10)	p = 0.396 (0.07)
Neutral Tape	0.66 (0.10)	
No Tape	0.68 (0.12)	

Friedman tests revealed that there were no significant differences seen in the integrated GM or VM muscle activity during the single leg stance phase, Table 8.16.

Table 8.16 Integrated Muscle Activity for Gluteus Medius and Vastus Medialis Activity for the Three Taping Conditions During the Single Leg Stance Phase

	Median (25th/75th Percentile)	Chi Square	p value
	Single Leg Stance Phase		
Gluteus Medius			
Active Tape	0.66 (0.60 / 0.71)	0.76	p = 0.683
Neutral Tape	0.63 (0.60 / 0.72)		
No Tape	0.69 (0.57 / 0.72)		
Vastus Medialis			
Active Tape	0.68 (0.56 / 0.74)	0.14	p = 0.931
Neutral Tape	0.66 (0.58 / 0.75)		
No Tape	0.67 (0.55 / 0.76)		

During the second double support phase, repeated measures ANOVA revealed that there was no significant main effect seen in the integrated VL muscle activity between the taping conditions, Table 8.17.

Table 8.17 Integrated Muscle Activity for Vastus Lateralis for the Three Taping Conditions during the Second Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Second Double Support Phase	
Vastus Lateralis		
Active Tape	0.72 (0.11)	p = 0.385 (0.07)
Neutral Tape	0.73 (0.09)	
No Tape	0.76 (0.10)	

For the integrated GM and VM muscle activity data in the second double support phase, Friedman tests revealed that there were no significant differences seen, Table 8.18.

Table 8.18 Integrated Muscle Activity for Gluteus Medius and Vastus Medialis Activity for the Three Taping Conditions during the Second Double Support Phase

	Median (25th/75th Percentile)	Chi Square	p value
	Second Double Support Phase		
Gluteus Medius			
Active Tape	0.78 (0.74 / 0.85)	0.14	p = 0.931
Neutral Tape	0.76 (0.70 / 0.85)		
No Tape	0.81 (0.71 / 0.86)		
Vastus Medialis			
Active Tape	0.78 (0.63 / 0.82)	0.14	p = 0.931
Neutral Tape	0.74 (0.70 / 0.79)		
No Tape	0.77 (0.64 / 0.83)		

Repeated measures ANOVA showed that for the whole of stance phase, there were no significant main effects seen in the integrated VL muscle activity between the taping conditions, Table 8.19.

Table 8.19 Integrated Muscle Activity for Vastus Lateralis for the Three Taping Conditions during the Whole of Stance Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Whole of Stance Phase	
Vastus Lateralis		
Active Tape	0.72 (0.11)	p = 0.385 (0.07)
Neutral Tape	0.73 (0.09)	
No Tape	0.76 (0.10)	

Finally, for the integrated GM and VM muscle activity, Friedman tests revealed that there were no significant differences seen over the whole of stance phase, Table 8.20.

Table 8.20 Integrated Muscle Activity for Gluteus Medius and Vastus Medialis Activity for the Three Taping Conditions during the Whole of Stance Phase

	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p value
	Whole of Stance Phase		
Gluteus Medius			
Active Tape	0.78 (0.74 / 0.85)	0.14	p = 0.931
Neutral Tape	0.76 (0.70 / 0.85)		
No Tape	0.81 (0.71 / 0.86)		
Vastus Medialis			
Active Tape	0.78 (0.63 / 0.82)	0.14	p = 0.931
Neutral Tape	0.74 (0.70 / 079)		
No Tape	0.77 (0.64 / 0.83)		

8.6.3 Peak Muscle Activity

The peak muscle activity for VM, VL and GM were found to be normally distributed and suitable for parametric testing. Repeated measures ANOVA tests showed no significant main effects between the taping conditions for any of the muscles during the first double support phase, see Table 8.21.

Table 8.21 Peak Muscle Activity for GM, VL and VM for the Three Taping Conditions during the First Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	First Double Support Phase	
Gluteus Medius		
Active Tape	0.37 (0.10)	p = 0.093 (0.017)
Neutral Tape	0.36 (0.08)	
No Tape	0.38 (0.09)	
Vastus Lateralis		
Active Tape	0.24 (0.10)	p = 0.553 (0.05)
Neutral Tape	0.24 (0.09)	
No Tape	0.25 (0.09)	
Vastus Medialis		
Active Tape	0.19 (0.09)	p = 0.596 (0.04)
Neutral Tape	0.19 (0.09)	
No Tape	0.20 (0.09)	

For the peak VM, VL and GM muscle activity during the single leg stance phase, repeated measures ANOVA revealed no significant main effects between the taping conditions, Table 8.22.

Table 8.22 Peak Muscle Activity for GM, VL and VM for the Three Taping Conditions during the Single Leg Stance Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Single Leg Stance Phase	
Gluteus Medius		
Active Tape	0.31 (0.10)	p = 0.691 (0.03)
Neutral Tape	0.30 (0.08)	
No Tape	0.31 (0.09)	
Vastus Lateralis		
Active Tape	0.25 (0.06)	p = 0.071 (0.018)
Neutral Tape	0.26 (0.05)	
No Tape	0.28 (0.07)	
Vastus Medialis		
Active Tape	0.24 (0.09)	p = 0.804 (0.02)
Neutral Tape	0.24 (0.08)	
No Tape	0.25 (0.09)	

During the second double support phase, repeated measures ANOVA revealed no significant main effects between the taping conditions for the peak VM, VL and GM muscle activity, Table 8.23.

Table 8.23 Peak Muscle Activity for GM, VL and VM for the Three Taping Conditions during the Second Double Support Phase

	Mean (Standard Deviation)	Tape Effect p value ($p\eta^2$)
	Second Double Support Phase	
Gluteus Medius		
Active Tape	0.25 (0.11)	p = 0.677 (0.03)
Neutral Tape	0.24 (0.10)	
No Tape	0.25 (0.11)	
Vastus Lateralis		
Active Tape	0.11 (0.05)	p = 0.379 (0.07)
Neutral Tape	0.10 (0.05)	
No Tape	0.12 (0.08)	
Vastus Medialis		
Active Tape	0.11 (0.06)	p = 0.387 (0.07)
Neutral Tape	0.10 (0.06)	
No Tape	0.12 (0.06)	

Finally, over the whole of stance phase, repeated measures ANOVA revealed no significant main effects between the taping conditions for peak VM, VL and GM muscle activity, Table 8.24.

Table 8.24 Peak Muscle Activity for GM, VL and VM for the Three Taping Conditions During the Whole of Stance Phase

	Whole of Stance Phase	
Gluteus Medius		
Active Tape	0.31 (0.09)	
Neutral Tape	0.30 (0.08)	p = 0.446 (0.06)
No Tape	0.32 (0.09)	
Vastus Lateralis		
Active Tape	0.22 (0.05)	
Neutral Tape	0.22 (0.04)	p = 0.053 (0.20)
No Tape	0.24 (0.06)	
Vastus Medialis		
Active Tape	0.20 (0.07)	
Neutral Tape	0.20 (0.07)	p = 0.541 (0.05)
No Tape	0.20 (0.07)	

8.7 Tibial Angular Velocities for the Three Taping Conditions During the Stance Phase of Stair Descent

8.7.1 Tibial Flexion-Extension Angular Velocity

The tibial flexion angular velocities were found to be normally distributed and suitable for parametric testing. Repeated measures ANOVA tests showed no significant main effects during the first double support phase of the stair descent, Table 8.25.

Table 8.25 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the First Double Support Phase – Parametric

Tibial Flexion Extension Angular Velocity	Mean (Standard Deviation)	p value (pη^2)
	First Double Support Phase	
AT Flexion	-133.16 (45.23)	
NT Flexion	-137.36 (47.11)	p = 0.783 (0.02)
NoT Flexion	-140.35 (52.59)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

The tibial extension and range of flexion-extension angular velocities were found to be not normally distributed and therefore unsuitable for parametric testing. Therefore, for the first double support phase, Friedman tests were performed and they revealed that there were no significant differences between the taping conditions, Table 8.26.

Table 8.26 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions During the First Double Support Phase– Non-Parametric

Tibial Flexion Extension Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Extension	-28.97 (-49.92 / -18.80)	0.57	p = 0.751
NT Extension	-40.07 (-54.82 / -14.41)		
NoT Extension	-37.79 (-53.33 / -16.07)		
AT Range	92.88 (67.87 / 149.02)	0.43	p = 0.807
NT Range	98.95 (61.20 / 117.98)		
NoT Range	90.17 (57.63 / 133.75)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

During the single leg stance phase, the repeated measures ANOVA revealed no significant main effects between the taping conditions, Table 7.27.

Table 8.27 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase - Parametric

Tibial Flexion Extension Angular Velocity	Mean (Standard Deviation)	p value (pη^2)
	Single Leg Stance Phase	
AT Flexion	-117.98 (35.92)	p = 0.851 (0.01)
NT Flexion	-117.64 (28.04)	
NoT Flexion	-119.90 (30.42)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

During the single leg stance support phase, Friedman test revealed no significant differences between the taping conditions for the flexion angular velocity, Table 8.28.

Table 8.28 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase– Non-Parametric

Tibial Flexion Extension Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Extension	-12.37 (-20.08 / -8.35)	1.29	p = 0.526
NT Extension	-12.60 (-22.37 / -2.45)		
NoT Extension	-10.91 (-27.52 / 1.71)		
AT Range	98.98 (75.10 / 144.66)	0.14	p = 0.931
NT Range	98.95 (87.74 / 126.16)		
NoT Range	105.38 (77.57 / 123.77)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

During the second double support phase, there were no significant main effects seen between the taping conditions for the flexion angular velocity, Table 8.29.

Table 8.29 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Second Double Support Phase - Parametric

Tibial Flexion Extension Angular Velocity	Mean (Standard Deviation)	p value (pη^2)
	Second Double Support Phase	
AT Flexion	-143.71 (42.57)	p = 0.982 (0.00)
NT Flexion	-144.53 (36.73)	
NoT Flexion	-143.59 (32.16)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

For the second double support phase, there were no significant differences found between the taping conditions for the extension angular velocity or the range of flexion-extension angular velocity by the Friedman test, Table 8.30.

Table 8.30 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Second Double Support Phase– Non-Parametric

Tibial Flexion Extension Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Extension	-8.42 (-20.62 / 40.56)	1.86	p = 0.395
NT Extension	-4.52 (-22.69 / 16.19)		
NoT Extension	6.06 (-20.08 / 40.38)		
AT Range	134.57 (90.15 / 189.23)	1.00	p = 0.607
NT Range	136.36 (105.76 / 184.16)		
NoT Range	135.59 (130.49 / 190.09)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

During the whole of stance phase, repeated measures ANOVA revealed that there were no significant main effects seen between the taping conditions for the flexion angular velocity, Table 8.31.

Table 8.31 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase – Parametric

Tibial Flexion Extension Angular Velocity	Mean (Standard Deviation)	p value ($p\eta^2$)
	Whole of Stance Phase	
AT Flexion	-150.02 (42.36)	p = 0.532 (0.05)
NT Flexion	-151.03 (40.00)	
NoT Flexion	-158.38 (42.41)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

For the tibial flexion-extension angular velocity data, there were no significant differences found between the taping conditions during the whole of stance phase, Table 8.32.

Table 8.32 Tibial Flexion-Extension Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase– Non-Parametric

Tibial Flexion Extension Angular Velocity	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Extension	1.59 (-12.36 / 34.32)	0.14	p = 0.931
NT Extension	-0.26 (-9.54 / 16.98)		
NoT Extension	6.06 (-2.73 / 39.27)		
AT Range	154.29 (114.25 / 200.85)	2.71	p = 0.257
NT Range	156.18 (129.77 / 190.56)		
NoT Range	168.58 (129.07 / 248.10)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = flexion, positive values = extension

8.7.2 Tibial Internal-External Rotation Angular Velocity

For the transverse plane, tibial external rotation angular velocities were found to be normally distributed and suitable for parametric testing. Repeated measures ANOVA tests showed no significant main effects between the taping conditions for the external rotation angular velocity during the first double support phase of the stair descent Table 8.33.

Table 8.33 Tibial Internal-External Rotation Angular Velocity for the Three Taping Conditions during the First Double Support Phase - Parametric

Tibial Internal External Rotation Angular Velocity	Mean (Standard Deviation)	p value ($p\eta^2$)
First Double Support Phase		
AT External	204.87 (99.98)	p = 0.363 (0.08)
NT External	248.17 (138.43)	
NoT External	220.63 (94.74)	

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

When the tibial internal rotation and range of transverse plane angular velocities data were explored, they were found to be not normally distributed. Friedman tests were therefore carried out and showed no significant differences between the taping conditions during the first double support phase of the stance phase, Table 8.34.

Table 8.34 Tibial Internal-External Rotation Angular Velocity for the Three Taping Conditions during the First Double Support Phase – Non-Parametric

Tibial Internal External Rotation Angular Velocity	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
First Double Support Phase			
AT Internal	-193.95 (-231.73 / -128.67)	1.27	p = 0.526
NT Internal	-197.15 (-309.86 / -127.59)		
NoT Internal	-194.84 (-300.11 / -84.20)		
AT Range	400.80 (327.46 / 471.82)	1.71	p = 0.424
NT Range	449.63 (311.50 / 650.17)		
NoT Range	398.29 (357.50 / 543.27)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

Repeated measures ANOVA revealed that there were no significant main effects between the taping conditions during the single leg stance phase for the tibial external rotation angular velocity, Table 8.35.

Table 8.35 Tibial Internal-External Rotation Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase - Parametric

Tibial Internal External Rotation Angular Velocity	Mean (Standard Deviation)	p value ($p\eta^2$)
	Single Leg Stance Phase	
AT External	39.32 (20.36)	p = 0.380 (0.07)
NT External	41.81 (24.31)	
NoT External	36.10 (18.64)	

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

Friedman tests revealed that there were no significant differences between the taping conditions for the single leg stance phase, Table 8.36.

Table 8.36 Tibial Internal External Rotation Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase – Non-Parametric

Tibial Internal External Rotation Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Internal	-52.68 (-71.81 / -28.60)	1.00	p = 0.607
NT Internal	-48.01 (-61.47 / -36.23)		
NoT Internal	-55.52 (-76.40 / -39.99)		
AT Range	90.57 (58.07 / 136.17)	0.14	p = 0.931
NT Range	90.52 (63.52 / 118.17)		
NoT Range	89.96 (61.88 / 124.47)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

For the second double support phase, there were no significant main effects seen between the taping conditions, Table 8.37.

Table 8.37 Tibial Internal-External Rotation Angular Velocity for the Three Taping Conditions during the Second Double Support Phase - Parametric

Tibial Internal External Rotation Angular Velocity	Mean (Standard Deviation)	p value ($p\eta^2$)
	Second Double Support Phase	
AT External	94.25 (46.63)	p = 0.382 (0.07)
NT External	109.95 (72.87)	
NoT External	110.39 (58.70)	

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

There were also no significant differences found between the taping conditions for the second double support phase, Table 8.38.

Table 8.38 Tibial Internal External Rotation Angular Velocity for the Three Taping Conditions during the Second Double Support Phase – Non-Parametric

Tibial Internal External Rotation Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Internal	-62.91 (-76.82 / -47.10)	0.14	p = 0.931
NT Internal	-55.59 (-75.80 / -47.96)		
NoT Internal	-62.03 (-95.32 / -48.43)		
AT Range	171.84 (140.79 / 208.79)	1.86	p = 0.395
NT Range	186.09 (98.59 / 257.51)		
NoT Range	184.46 (153.32 / 260.33)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

For the whole of stance phase there were also no significant main effects seen between the taping conditions, Table 8.39.

Table 8.39 Tibial Internal External Rotation Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase - Parametric

Tibial Internal External Rotation Angular Velocity	Mean (Standard Deviation)	p value ($p\eta^2$)
	All Stance Phase	
AT External	195.49 (97.75)	p = 0.274 (0.10)
NT External	235.64 (131.37)	
NoT External	217.71 (96.18)	

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

Finally for the tibial internal external angular velocity, there were no significant differences found between the taping conditions, this time during the whole of stance phase, Table 8.40.

Table 8.40 Tibial Internal External Rotation Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase – Non-Parametric

Tibial Internal External Rotation Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Internal	-170.28 (-239.28 / -119.18)	0.14	p = 0.931
NT Internal	-191.15 (278.53 / -129.11)		
NoT Internal	-186.68 (-300.77 / -83.63)		
AT Range	372.13 (294.56 / 483.08)	1.29	p = 0.526
NT Range	415 89 (288.17 / 586.69)		
NoT Range	391.14 (356.61 / 504.40)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

8.7.3 Tibial Abduction-Adduction Angular Velocity

None of the coronal plane angular velocity data were normally distributed, therefore Friedman tests were used to examine all these data. During the first double support phase, there were no significant differences found between the three taping conditions, Table 8.41.

Table 8.41 Tibial Abduction-Adduction Angular Velocity for the Three Taping Conditions during the First Double Support Phase

Abduction Adduction Tibial Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Abduction	-61.53 (-73.44 / 10.73)	1.00	p = 0.607
NT Abduction	-56.27 (-74.34 / 13.11)		
NoT Abduction	-49.46 (-74.71 / 10.41)		
AT Adduction	0.31 (-13.19 / 50.96)	1.71	p = 0.424
NT Adduction	5.79 (-14.17 / 62.78)		
NoT Adduction	3.62 (-15.50 / 63.02)		
AT Range	55.81 (46.81 / 81.25)	1.00	p = 0.607
NT Range	61.92 (48.34 / 73.07)		
NoT Range	54.14 (43.03 / 82.15)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

During the single leg stance phase, there were no significant differences found between the three taping conditions, Table 8.42.

Table 8.42 Tibial Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase

Abduction Adduction Tibial Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Abduction	-26.87 (-33.20 / -5.26)	0.57	p = 0.751
NT Abduction	-23.08 (-36.22 / -4.73)		
NoT Abduction	-22.18 (-32.74 / -0.96)		
AT Adduction	19.84 (2.40 / 38.51)	3.86	p = 0.145
NT Adduction	17.60 (5.48 / 34.30)		
NoT Adduction	17.57 (1.39 / 39.46)		
AT Range	36.29 (28.28 / 59.38)	0.43	p = 0.807
NT Range	34.56 (28.80 / 53.83)		
NoT Range	35.13 (30.96 / 46.87)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

For the second double support phase, a significant difference was seen between the taping conditions for the tibial adduction angular velocity, Table 8.43. The post-hoc analysis using Wilcoxon Signed Rank tests revealed that the active tape condition significantly decreased the tibial adduction angular velocity compared to the no tape condition (p = 0.006). The difference between the active tape and neutral tape conditions and between the no tape and neutral tape conditions was not significant (p = 0.084 and p = 0.272 respectively). A significant difference was also seen between the taping conditions for the range of tibial abduction-adduction angular velocity during the second double support phase, Table 8.43. The post-hoc analysis using Wilcoxon Signed Rank tests revealed that the active tape significantly decreased the range of tibial abduction-adduction angular velocity compared to the no tape condition (p = 0.013). There was no significant difference between the active and neutral tape (p = 0.064), or between the no tape and neutral tape conditions (p = 0.245).

Table 8.43 Tibial Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Second Double Support Phase

Abduction Adduction Tibial Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Abduction	-27.48 (-44.35 / 0.78)	0.57	p = 0.751
NT Abduction	-26.12 (-46.42 / -11.64)		
NoT Abduction	-30.46 (-44.01 / 02.00)		
AT Adduction	32.02 (10.30 / 44.64)	8.71	p = 0.013[b]
NT Adduction	37.92 (16.34 / 46.48)		
NoT Adduction	39.56 (16.73 / 47.25)		
AT Range	45.17 (34.59 / 67.05)	11.57	p = 0.003[b]
NT Range	58.04 (40.15 / 72.42)		
NoT Range	59.39 (43.34 / 79.84)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

Finally for the tibial abduction-adduction angular velocity, significant differences were also seen between the taping conditions for both the tibial adduction angular velocity and the range of abduction-adduction angular velocity during the whole of stance phase, Table 8.44. Post-hoc analysis using Wilcoxon Signed Rank tests revealed that the active tape significantly decreased the adduction tibial angular velocity compared to the no tape condition (p = 0.002), and also compared to the neutral tape condition (p = 0.005). No differences were seen between the no tape and neutral tape conditions (p = 0.730). For the range of abduction-adduction angular velocities, the Wilcoxon Signed Rank Tests revealed that the active tape significantly decreased the range compared to the no tape condition (p = 0.019), and also compared to the neutral tape condition (p = 0.011). No differences were seen between the no tape and neutral tape conditions (p = 0.925).

Table 8.44 Tibial Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase

Abduction Adduction Tibial Angular Velocity	Median (25th/75th Percentile)	Chi Square	p-value
	All Stance Phase		
AT Abduction	-61.24 (-68.06) / -46.27)		
NT Abduction	-59.90 (69.57 / -48.88)	1.71	p = 0.424
NoT Abduction	-60.88 (-73.57 / -39.79)		
AT Adduction	41.45 (17.12 / 49.04)		
NT Adduction	49.30 (31.95 / 63.20)	12.00	p = 0.002[a,b]
NoT Adduction	48.36 (32.30 / 60.39)		
AT Range	90.38 (75.67 / 121.53)		
NT Range	105.75 (89.78 / 127.54)	6.14	p = 0.046[a,b]
NoT Range	103.94 (80.74 / 132.79)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

8.8 Patellar Angular Velocities for the Three Taping Conditions During the Stance Phase of Stair Descent

8.8.1 Patellar Anterior-Posterior Angular Velocity

The repeated measures ANOVA performed on the normally distributed patellar posterior angular velocity data found that there were no significant main effects during the first double support phase, Table 8.45.

Table 8.45 Patellar Anterior Posterior Angular Velocity for the Three Taping Conditions during the First Double Support Phase - Parametric

Anterior Posterior Patellar Gyroscope	Mean (Standard Deviation)	p value ($p\eta^2$)
	First Double Support Phase	
AT Posterior	27.96 (28.02)	
NT Posterior	37.21 (34.39)	p = 0.168 (0.13)
NoT Posterior	36.00 (34.67)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

The rest of the patellar anterior-posterior angular velocity data were not normally distributed and were therefore subjected to Friedman tests. For the first double support phase, there were no significant differences found, Table 8.46.

Table 8.46 Patellar Anterior-Posterior Angular Velocity for the Three Taping Conditions during the First Double Support Phase – Non-Parametric

Anterior Posterior Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Anterior	-72.69 (-79.21 / -55.53)	4.43	p = 0.109
NT Anterior	-74.54 (-96.32 / -58.44)		
NoT Anterior	-76.83 (-86.06 / -66.09)		
AT Range	85.76 (70.44 / 128.76)	3.00	p = 0.223
NT Range	113.54 (77.37 / 153.68)		
NoT Range	112.88 (90.19 / 144.39)		

Repeated measures ANOVA revealed that there were no significant main effects seen during the single leg stance phase, Table 8.47.

Table 8.47 Patellar Anterior Posterior Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase - Parametric

Anterior Posterior Patellar Gyroscope	Mean (Standard Deviation)	p value ($p\eta^2$)
	Single Leg Stance Phase	
AT Posterior	21.47 (22.76)	p = 0.730 (0.02)
NT Posterior	25.90 (27.01)	
NoT Posterior	22.35 (31.21)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

There were also no significant differences found for the non-parametric data during the single leg stance phase, Table 8.48.

Table 8.48 Patellar Anterior-Posterior Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase – Non-Parametric

Anterior Posterior Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Anterior	-45.05 (-53.67 / -32.69)	0.00	p = 1.000
NT Anterior	-41.77 (-55.53 / -33.85)		
NoT Anterior	-39.73 (-80.64 / -23.91)		
AT Range	71.54 (33.19 / 92.90)	0.14	p = 0.931
NT Range	77.57 (37.31 / 100.98)		
NoT Range	57.15 (33.90 / 97.90)		

The repeated measures ANOVA also revealed that there were no significant main effects seen in the second double support phase, Table 8.49.

Table 8.49 Patellar Anterior Posterior Angular Velocity for the Three Taping Conditions during the Second Double Support Phase - Parametric

Anterior Posterior Patellar Gyroscope	Mean (Standard Deviation)	p value (pη^2)
Second Double Support Phase		
AT Posterior	72.45 (29.91)	p = 0.209 (0.11)
NT Posterior	76.09 (35.51)	
NoT Posterior	89.31 (37.72)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the second double support phase, there was a significant difference found with the Friedman test for the patellar anterior angular velocity. Post-hoc analysis with a Wilcoxon Signed Ranks test showed that the difference between the active tape and neutral tape was close to significant (p = 0.056), whilst the differences between the active tape and no tape conditions and between the no tape and neutral tape conditions were not significantly different (p = 0.683 and p = 0.198 respectively). There were no other significant differences found, Table 8.50.

Table 8.50 Patellar Anterior-Posterior Angular Velocity for the Three Taping Conditions during the Second Double Support Phase – Non-Parametric

Anterior Posterior Patellar Gyroscope	Median (25^{th}/75^{th} Percentile)	Chi Square	p-value
Second Double Support Phase			
AT Anterior	-22.93 (-62.19 / -0.99)	7.43	p = 0.024
NT Anterior	-20.90 (-49.32 / 2.46)		
NoT Anterior	-20.68 (-81.51 / 5.45)		
AT Range	87.89 (69.17 / 126.99)	0.14	p = 0.931
NT Range	85.23 (64.72 / 128.57)		
NoT Range	100.26 (75,52 / 164.27)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

Finally, for the patellar posterior angular velocity, the repeated measures ANOVA revealed that for the whole of stance phase, there were no significant main effects seen, Table 8.51.

Table 8.51 Patellar Anterior Posterior Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase - Parametric

Anterior Posterior Patellar Gyroscope	Mean (Standard Deviation)	p value (pη^2)
Whole of Stance Phase		
AT Posterior	69.85 (29.37)	p = 0.123 (0.15)
NT Posterior	80.20 (29.58)	
NoT Posterior	89.54 (34.91)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

Friedman tests on the patellar anterior and range angular velocities revealed that for the whole of stance phase, there were no significant differences found, Table 8.52.

Table 8.52 Patellar Anterior-Posterior Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase – Non-Parametric

Anterior Posterior Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
Whole of Stance Phase			
AT Anterior	-69.34 (-84.53 / -55.20)	4.00	p = 0.135
NT Anterior	-75.90 (-101.06 / -60.87)		
NoT Anterior	-76.27 (-85.56 / -60.94)		
AT Range	138.53 (101.70 / 172.21)	2.71	p = 0.257
NT Range	173.53 (124.31 / 187.73)		
NoT Range	165.89 (136.10 / 185.67)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

8.8.2 Patellar Internal Rotation-External Rotation Angular Velocity

The results of the Friedman tests performed on all of the internal rotation-external rotation reveal that there was a significant difference in the patellar external rotation angular velocity in the first double support phase, Table 8.53. The Wilcoxon Signed Ranks post-hoc revealed that the active tape decreased the external rotation compared to the neutral tape condition (p = 0.022). There were no significant differences between the active tape and no tape conditions nor between the no tape and neutral tape conditions (p = 0.245 for both parameters).

Table 8.53 Patellar Internal-External Rotation Angular Velocity for the Three Taping Conditions during the First Double Support Phase

Internal External Rotation Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Internal	-117.33 (-142.72 / -86.18)		
NT Internal	-153.46 (-187.21 / -111.11)	1.86	p = 0.395
NoT Internal	-132.61 (-117.12 / -102.12)		
AT External	127.98 (68.17 / 179.97)		
NT External	160.06 (70.02 / 230.12)	7.43	p = 0.024[a]
NoT External	135.27 (109.05 / 180.06)		
AT Range	210.78 (181.41 / 314.16)		
NT Range	296.42 (226.11 / 414.82)	4.43	p = 0.109
NoT Range	267.88 (214.39 / 323.78)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

The Friedman tests revealed that there were no significant differences seen between the taping conditions during the single leg stance phase, Table 8.54.

Table 8.54 Patellar Internal-External Rotation Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase

Internal External Rotation Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stand Phase		
AT Internal	-58.31 (-96.49 / -35.33)		
NT Internal	-59.29 (-98.11 / 38.22)	0.14	p = 0.931
NoT Internal	-66.32 (-97.13 / -41.77)		
AT External	62.53 (29.80 / 103.81)		
NT External	85.25 (35.01 / 127.20)	0.43	p = 0.807
NoT External	64.73 (45.66 / 113 70)		
AT Range	129.84 (84.24 / 191.43)		
NT Range	143.49 (88.28 / 260.03)	0.57	p = 0.751
NoT Range	140.96 (86.31 / 196.46)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation

During the second double support phase, there were significant differences seen between the taping conditions for the internal rotation angular velocity, the external rotation angular velocity and the range of internal-eternal rotation angular velocity, Table 8.55. The post-hoc analysis with the Wilcoxon tests revealed that the active tape decreased the patellar internal rotation compared to the no tape condition (p = 0.019). No significant differences were seen between the active tape and neutral tape conditions nor the no tape and neutral tape conditions (p = 0.363 and p = 0.198 respectively). For the patellar external rotation, the significant difference in the post-hoc analysis was found to have been between the active tape and the no tape conditions with the active tape providing the lower value (p = 0.019). The difference between the active tape and the neutral tape trended towards significance without actually reaching it (p = 0.074), while the result between the no tape and neutral tape conditions was not significant (p = 0.826). For the range of internal rotation-external rotation in the second double support phase, the post-hoc analysis revealed that the active tape decreased the range compared to the no tape condition (p = 0.002). There was a slight trend towards significance with the active tape and neutral tape result (p = 0.096), while the result between the no tape and neutral tape conditions was simply not significant.

Table 8.55 Patellar Internal-External Rotation Angular Velocity for the Three Taping Conditions During the Second Double Support Phase

Internal External Rotation Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Internal	-23.49 (-46.07 / -12.94)	6.14	p = 0.046[b]
NT Internal	-27.69 (-46.91 / -12.77)		
NoT Internal	-30.13 (-58.37/ -13.05)		
AT External	38.06 (18.01 / 56,56)	8.71	p = 0.013[b]
NT External	42.80 (24.75 / 64.29)		
NoT External	57.32 (29.66 / 82.83)		
AT Range	60.65 (39.82 / 85.50)	8.14	p = 0.017[b]
NT Range	71.14 (51.46 / 105.23)		
NoT Range	80.09 (60.45 / 117.62)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

Finally, viewing the whole of stance phase, there were significant differences found in the patellar internal rotation angular velocity and the range of patellar internal rotation-external rotation angular velocities, Table 8.56. The post-hoc analysis of the patellar internal rotation result found that the active tape decreased the patellar internal rotation compared to the neutral tape (p = 0.004). It was also found that there was a significant difference between the no tape and neutral tape conditions (p = 0.019) where the no tape condition provided the lower value. The result between the active tape and no tape conditions was not significant (p = 0.124). Meanwhile, the post-hoc analyses of the result for the range of patellar internal rotation-external rotation for the whole of the stance phase were similar as they revealed that the significant differences lay between the active tape and neutral tape conditions (p = 0.011) where the active tape value was the lower of the two, and between the no tape and neutral tape conditions (p = 0.030) where the no tape condition provided the lower value. Although this time the result of the post-hoc analysis between the active tape and the no tape conditions trended slightly towards significance at p = 0.096, it did not reach significance.

Table 8.56 Patellar Internal-External Rotation Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase

Internal External Rotation Patellar Gyroscope	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Internal	-113.52 (-144.73 / -82.88)	9.57	p = 0.008[a,c]
NT Internal	-163.03 (-192.04 / -118.95)		
NoT Internal	-123.98 (-167.99 / -112.17)		
AT External	130.39 (103.28 / 156.81)	3.57	p = 0.168
NT External	165.04 (113.37 / 196.06)		
NoT External	146.89 (108.70 / 199.77)		
AT Range	237.58 (189.68 / 288.25)	6.14	p = 0.046[a,c]
NT Range	319.27 (239.45 / 393.63)		
NoT Range	264.96 (221.22 / 367.76)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = internal rotation, positive values = external rotation, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

8.8.3 Patellar Abduction-Adduction Angular Velocity in the Coronal Plane

The results of the Friedman tests which were performed on the abduction-adduction angular velocity data reveal that there were no significant differences found between the taping conditions during the first double support phase, Table 8.57.

Table 8.57 Patellar Abduction-Adduction Angular Velocity for the Three Taping Conditions during the First Double Support Phase

Abduction Adduction Patellar Gyroscope	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Abduction	-34.11 (-64.26 / -24.38)	0.14	P = 0.931
NT Abduction	-44.89 (-67.87 / -29.26)		
NoT Abduction	-40.63 (-65.23 / -18.39)		
AT Adduction	14.84 (10.60 / 35.97)	4.43	p = 0.109
NT Adduction	26.15 (17.23 / 47.23)		
NoT Adduction	26.68 (17.38 / 34.52)		
AT Range	58.07 (46.13 / 86.18)	2.71	p = 0.257
NT Range	75.51 (51.78 / 94.83)		
NoT Range	63.46 (54.14 / 86.50)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

The Friedman tests also revealed no significant differences between the taping conditions during the single leg stance phase, Table 8.58.

Table 8.58 Patellar Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Single Leg Stance Phase

Abduction Adduction Patellar Gyroscope	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Abduction	-19.24 (-29.28 / -13.77)	0.57	p = 0.751
NT Abduction	-19.41 (-29.80 / -14.87)		
NoT Abduction	-24.22 (-32.26 / -15.77)		
AT Adduction	16.88 (11.33 / 21.89)	3.57	p = 0.168
NT Adduction	21.48 (13.27 / 25.56)		
NoT Adduction	23.24 (14.02 / 36.82)		
AT Range	33.46 (25.27 / 51.38)	3.00	p = 0.223
NT Range	41.66 (29.49 / 55.04)		
NoT Range	44.19 (37.74 / 65.91)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction

For the second double support phase, there was a significant difference between the taping conditions for the adduction angular velocity, Table 8.59. The post-hoc analysis with Wilcoxon tests showed that this difference was due to the neutral tape decreasing the patellar adduction angular velocity compared to the no tape condition (p = 0.011). The result between the active tape and no tape conditions and between the active tape and neutral taping conditions were not significant (p = 0.064 and p = 0.198 respectively).

Table 8.59 Patellar Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Second Double Support Phase

Abduction Adduction Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Abduction	-20.40 (-30.26 / -5.63)	0.14	p = 0.931
NT Abduction	-19.17 (-32.58 / -5.90)		
NoT Abduction	-22.58 (-34.40 / -5.04)		
AT Adduction	25.49 (-2.07 / 32.94)	13.00	p = 0.002[c]
NT Adduction	23.18 (-5.93 / 37.94)		
NoT Adduction	31.59 (9.38 / 43.95)		
AT Range	46.83 (17.01 / 57.56)	5.57	p = 0.062
NT Range	38.63 (25.03 / 52.16)		
NoT Range	44.78 (30.34 / 58.58)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

Finally, for the whole of stance phase, there were also significant differences found between the taping conditions for the patellar adduction angular velocity and the range of patellar abduction-adduction angular velocities. Post-hoc analysis of these results showed that for the patellar adduction angular velocity, the active tape decreased the patellar adduction compared to the no tape condition (p = 0.030). The differences between the active tape and the neutral tape, and between the no tape and the neutral tape conditions both trended towards significance without actually reaching it (p = 0.074 and p = 0.096 respectively). For the range of patellar abduction-adduction angular velocities, the post-hoc analysis showed that the active tape decreased the patellar range of abduction-adduction compared to the no tape condition (p = 0.011) and compare to the neutral tape condition (p = 0.026). The result between the no tape and neutral tape condition was not significant (p = 0.300), Table 8.60.

Table 8.60 Patellar Abduction-Adduction Angular Velocity for the Three Taping Conditions during the Whole of Stance Phase

Abduction Adduction Patellar Gyroscope	Median (25th/75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Abduction	-37.54 (-61.71 / -26.21)	4.00	p = 0.135
NT Abduction	-42.79 (-67.91 / -29.96)		
NoT Abduction	-47.99 (-66.51 / -33.62)		
AT Adduction	36.36 (24.22 / 45.39)	6.14	p = 0.046[b]
NT Adduction	36.24 (30.57 / 50.22)		
NoT Adduction	42.61 (34.34 / 54.68)		
AT Range	73.81 (57.36 / 98.27)	7.00	p = 0.030[a,b]
NT Range	83.29 (66.29 / 104.38)		
NoT Range	94.69 (73.55 / 109.09)		

Key: HR = AT = active tape, NoT = no tape, NT = neutral tape, negative values = abduction, positive values = adduction, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

8.9 Tibial Acceleration for the Three Taping Conditions During the Stance Phase of Stair Descent

8.9.1 Tibial Medial-Lateral Accelerations

All the tibial medial-lateral acceleration data was not normally distributed. Therefore, Friedman tests were performed and demonstrated that there were no significant differences found between the taping conditions for the medial-lateral tibial acceleration during the first double support phase, Table 8.61.

Table 8.61 Tibial Medial-Lateral Acceleration for the Three Taping Conditions during the First Double Support Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Medial	-0.69 (-0.87 / -0.45)	1.00	p = 0.607
NT Medial	-0.86 (-1.16 / -0.49)		
NoT Medial	-0.64 (-0.97 / -0.37)		
AT Lateral	0.58 (0.40 / 0.90)	1.29	p = 0.526
NT Lateral	0.51 (0.43 / 1.07)		
NoT Lateral	0.63 (0.41 / 0.77)		
AT Range	1.39 (0.93 / 1.68)	3.86	p = 0.145
NT Range	1.36 (0.94 / 1.96)		
NoT Range	1.26 (1.04 / 1.77)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

For the single leg stance phase, Friedman tests revealed that there were no significant differences found between the taping conditions, Table 8.62.

Table 8.62 Tibial Medial-Lateral Acceleration for the Three Taping Conditions during the Single Leg Stance Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Medial	-0.20 (-0.42 / -0.06)	2.71	p = 0.257
NT Medial	-0.20 (-0.35 / -0.01)		
NoT Medial	-0.20 (-0.47 / -0.01)		
AT Lateral	0.28 (-0.11 / 0.35)	1.00	p = 0.607
NT Lateral	0.20 (-0.10 / 0.33)		
NoT Lateral	0.28 (-0.13 / 0.33)		
AT Range	0.31 (0.24 / 0.40)	1.00	p = 0.607
NT Range	0.35 (0.19 / 0.50)		
NoT Range	0.33 (0.24 / 0.44)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

Friedman test revealed that during the second double support phase, there were no significant differences found between the taping conditions for any of the parameters, Table 8.63.

Table 8.63 Tibial Medial-Lateral Acceleration for the Three Taping Conditions during the Second Double Support Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Medial	-0.17 (-0.48 / -0.10)	1.86	p = 0.395
NT Medial	-0.32 (-0.52 / -0.07)		
NoT Medial	-0.22 (-0.47 / -0.08)		
AT Lateral	0.27 (0.23 / 0.34)	1.00	p = 0.607
NT Lateral	0.32 (0.25 / 0.35)		
NoT Lateral	0.31 (0.20 / 0.41)		
AT Range	0.45 (0.36 / 0.63)	2.29	p = 0.319
NT Range	0.54 (0.30 / 0.77)		
NoT Range	0.56 (0.35 / 0.79)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

Finally, for the tibial medial-lateral acceleration, there were no significant differences found between the taping conditions for any of the parameters during the whole of stance phase, Table 8.64.

Table 8.64 Tibial Medial-Lateral Acceleration for the Three Taping Conditions during the Whole of Stance Phase

Medial Lateral Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Medial	-0.56 (-0.82 / -0.42)		
NT Medial	-0.89 (-0.99 / -0.64)	1.71	p = 0.424
NoT Medial	-0.68 (-1.01 / -0.46)		
AT Lateral	0.51 (0.36 / 0.89)		
NT Lateral	0.45 (0.39 / 1.07)	1.00	p = 0.607
NoT Lateral	0.61 (0.41 / 0.73)		
AT Range	1.28 (0.85 / 1.52)		
NT Range	1.30 (1.02 / 1.97)	2.71	p = 0.257
NoT Range	1.29 (0.99 / 1.66)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

8.9.2 Tibial Vertical Accelerations

Friedman test revealed that there were no significant differences found between the taping conditions for the tibial vertical acceleration parameters during the first double support phase, Table 8.65.

Table 8.65 Tibial Vertical Acceleration for the Three Taping Conditions during the First Double Support Phase

Vertical Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	First Double Support Phase		
AT Caudad	-1.71 (-2.05 / -1.38)		
NT Caudad	-1.82 (-1.89 / -1.50)	0.43	p = 0.807
NoT Caudad	-1.72 (-2.20 / -1.55)		
AT Cephalad	-0.69 (-0.75 / 0.58)		
NT Cephalad	-0.64 (-0.70 / -0.59)	1.00	p = 0.607
NoT Cephalad	-0.64 (-0.73 / -050)		
AT Range	1.04 (0.79 / 1.44)		
NT Range	1.15 (0.84 / 1.31)	0.14	p = 0.931
NoT Range	1.24 (0.95 / 1.52)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

During the single leg stance phase, the Friedman tests revealed that there were no significant differences between the taping conditions for any of the parameters, Table 8.66.

Table 8.66 Tibial Vertical Acceleration for the Three Taping Conditions during the Single Leg Stance Phase

Vertical Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
Single Leg Stance Phase			
AT Caudad	-0.94 (-1.03 / -0.89)	1.86	p = 0.395
NT Caudad	-0.98 (-1.09 / -0.91)		
NoT Caudad	-1.00 (-1.08 / -0.91)		
AT Cephalad	-0.59 (-0.60 / -0.51)	0.14	p = 0.931
NT Cephalad	-0.54 (-0.61 / -0.50)		
NoT Cephalad	-0.57 (-0.62 / -0.46)		
AT Range	0.39 (0.31 / 0.53)	1.00	p = 0.607
NT Range	0.48 (0.40 / 0.55)		
NoT Range	0.48 (0.33 / 0.58)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

For the tibial vertical acceleration during the second double support phase, there were also no significant differences found between the taping conditions for any pf the parameters, Table 8.67.

Table 8.67 Tibial Vertical Acceleration for the Three Taping Conditions during the Second Double Support Phase

Vertical Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
Second Double Support Phase			
AT Caudad	-1.47 (-1.62 / -1.07)	0.43	p = 0.807
NT Caudad	-1.51 (-1.79 / -0.99)		
NoT Caudad	-1.49 (-1.66 / -1.09)		
AT Cephalad	0.20 (-0.33 / 0.47	0.14	p = 0.931
NT Cephalad	0.22 (-0.07 / 0.48)		
NoT Cephalad	0.16 (-0.19 / 0.51)		
AT Range	1.68 (0.82 / 2.06)	0.57	p = 0.751
NT Range	1.88 (0.94 / 2.11)		
NoT Range	1.68 (1.00 / 2.13)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

Finally, for the whole of stance phase, Friedman tests revealed that there were no significant differences between the taping conditions for any of the parameters, Table 8.68.

Table 8.68 Tibial Vertical Acceleration for the Three Taping Conditions during the Whole of Stance Phase

Vertical Tibial Acceleration	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Caudad	-1.63 (-1.84 / -1.39)	3.00	p = 0.223
NT Caudad	-1.76 (-1.85 / -1.52)		
NoT Caudad	-1.81 (-2.04 / -1.60)		
AT Cephalad	0.20 (-0.37 / 0.47)	0.14	p = 0.931
NT Cephalad	0.21 9-0.07 / 0.48)		
NoT Cephalad	0.15 (-0.19 / 0.51)		
AT Range	1.87 (1.24 / 2.28)	1.29	p = 0.526
NT Range	1.88 (1.42 / 2.36)		
NoT Range	2.03 (1.46 / 2.43)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

8.9.3 Tibial Anterior-Posterior Accelerations

For the tibial anterior-posterior accelerations, the posterior acceleration data were normally distributed and therefore repeated measures ANOVA were performed. The results revealed that for the first double support phase, there were no significant main effects found, Table 8.69.

Table 8.69 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the First Double Support Phase - Parametric

Anterior Posterior Tibial Acceleration	Mean (Standard Deviation)	p value ($p\eta^2$)
	First Double Support Phase	
AT Posterior	0.77 (0.46)	p = 0.750 (0.02)
NT Posterior	0.83 (0.41)	
NoT Posterior	0.81 (0.46)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

The anterior acceleration and the range of anterior-posterior acceleration data were found to be not normally distributed and were therefore subjected to Friedman tests. These tests revealed that there were no significant differences found between the taping conditions during the first double support phase, Table 8.70.

Table 8.70 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the First Double Support Phase – Non-Parametric

Anterior Posterior Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
First Double Support Phase			
AT Anterior	-0.46 (-0.64 / -0.29)	0.57	p = 0.751
NT Anterior	-0.52 (-0.62 / -0.33)		
NoT Anterior	-0.39 (-0.88 / -0.28)		
AT Range	1.13 (0.76 / 1.60)	1.86	p = 0.395
NT Range	1.30 (0.97 / 1.77)		
NoT Range	1.26 (1.03 / 1.68)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

The repeated measures ANOVA revealed that there were no significant main effects between the taping conditions for the tibial posterior acceleration during the single leg stance phase, Table 8.71.

Table 8.71 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Single Leg Stance Phase - Parametric

Anterior Posterior Tibial Acceleration	Mean (Standard Deviation)	p value (pη^2)
Single Leg Stance Phase		
AT Posterior	-0.07 (0.06)	p = 0.700 (0.03)
NT Posterior	-0.06 (0.07)	
NoT Posterior	-0.08 (0.08)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the tibial anterior acceleration and the range of tibial anterior-posterior acceleration during the single leg stance phase, Friedman tests revealed that there were no significant differences found between the taping conditions, Table 8.72.

Table 8.72 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Single Leg Stance Phase – Non-Parametric

Anterior Posterior Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Single Leg Stance Phase		
AT Anterior	-0.57 (-0.65 / -0.51)	0.14	p = 0.931
NT Anterior	-0.55 (-0.67 / -0.49)		
NoT Anterior	-0.54 (-0.63 / -0.52)		
AT Range	0.52 (0.42 / 0.58)	0.14	p = 0.931
NT Range	0.51 (0.46 / 0.57)		
NoT Range	0.50 (0.41 / 0.57)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the tibial posterior acceleration during the second double support phase, the repeated measures ANOVA revealed that there were no significant main effects found, Table 8.73.

Table 8.73 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Second Double Support Phase - Parametric

Anterior Posterior Tibial Acceleration	Mean (Standard Deviation)	p value ($p\eta^2$)
	Second Double Support Phase	
AT Posterior	0.01 (0.41)	p = 0.216 (0.11)
NT Posterior	0.06 (0.55)	
NoT Posterior	0.14 (0.55)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

During the second double support phase, the Friedman tests revealed that there were no significant differences between the taping conditions, Table 8.74.

Table 8.74 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Second Double Support Phase – Non-Parametric

Anterior Posterior Tibial Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Anterior	-0.81 (-0.94 / -0.68)	1.86	p = 0.395
NT Anterior	-0.82 (-0.85 / -0.75)		
NoT Anterior	-0.75 (-0.87 / -0.65)		
AT Range	0.72 (0.48 / 1.09)	0.57	p = 0.751
NT Range	0.64 (0.42 / 1.12)		
NoT Range	0.61 (0.50 / 1.38)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the tibial posterior acceleration during the whole of stance phase, the repeated measures ANOVA revealed that there were no significant main effects found, Table 8.75.

Table 8.75 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Whole of Stance Phase - Parametric

Anterior Posterior Tibial Acceleration	Mean (Standard Deviation)	p value ($p\eta^2$)
	Whole of Stance Phase	
AT Posterior	0.72 (0.41)	
NT Posterior	0.81 (0.40)	p = 0.139 (0.14)
NoT Posterior	0.85 (0.49)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

Finally, for the whole stance phase, there were no significant differences found between the taping conditions by the Friedman tests on the tibial anterior acceleration or the range of anterior-posterior accelerations, Table 8.76.

Table 8.76 Tibial Anterior-Posterior Acceleration for the Three Taping Conditions during the Whole of Stance Phase – Non-Parametric

Anterior Posterior Tibial Acceleration	Median ($25^{th}/75^{th}$ Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Anterior	-0.83 (-0.94 / -0.68)		
NT Anterior	-0.79 (-0.88 / -0.72)	1.00	p = 0.607
NoT Anterior	-0.80 (-0.88 / -0.65)		
AT Range	1.45 (1.11 / 1.79)		
NT Range	1.51 (1.29 / 1.84)	1.71	p = 0.424
NoT Range	1.47 (1.22 / 2.08)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

8.10 Patellar Acceleration for the Three Taping Conditions During the Stance Phase of Stair Descent

8.10.1 Patellar Medial-Lateral Accelerations

None of the patellar medial-lateral acceleration data was normally distributed, therefore Friedman tests were performed and they revealed that there were no significant differences found between the taping conditions for the patellar medial-lateral parameters during the first double support phase, Table 8.77.

Table 8.77 Patellar Medial-Lateral Acceleration for the Three Taping Conditions during the First Double Support Phase

Medial Lateral Patellar Acceleration	Median (25th / 75th Percentile)	Chi Square	p-value
First Double Support Phase			
AT Medial	-0.67 (-0.88 / -0.44)	0.57	p = 0.751
NT Medial	-0.78 (-1.06 / -0.44)		
NoT Medial	-0.52 (-0.88 / -0.38)		
AT Lateral	0.47 (-0.33 / 0.72)	1.86	p = 0.395
NT Lateral	0.63 (-0.31 / 0.88)		
NoT Lateral	0.68 (-0.33 / 0.79)		
AT Range	1.14 (0.90 / 1.45)	2.71	p = 0.257
NT Range	1.43 (0.81 / 1.85)		
NoT Range	1.25 (0.74 / 1.62)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

For the single leg stance phase, there were no significant differences found between the taping conditions for any of the parameters, Table 8.78.

Table 8.78 Patellar Medial-Lateral Acceleration for the Three Taping Conditions during the Single Leg Stance Phase

Medial Lateral Patellar Acceleration	Median (25th / 75th Percentile)	Chi Square	p-value
Single Leg Stance Phase			
AT Medial	-0.30 (-0.46 / -0.16)	1.00	p = 0.607
NT Medial	-0.32 (-0.46 / -0.21)		
NoT Medial	-0.27 (-0.42 / -0.19)		
AT Lateral	0.27 (0.04 / 0.42)	0.43	p = 0.807
NT Lateral	0.33 (0.06 / 0.66)		
NoT Lateral	0.23 (0.14 / 0.46)		
AT Range	0.47 (0.29 / 0.92)	0.57	p = 0.751
NT Range	0.61 (0.36 / 0.95)		
NoT Range	0.52 (0.34 / 1.00)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

There were no significant differences found during the second double support phase for any of the parameters, Table 8.79.

Table 8.79 Patellar Medial-Lateral Acceleration for the Three Taping Conditions during the Second Double Support Phase

Medial Lateral Patellar Acceleration	Median (25th / 75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Medial	-0.27 (-0.36 / -0.18)	5.29	p = 0.071
NT Medial	-.027 (-0.37 / -0.20)		
NoT Medial	-0.31 (-0.38 / -0.26)		
AT Lateral	0.26 (0.03 / 0.36)	2.71	p = 0.257
NT Lateral	0.24 (0.05 / 0.40)		
NoT Lateral	0.26 (0.10 / 0.46)		
AT Range	0.52 (0.39 / 0.59)	4.00	p = 0.135
NT Range	0.61 (0.40 / 0.62)		
NoT Range	0.57 (0.49 / 0.79)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral

For the whole of stance phase, Friedman tests found that there was a significant difference in the patellar lateral acceleration, Table 8.80. The post-hoc analysis with the Wilcoxon Signed Ranks Tests revealed that the active tape decreased the patellar lateral acceleration compared to the neutral tape condition ($p = 0.019$). The differences between the active tape and no tape conditions, and between the no tape and neutral tape conditions were not significant; $p = 0.245$ and $p = 0.363$ respectively.

Table 8.80 Patellar Medial-Lateral Acceleration for the Three Taping Conditions during the Whole of Stance Phase

Medial Lateral Patellar Acceleration	Median (25th / 75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Medial	-0.55 (-0.85 / -0.40)	1.86	p = 0.395
NT Medial	-0.90 (-1.01 / -0.42)		
NoT Medial	-0.48 (-0.79 / -0.40)		
AT Lateral	0.47 (0.41 / 0.55)	6.14	p = 0.046[a]
NT Lateral	0.67 (0.39 / 0.84)		
NoT Lateral	0.61 (0.33 / 0.79)		
AT Range	1.08 (0.80 / 1.32)	4.43	p = 0.109
NT Range	1.57 (0.81 / 1.85)		
NoT Range	1.16 (0.80 / 1.64)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = medial, positive values = lateral, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

8.10.2 Patellar Vertical Accelerations

The patellar vertical acceleration data were not normally distributed. The resultant Friedman tests revealed that there were no significant differences found between the taping conditions for any of the parameters during the first double support phase, Tables 8.81.

Table 8.81 Patellar Vertical Acceleration for the Three Taping Conditions during the First Double Support Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
First Double Support Phase			
AT Caudad	-1.64 (-1.99 / -1.52)	1.86	p = 0.395
NT Caudad	-1.94 (-2.10 / -1.50)		
NoT Caudad	-1.81 (-2.10 / -1.62)		
AT Cephalad	-0.79 (-0.87 / -0.67)	4.43	p = 0.109
NT Cephalad	-0.74 (-0.89 / -0.67)		
NoT Cephalad	-0.68 (-0.91 / -0.61)		
AT Range	0.97 (0.70 / 1.21)	1.86	p = 0.395
NT Range	1.20 (0.69 / 1.48)		
NoT Range	1.14 (0.86 / 1.48)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

Friedman tests revealed that during the single leg stance phase, there were no significant differences found between the taping conditions, Table 8.82.

Table 8.82 Patellar Vertical Acceleration for the Three Taping Conditions during the Single Leg Stance Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
Single Leg Stance Phase			
AT Caudad	-1.12 (-1.19 / -1.07)	3.00	p = 0.223
NT Caudad	-1.21 (-1.29 / -1.07)		
NoT Caudad	-1.13 (-1.26 / -1.03)		
AT Cephalad	-0.72 (-0.76 / -0.66)	0.14	p = 0.931
NT Cephalad	-0.70 (-0.76 / -0.65)		
NoT Cephalad	-0.72 (-0.78 / -0.63)		
AT Range	0.39 (0.33 / 0.49)	3.86	p = 0.145
NT Range	0.53 (0.34 / 0.63)		
NoT Range	0.40 (0.30 / 0.60)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

There were no significant differences found between the taping conditions during the second double support phase for any of the parameters, Table 8.83.

Table 8.83 Patellar Vertical Acceleration for the Three Taping Conditions During the Second Double Support Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Second Double Support Phase		
AT Caudad	-1.75 (-1.97 / -1.56)		
NT Caudad	-1.85 (-2.00 / -1.40)	0.43	p = 0.807
NoT Caudad	-1.77 (-1.97 / -1.55)		
AT Cephalad	-0.73 (-0.93 / -0.68)		
NT Cephalad	-0.74 (-0.90 / -0.65)	0.43	p = 0.807
NoT Cephalad	-0.73 (-0.93 / -0.58)		
AT Range	0.86 (0.73 / 1.15)		
NT Range	1.08 (0.63 / 1.21)	0.57	p = 0.751
NoT Range	0.94 (0.77 / 1.13)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

During the whole of stance phase, Friedman tests revealed that there were no significant differences seen between the taping conditions, Table 8.84.

Table 8.84 Patellar Vertical Acceleration for the Three Taping Conditions during the Whole of Stance Phase

Vertical Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Caudad	-1.82 (-1.94 / -1.60)		
NT Caudad	-1.89 (-1.95 / -1.85)	2.29	p = 0.319
NoT Caudad	-1.88 (-2.08 / -1.76)		
AT Cephalad	-0.69 (-0.73 / -0.63)		
NT Cephalad	-0.63 (-0.70 / -0.54)	4.43	p = 0.109
NoT Cephalad	-0.66 (-0.73 / -0.49)		
AT Range	1.13 (0.88 / 1.34)		
NT Range	1.23 (1.18 / 1.44)	1.71	p = 0.424
NoT Range	1.25 (1.12 / 1.46)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = caudad, positive values = cephalad

8.10.3 Patellar Anterior-Posterior Accelerations

The range of anterior-posterior patellar acceleration data were normally distributed. The results of the repeated measures ANOVA are presented in Table 8.85 below. They show that there were no significant main effects found between the taping conditions.

Table 8.85 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the First Double Support Phase - Parametric

Anterior Posterior Patellar Acceleration	Mean (Standard Deviation)	p value (pη²)
First Double Support Phase		
AT Range	1.02 (0.50)	p = 0.182 (0.12)
NT Range	1.25 (0.58)	
NoT Range	1.21 (0.40)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

The rest of the patellar anterior-posterior acceleration data were not normally distributed and were therefore subjected to Friedman tests. For the first double support phase, there were no significant differences found between the taping conditions, Table 8.86.

Table 8.86 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the First Double Support Phase – Non-Parametric

Anterior Posterior Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
First Double Support Phase			
AT Anterior	-0.67 (-0.81 / -0.45)	1.71	p = 0.424
NT Anterior	-0.79 (-0.98 / -0.51)		
NoT Anterior	-0.72 (-0.81 / -0.66)		
AT Posterior	0.35 (0.11 / 0.54)	3.57	p = 0.168
NT Posterior	0.49 (0.16 / 0.76)		
NoT Posterior	0.48 (0.14 / 0.70)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the single leg stance phase, repeated measures ANOVA on the patellar range data revealed that there were also no significant main effects seen, Table 8.87.

Table 8.87 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Single Leg Stance Phase - Parametric

Anterior Posterior Patellar Acceleration	Mean (Standard Deviation)	p value (pη²)
Single Leg Stance Phase		
AT Range	0.90 (0.60)	p = 0.953 (0.00)
NT Range	0.92 (0.57)	
NoT Range	0.92 (0.43)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the patellar anterior and posterior acceleration data, Friedman tests for the single leg stance phase revealed that there were no significant differences seen between the taping conditions, Table 8.88.

Table 8.88 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Single Leg Stance Phase – Non-Parametric

Anterior Posterior Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
Single Leg Stance Phase			
AT Anterior	-0.68 (-0.88 / -0.43)	1.71	p = 0.424
NT Anterior	-0.61 (-0.95 / -0.49)		
NoT Anterior	-0.72 (-0.89 / -0.53)		
AT Posterior	0.29 (-0.01 / 0.37)	0.00	p = 0.467
NT Posterior	0.20 (0.03 / 0.43)		
NoT Posterior	0.21 (0.01 / 0.39)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the parametric patellar range data during the second double support phase, repeated measures ANOVA revealed that there were no significant main effects seen, Table 8.89.

Table 8.89 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Second Double Support Phase - Parametric

Anterior Posterior Patellar Acceleration	Mean (Standard Deviation)	p value ($p\eta^2$)
Second Double Support Phase		
AT Range	1.07 (0.50)	p = 0.447 (0.06)
NT Range	1.12 (0.45)	
NoT Range	1.20 (0.45)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

For the non-parametric patellar anterior and posterior acceleration data during the second double support phase, there were no significant differences found between the taping conditions, Table 8.90.

Table 8.90 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Second Double Support Phase – Non-Parametric

Anterior Posterior Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	2nd Double Support Phase		
AT Anterior	-0.85 (-0.94 / -0.62)	0.14	p = 0.931
NT Anterior	-0.84 (-0.99 / -0.59)		
NoT Anterior	-0.89 (-0.99 / -0.67)		
AT Posterior	0.31 (-0.06 / 0.47)	3.00	p = 0.223
NT Posterior	0.36 (0.04 / 0.53)		
NoT Posterior	0.42 (0.10 / 0.58)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

During the whole of stance phase, there was a significant main effect found, and this was for the range of anterior-posterior patellar acceleration, Table 8.91. The post-hoc pairwise comparisons revealed that active tape decreased the patellar range of anterior-posterior acceleration compared to both the no tape condition (p = 0.007) and the neutral tape condition (p = 0.013). The result between the no tape and neutral tape conditions was not significant (p = 0.548).

Table 8.91 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Whole of Stance Phase - Parametric

Anterior Posterior Patellar Acceleration	Mean (Standard Deviation)	p value ($p\eta^2$)
	Whole of Stance Phase	
AT Range	1.23 (0.45)	$p = 0.007^{a,b}$ (0.32)
NT Range	1.50 (0.51)	
NoT Range	1.44 (0.37)	

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

Finally, for the patellar anterior-posterior acceleration, there were no significant differences found between the taping conditions during the whole of the stance phase, Table 8.92.

Table 8.92 Patellar Anterior-Posterior Acceleration for the Three Taping Conditions during the Whole of Stance Phase – Non-Parametric

Anterior Posterior Patellar Acceleration	Median (25th/75th Percentile)	Chi Square	p-value
	Whole of Stance Phase		
AT Anterior	-0.88 (-0.98 / -0.69)	3.00	p = 0.223
NT Anterior	-0.89 (-1.20 / -0.81)		
NoT Anterior	-0.89 (-1.06 / -0.80)		
AT Posterior	0.41 (0.18 / 0.49)	5.57	p = 0.062
NT Posterior	0.58 (0.31 / 0.71)		
NoT Posterior	0.54 (0.33 / 0.75)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior

8.11 Pain and Perceived Stability Results for the Three Taping Conditions

8.11.1 Participant Reported Outcome Measures

The descriptive participant reported outcome measure data for the pain levels and perceived stability during the stair descent under each of the taping conditions are presented in Tables 8.93 and 8.94 respectively.

Table 8.93 Participant Reported Variables – Descriptive Pain Data

Participant Number	Pain with Active Tape	Pain with Neutral Tape	Pain with No Tape
1	1	4	5
2	4	5	5
3	0	4	2
4	0	0	3
5	1	3	5
6	0	4	4
7	0	6	9
8	4	4	6
9	5	6	6
10	4	4	5
11	2	2	5
12	3	4	5
13	4	4	5
14	2	3	4
15	0	0	3
16	2	4	6

Table 8.94 Participant Reported Variable – Descriptive Perceived Stability Data

Participant Number	With Active Tape	With Neutral Tape	With No Tape
01	Stable	Neither	Unstable
02	Stable	Neither	Neither
03	Neither	Neither	Unstable
04	Stable	Unstable	Unstable
05	Very stable	Neither	Unstable
06	Stable	Unstable	Unstable
07	Stable	Unstable	Unstable
08	Stable	Neither	Unstable
09	Stable	Stable	Neither
10	Stable	Neither	Neither
11	Stable	Neither	Unstable
12	Stable	Stable	Stable
13	Stable	Stable	Neither
14	Very stable	Neither	Unstable
15	Very stable	Stable	Stable
16	Stable	Unstable	Unstable

8.11.2 Participant Reported Outcome Measures

The participant reported pain and perceived stability data were found to be not normally distributed. Therefore, Friedman tests were performed on these data and the results are presented in Table 8.95. Significant differences were seen between the three taping conditions for both the patient reported pain and the perceived stability. For the pain data, post-hoc Wilcoxon Signed Rank tests revealed the active tape condition significantly reduced participant reported pain compared to no tape (p=0.001) and the neutral tape (p=0.007). Additionally, the neutral tape significant reduced reported pain compared to no tape (p=0.011).

For the perceived stability data, the post-hoc Wilcoxon Signed Rank tests revealed that, as with the reported pain data, there were significant differences between all combinations of the taping conditions. Specifically, the active tape condition significantly increased perceived stability compared to the no tape condition (p=0.001), and compared to the neutral tape condition (p=0.003). Additionally, the neutral tape increased the perceived stability compared to the no tape condition (p=0.014). The perceived stability data are presented in Table 8.95.

Table 8.95 Participant Reported Pain and Perceived Stability

	Median (25th/75th Percentile)	Chi Square	p-value
Pain			
AT	1.50 (0.00 / 3.25)	22.57	$p < 0.001^{a,b,c}$
NT	4.00 (2.75 / 4.00)		
NoT	5.00 (3.75 / 5.00)		
Perceived Stability			
AT	1.00 (1.00 / 1.25)	22.37	$p < 0.001^{a,b,c}$
NT	0.00 (-1.00 / 0.25)		
NoT	-1.00 (-1.00 / 0.00)		

Key: AT = active tape, NoT = no tape, NT = neutral tape, negative values = anterior, positive values = posterior, a = significant difference between AT and NT; b = significant different between AT and NoT; c = significant difference between NT and NoT

8.12 Chapter Summary

This chapter has presented the results from the symptomatic participant cohort with several very interesting results which are highlighted below and will be discussed in more depth in the next chapter. For the pre-testing descriptive data, the mean KOOS-PF (45) score and the mean pain score (6) indicated that the cohort had a considerable level of baseline symptoms and dysfunction from their PFP. Therefore, it can be argued that they formed an ideal PFP cohort to study. However, although the cohort may have been an ideal one to study in terms of their PFP symptoms, it should be borne in mind that that the generalisability of these results is limited by the demographic characteristics of the participants. For example, since participant recruitment was not conducted from an NHS or sports clinic setting, the sample may not be representative of people who typically present to an NHS or sports clinic with symptoms of PFP.

Although care must be taken with the interpretation of these results due to the small sample size, the most striking results appear to have been those from the patient reported measures, i.e., the pain and perceived stability levels. It can be seen in section 8.11.2 that the active tape had a significant effect on the pain levels of the cohort, decreasing the pain during stair descent with respect to both the neutral tape and the no tape conditions. It is also interesting that the neutral tape reduced the reported pain with respect to the no tape condition. For the perceived stability, the active tape had a significant effect, improving this measure when compared to both the neutral tape condition and the no tape condition. The neutral tape also improved matters with respect to the no tape condition. This implies that the active tape could have an important clinical role to play in the management of PFP, and also that the neutral tape could potentially be used to similar effect.

For the movement control data, the only significant tibial angular velocity results were found in the coronal plane with the active tape reducing the peak adduction and range of abduction-adduction in the double support phase with respect to the no tape condition, and during the whole of stance phase with respect to the no tape and neutral taping conditions. There were also no significant differences in any of the tibial acceleration directions indicating that the taping conditions did not have a great deal of impact on the movement of the tibia. With respect to the patellar kinematics, there was a little more happening, especially in the transverse plane involving the internal and external rotations. It can be seen in section 8.8.2 that the active tape condition reduced the values of several parameters indicating an increase in stability for this domain during the stair descent. There were also significant results in the coronal plane for the patellar kinematics, with the active tape reducing movements indicating an increase in stability. Finally for the patellar data, when considering the acceleration data, although there were some significant results, overall, there was not much happening in any of the directions which is similar to the tibial accelerations.

From the muscle activity data, the key significant result was that the active tape reduced the average VL activity during the single leg stand phase of the stance phase. Although it was the only significant muscle activity result, it should not be dismissed too lightly as it could be argued that it is still clinically relevant that there was a reduction in VL activity, especially as it was during the single leg stand phase which has been suggested to be the phase with the greatest eccentric demands on the muscle (Zachazewski et al 1993, McFadyen and Winter 1988). Furthermore, it suggests that with a more sensitive measurement technique, such as sEMG decomposition, VL inhibition may be more readily detected.

In summary, the key findings of the second study comprising this thesis are:

- The active tape technique significantly reduced reported pain during stair descent
- The neutral tape technique also significantly reduced reported pain during stair descent
- The active tape technique significantly increased reported perceived stability during stair descent
- The neutral tape technique also significantly increased reported perceived stability during stair descent
- The active tape reduced the average VL sEMG activity during the single leg stance phase
- Both taping techniques had an impact on the kinematics of the lower limb during stair descent.
- The IMUs were sensitive enough to detect these kinematic changes, and their properties and characteristics makes them suitable for research in clinics as well as laboratories.

Chapter 9 Discussion: Efficacy of Taping in a Symptomatic Cohort

9.1 Introduction

The first objective of this study was to describe the symptomatic cohort by using common clinical tools including the KOOS-PF and the TIPPS classification system. The results from both of these assessments can be seen in Table 8.3, along with the average pain from the previous week (prior to testing) scores. These are the first results that will be discussed in this chapter.

The second objective was to explore the efficacy of a taping technique purported to inhibit VL activity in a symptomatic PFP cohort. As with the asymptomatic cohort, the effect of the taping was again assessed under the same three taping conditions; active tape, neutral tape and a no tape control condition. Given that the cohort for this study were symptomatic, part of this objective was also to explore the effect of the taping conditions on two patient-reported outcome measures; self-reported pain and perceived knee stability during stair descent. These were recorded after the five trials of stair descent for each of the taping conditions. In addition, the effects of these taping conditions on different biomechanical parameters, which again included stance phase duration, muscle activity, and lower limb control factors, were also assessed. Although, as previously, the tape was applied to the skin over VL and was designed to have a direct effect on that muscle, VM and GM were again included as they are frequently investigated alongside VL in the PFP research literature and can therefore be said to have been identified as key muscles to study in relation to PFP (De Oliveira Silva et al 2016, Bolgla et al 2011b). However, in a change from the previous asymptomatic study, only the high riser was used for this study with a symptomatic cohort. This was done to minimise the impact of a known PFP provocative task and the high riser was chosen over the low riser because it more closely reflected the riser height typically seen in public places (Spanjaard et al 2008). As with the asymptomatic discussion chapter, the current chapter will conclude with sections where the limitations of the study are identified and the implications of the results from the symptomatic cohort for clinical practice and further research are highlighted.

9.2 KOOS-PF and TIPPS Data

The range of the KOOS-PF scores was 21 - 65 with an average of 44.9 and a standard deviation of 12.21, with the lower the KOOS-PF score out of 100 the more severe the symptoms and dysfunction are. The average KOOS-PF score for the current study was considerably lower than the pre-intervention scores that have been reported previously, for example by Barton et al (2019) and Sinclair et al (2018). Barton et al (2019) recorded a pre-intervention score of 74 while Sinclair recorded pre-intervention scores of 64 for their strong sub-group and 53 for their weak and tight sub-group. This therefore confirms that the participants in the current study had considerable levels of impairment due to PFP, with even the highest score recorded representing substantial impairment

With respect to the TIPPS classifications, in the current study, 19% of participants (n=3) were classified as strong, 31% (n=5) of participants were classified as weak and tight, and 50% (n=8) of participants were classified as weak and pronated. The percentage of participants who were classified as strong in the current study compares with Selfe et al (2018) who found that 22% of their sample were classified as strong. However, Selfe et al (2018) then found that each of the other two categories, weak and tight and weak and pronated, had 39% of the sample classified to them. However, it should be noted that the Selfe et al study had a sample size of 130 participants compared to the 16 of the current study. Therefore, a direct comparison of the figures may be difficult as with a relatively small sample size, the effect of one participant's classification can make a bigger difference to the overall classifications percentage than that made by a participant from a larger sample.

9.3 Taping Effects on Pain

As the current study involved a symptomatic cohort, self-reported pain data were also collected. This was deemed necessary as pain is one of the main issues that patients are primarily concerned about, with pain often being an outcome measure used in the literature to assess the effect of an intervention. Therefore, participants were asked to rate their pain at several stages during the session. Firstly, they were asked to rate their average pain over the previous week. This revealed a mean score of 5.6 with a range of 4 - 7 out of 10 on the NPRS. Upon this background, participants also rated their pain after their five trials of stair descent for each of the taping conditions (see Table 8.65).

The results of the inferential statistical analysis of these data revealed that the active tape significantly reduced the reported pain with respect to both the neutral and no tape conditions, and also that the neutral tape significantly reduced the reported pain with respect to the no tape condition. Exploring the descriptive reported pain data further, it was revealed that for the no tape baseline condition, the mean reported pain score was 4.9 out of 10 (range 2 – 9), for the neutral tape condition, the mean reported pain score was 3.6 (range 0 – 6), and for the active tape condition the mean reported pain score was 2.0 (range 0 – 5). These values are important clinically, as reductions in pain of two or more points on a NPRS have been reported to be a clinically meaningful change (Salaffi et al 2004). It can be seen from Table 8.65 that several participants reported this clinically important reduction in pain of 2 or more points on the NPRS used in the current study. Specifically, Table 8.65 reveals that the active tape reduced the reported pain with respect to the no tape control condition by the required 2 points in twelve participants, or 75% of the cohort. For the other four participants, each reported a 1-point decrease in their pain with the active tape condition compared to the no tape condition. Reviewing the pain data with the KOOS-PF and TIPPS data revealed that there did not appear to be any association between the responders/non-responders and their KOOS-PF and TIPPS classifications. Meanwhile, the neutral tape reduced the pain with respect to the no tape by a margin of 2 or more points for seven participants, or almost half of the cohort. For the rest of the cohort, five participants reported that their pain had reduced by 1 point with the neutral tape, three that their pain had remained the same with the neutral tape and one reported that their pain had actually increased with the neutral tape.

The significant reduction in pain found in the current study compares with Lim et al (2020) who found that their posterior X taping technique significantly reduced the pain associated with their forward step-down task. It also compares with the findings of Hickey et al (2016) who reported that the Mulligan taping technique significantly reduced pain in their participants. What makes the Lim et al (2020) and the Hickey et al (2016) studies even more relevant to the current study is that neither of the taping techniques used in these studies involved taping over the patella. The posterior X technique used by Lim et al (2020) involved applying a strip of tape in a spiral pattern starting from the proximal lateral thigh and winding posteriorly before ending at the distal medial tibia. Another strip of tape was then applied starting from the proximal medial thigh and again winding posteriorly before this time ending at the distal lateral tibia. The end result is an x-shape which crosses in the popliteal fossa and a taping technique that purports to limit hyperextension at the knee and also tibiofemoral rotation. Meanwhile, the Mulligan technique favoured by Hickey et al (2016) involves creating tension in external tibial rotation at the knee which theoretically induces internal tibial rotation and forces the femur to rotate externally to compensate for the tibiofemoral tape tension (Hickey et al 2016). Both the posterior X and the Mulligan taping techniques use a considerable amount of tape, much more than that used in patellar taping, and similar to that used in the current study. Therefore, a substantial proprioceptive effect may have been created by the tape.

It is difficult to make direct comparisons with existing research as, to the authors knowledge, this was the first study to explore a taping technique purported to inhibit VL on a symptomatic cohort. Apart from Singer et al (2015) who used botulinum toxin on a symptomatic cohort, Tobin and Robinson (2000), Janwantanakul and Gaogasigam (2005), and McCarthy Persson et al (2009) are the only studies known to the author to have explored the potential of inhibiting VL with tape and all of them involved only asymptomatic participants.

The results of the current study with respect to the taping effects on the perceived pain align with those of Chen et al (2018a) who stated that therapeutic taping has been shown to relieve pain in different musculoskeletal conditions although the underlying mechanisms for this are still unclear. Nevertheless, various theories have been proposed. Houglam (2004) suggested that there are three possible mechanisms by which taping could reduce pain: biomechanical (e.g., a change in patellar position during function), neurological (i.e., altered neural input and muscular response), or psychological. Meanwhile, Leibbrandt and Louw (2015) stated that there are four potential mechanisms by which taping can reduce pain: neuromuscular, biomechanical, proprioceptive or placebo. Park and Kim (2018) found that both the posterior-X taping technique and their sham taping technique significantly reduced pain, and they concluded that any taping, regardless of pattern, alters fast afferent fibre action causing inhibition of pain transmission to the brain which they say explains why the posterior-X and their sham taping technique both led to pain reduction in their cohort. Finally, Warden et al 2008 found in their systematic review that there was an average reduction of pain of 16mm on a visual analogue scale with a medially directed patellar tape. They also found a reduction in pain of 10mm on the same scale with what they called sham taping techniques. They concluded that 50% of the effect of a medially directed patellar taping technique could be explained by the effects associated with sham taping techniques, which they attributed to sensory and/or placebo effects. However, they also recognised that there were greater reductions in pain when the tape was applied with a medially directed force suggesting that the active taping techniques are more effective than sham techniques for relieving pain. This compares with and supports the findings of the current study where the data suggests that the active tape condition had a greater effect on the participant's pain than the neutral tape condition did.

9.4 Taping Effects on Perceived Stability

Perceived stability was another variable explored in the current study. This is an important concept to measure as it has been reported that perceived instability is frequently reported by patients with PFP (Greenwald et al 1996). As with the reported pain data, participants rated their knee stability after their five trials of stair descent for each of the taping conditions, this time on a 5-point Likert scale that ranged from very unstable through unstable, neither stable nor unstable, and stable to very stable. The inferential statistics confirmed that the active tape significantly increased perceived stability with respect to the neutral tape and no tape conditions, while the neutral tape significantly increased perceived stability with respect to the no tape condition. Therefore, both taping techniques had a significant impact on perceived stability, albeit with the data suggesting that, as with the reported pain data, the active tape condition had the greater effect. Exploring the descriptive data further, it can be seen in Table 8.66 that after the no tape condition, the participant responses ranged from stable to unstable; with ten reporting being stable, four were neither stable nor unstable and two were unstable; after the neutral tape condition, the responses also ranged from stable to unstable; with four reporting being stable, eight were neither stable nor unstable and four were unstable); and after the active tape condition they ranged from very stable to neither stable nor unstable; with three reporting being very stable, twelve being stable and one reporting being neither stable nor unstable. As with the pain data described and discussed above, there was no apparent association between the perceived stability data and the participant's KOOS-PF and TIPPS classifications. The perceived stability findings of the current study compare with those of Greenwald et al (1996) who found that patellofemoral bracing increased perceived stability although they found that there were no significant differences in the biomechanical parameters which differs from the current study. They also compare with those of Hébert-Losier et al (2019) who found that patellar kinesio tape enhanced perceived knee stability in a cohort of elite cyclists and with those of Park and Kim (2018) who measured perceived stability with a 5-point Likert scale in a cohort of older adults with osteoarthritis (OA). Park and Kim (2018) found that the posterior-X taping technique they used improved the perceived stability of their knee OA participants with respect to their control/sham taping group during activities including; squat, step down and stair ascent and descent. In addition, Hart et al (2016) also found enhanced perceived knee stability following the application of a knee brace with and without frontal plane adjustments in a cohort of participants with post-traumatic knee OA. Hart et al (2016) postulated that their result may have been due to the positive psychological effects provided by the brace.

9.5 Taping Effects on Stance Phase Duration

There was no significant effect of the taping conditions on stance phase duration, which suggests that participants descended the stairs at similar speeds regardless of the taping condition. This finding is consistent with the findings from the asymptomatic cohort (Chapter 6), with possible explanations and an overview of relevant literature being provided in section 6.2.1. To recap briefly, previous research has identified that patellar taping has had no effect on stance phase duration (Roy et al 2016). However, there has also been evidence that stair descent cadence actually increased with the application of patellar taping (Salsich et al 2002). Salsich et al (2002) attributed their results to the significant pain reduction (92.6%) created by their patellar taping intervention, and suggested that because the tape made their PFP participants more able to tolerate the loading at the PF joint, they moved more freely and with significantly greater cadence.

Comparing the results of the two studies within this thesis, the symptomatic participants had a much longer mean stance phase duration than the asymptomatic participants, with Table 8.4 revealing that the symptomatic participants had a mean stance phase duration of 0.96 seconds under the active tape condition, 0.96 seconds under the neutral tape condition and 0.93 seconds under the no tape condition. However, for the asymptomatic participants on the high riser, the stance phase duration values were 0.78 seconds under the active tape condition, 0.78 seconds under the neutral tape condition and 0.77 seconds under the no tape condition (see Table 5.2). Therefore, it would appear that the symptomatic participants descended the stairs substantially slower than their asymptomatic counterparts. This may be due to the fact that, despite there being a significant decrease in overall pain reported with the two taping conditions, most of the participants were not completely pain-free (n=11 with the active tape and n=14 with the neutral tape still had some, albeit less intense, pain) and this may have had a residual effect on their confidence and happiness to move more quickly. The results of the two studies within this thesis regarding stance phase duration compare with those of Salsich et al (2001) who found that their symptomatic participants had a significantly slower cadence than their asymptomatic controls. Although recognising that cadence and stance phase duration are not the same, it may be that decreased cadence may lead to increased stance phase and vice versa.

Previous research has associated pain with a decreased cadence (Grenholm et al 2009). Therefore, given the significant reduction in reported pain in the current study with symptomatic participants, it is an interesting finding that the taping conditions had no significant effects on stance phase duration within the cohort. It would seem reasonable to expect that as both the active tape condition and the neutral tape condition reduced the pain during stair descent, so participants may have been more comfortable and had more confidence when descending the stairs with a consequential increase in the cadence and reduction in the stance phase duration. However, this was not found to be the case in the current study. Section 6.2.2(i) provides a discussion regarding increased confidence as a result of reduced pain following the application of tape and the potential effects of performance. Nevertheless, as the current study found a significant decrease in pain with both the taping techniques, it may have been reasonable to expect a change in stance phase duration, especially if it was the pain reduction that was responsible for the changes in cadence noted by Grenholm et al (2009) and Salsich et al (2002). However, the lack of change in stance phase duration found in the current study may be a reflection that the changes in cadence found by Salsich et al were not simply due to their participants having less pain. It may be that as the taping conditions in the current study were different to the patellar taping used in the Salsich et al (2002) study, potentially they could have had a different effect mechanism. For example, it is plausible that the taping conditions from the current study could be expected to have had a greater proprioceptive effect as they covered a greater area than a patellar taping technique would, with Selfe et al (2011 and 2008) proposing the greater coverage as an explanation for their bracing condition having a greater effect than their patellar taping technique. However, why the taping techniques used in the current study had no effect on stance phase duration is unknown. Plausible explanations could include that, given that the participants descended the stairs immediately after the tape had been applied, there was insufficient time for them to adapt to the tape and alter their movement strategies. It is also possible that they may have had an existing fear of movement and apprehension about the expected potential pain associated with the stair descent which may also have reduced the speed of their descent.

9.6 Taping Effects on Lower Limb Control

The results of the current study involving symptomatic participants were that, as with the previous study into asymptomatic participants, there were several significant and interesting lower limb control findings. However, as with the previous study, no thresholds have been found in the literature for establishing or determining what may be a MCID when evaluating magnitudes of difference in the parameters explored in the current study. Therefore, the same pragmatic approach as described in Chapter 6 has again been taken, although for the current study, as there is also pain data available, the improvement in the pain scores will be used as support when determining whether a MCID has been found.

Taping had an effect on the tibial control in the coronal plane, where the active tape condition significantly reduced both the peak tibial adduction and the range of tibial abduction-adduction when compared to the no tape condition in both the second double support phase and the whole of stance phase. The active tape condition also reduced these same parameters when compared to the neutral tape condition in the whole of stance phase. With regards to the magnitude of the differences, the active tape reduced the peak tibial adduction by 21% with respect to the no tape in the second double support phase, and the range of tibial adduction-abduction angular velocity by 27% again with respect to the no tape condition in the same phase. For the whole of stance phase, the magnitude of the differences for the peak adduction velocity between the active tape and no tape conditions was 15%, and 17% between the active tape and neutral tape conditions. For the range of tibial abduction-adduction angular velocity values in the whole stance phase, the magnitude of difference between the active tape and no tape conditions was 14% while between the active tape and neutral tape conditions it was 16%. Functionally, it can be seen that, by reducing these parameters, the active tape condition increased the control of the knee in the coronal plane. Relating these values to the extrapolated MCID value calculated from Baldon et al (2014), which was 10%, it can be seen that all these values exceed the threshold and thus can be said to be not only clinically important but also functionally relevant. It is also relevant to consider these results in conjunction with the reported pain results since the two may well be associated. Improving the control of the lower limb when descending the stairs may well make the task less provocative and therefore the participant's experienced and reported less pain.

Coronal plane biomechanics have been reported as being important, with coronal plane moments being associated with medial-lateral stability and propulsion (Kowalk et al 1996), with greater ranges of movement in this plane potentially contributing to excessive patellofemoral joint loading and pain (Richards et al 2019). Thus, a taping technique that can reduce these movements may also reduce patellofemoral joint loading. This could not only produce an immediate reduction in pain which is clearly beneficial for patients, but it could also reduce the risk of further problems in the future that would have been caused by the excessive loading associated with the greater movements causing a repetitive microtrauma scenario. Furthermore, coronal plane kinematics have been reported to be a good indicator of the general control of the knee (Burston et al 2018). Therefore, any technique that reduces these coronal plane movements, especially by an amount that represents a MCID as was the case in the current study, could be useful in the treatment of PFP. The findings of the current study also compare with those of Selfe et al (2011 and 2008) who reported a significant difference in the coronal plane angular velocities and a reduction in the maximum knee adduction moment, when considering the effects of both patellar taping and bracing in symptomatic PFP and asymptomatic individuals.

The occurrence of the significant coronal plane findings in the current study being during both the second double support phase and the whole of the stance phase, contrasts with that of the previous study of this thesis where the only significant difference due to the taping for this parameter was in the early phase. However, this is a difficult comparison to make as the study on the asymptomatic individuals only used one FSR compared to the two used with the symptomatic individuals, meaning that the description of the sub-phases is different between the two studies. Nevertheless, it is worth noting that the second double support phase found in the symptomatic individuals would fall within the late phase of the study on asymptomatic individuals, and therefore the response to tape appears to have occurred in different phases in the symptomatic and asymptomatic individuals.

Another difference between the two studies comprising this thesis is that the taping condition responsible for the changes seen differs between the two studies. In the first study, which involved asymptomatic participants, it was the neutral tape that created the change, which was an increase in the peak tibial abduction with respect to both the active tape condition and the no tape condition. However, in the second study which involved a symptomatic cohort, it was the active tape that created the effect of reducing the peak adduction and range of abduction-adduction angular velocities with respect to the neutral tape condition and the no tape condition. The effect of the neutral tape in the asymptomatic study increasing the peak tibial abduction is an important one to consider as it could potentially increase the dynamic knee valgus that is accepted to be an abnormal movement pattern often seen in PFP patients (Di Staulo et al 2019). Therefore, care must be taken when considering the use of this technique.

The lack of significant effects of taping on the tibial angular velocities in the sagittal and transverse planes contrasts with the results of the first study which involved an asymptomatic cohort. For example, in the study with asymptomatic participants, significant differences including increases in the peak flexion and range of flexion-extension angular velocities were found in the sagittal plane, and these were attributable to the active tape technique. Meanwhile in the transverse plane there were differences in the range of internal rotation-external rotation angular velocity. The lack of effect in the current study with asymptomatic participants also contrasts with the findings of Clifford and Harrington (2013) who found that their patellar (medial glide) taping led to a significant increase in squat depth in the sagittal plane and also to a significant decrease in reported pain in their symptomatic cohort. Although squatting is a different task to stair descent, it still involves eccentric control and therefore is relevant to the current study. Lim et al (2020) explored a forward step-down task using a posterior X taping technique, also with a symptomatic cohort, and had similar findings to the current study in that their results included a significant reduction in pain due to their taping technique. They also found no significant kinematic changes which makes their study comparable to the current study in this respect.

When considering the patellar angular velocity data, significant main effects were seen in the transverse and coronal planes. In the transverse plane, the active tape condition reduced the external rotation in the first double support phase by 22% with respect to the neutral tape condition, reduced the external rotation in the second double support phase by 25% with respect to the no tape condition, reduced internal rotation in the second double support phase by 40% with respect to the no tape condition, and reduced the range in the second double support phase by 28% with respect to the no tape condition. There were further significant findings over the whole of the stance phase, and these included reduced internal rotation due to the active tape condition with respect to the neutral tape condition where there was a magnitude of difference of 36%, and due to the no tape condition with respect to the neutral tape condition where the magnitude of difference was 27%. There were also similar results for the range of rotations over the whole of the stance phase, with the active tape condition reducing the value with respect to the neutral tape by 29%, and the no tape condition reducing it with respect to the neutral tape condition by 9%.

When considering the clinical relevance of these findings, the MCID may be extrapolated from Kwaees et al (2019), where a MCID for the transverse plane are 4% for the internal rotation, external rotation and range of movements were calculated. Therefore, all the results from the current study are considerably larger than this cut-off point and can thus be said to be clinically important. As with the coronal plane data discussed above. It can be seen that functionally, there was an improvement in the stability of the patellar in terms of it's internal and external rotations. Again, an association can be made between these results and the reported pain values, with the improved control of the lower limb when descending the stairs making the task less provocative and therefore the participant's experienced and reported less pain. Patellar rotations are an important kinematic variable to assess in PFP patients as they are one of the three key patellar movements that McConnell recommends correcting with taping, the others being patellar tilt and glide (McConnell 1986). The reduction of the rotational patellar movements found in the current study with the active tape condition is an important one as it has a functional impact that has the potential to contribute to the future management of PFP patients.

These results from the transverse plane imply that the active tape improved the rotational stability of the patella with respect to both the neutral tape condition and the no tape condition, with the reduced angular velocities as outlined above representing increased overall control. As the active tape improved the rotational stability with respect to the neutral tape, since the amount of tension that was applied was the only difference between the two taping techniques, this implies that it was the amount of tension that the active tape was applied with that made the difference. This contrasts with the results of the asymptomatic study in this thesis where there were no significant effects of the tape on the transverse plane patellar angular velocities. A plausible explanation for this may lie in the different cohort characteristics. In the previous study, the participants were asymptomatic and therefore their patellae may have been more stable in the transverse plane meaning that the tape may not have much impact on this variable. However, in the current study, the participants all had PFP and it may be that their patellae were more unstable in the transverse plane which could have been a biomechanical contribution to their pain. The association between PFP and patellar instability has been made previously by, with both pathologies identified as having features in common (Smith et al 2009d). This instability could then have been addressed by the tape which therefore had more of an impact on the transverse plane angular velocity resulting in the significant differences that were found. The findings of improved rotational stability in the current study compares with the results of Kwaees et al (2019) who found that proprioceptive bracing had much the same effect. In their study on asymptomatic participants, Selfe et al (2008) also found that the range of torsional movements were significantly reduced by both patellar taping and bracing techniques, thereby implying increased stability with both techniques with respect to their no intervention control. However, in their later study involving symptomatic participants, Selfe et al (2011) found that only the brace improved torsional stability in the transverse plane, with the differences between the patellar taping technique and their no intervention control condition being not significant. This may have been due to the taping technique being a neutral one with the tape being applied with no medially directed force whereas the brace did apply a medially directed force on the patella.

In the coronal plane, the active tape produced significant differences in the peak patellar adduction angular velocity and the range of patellar abduction-adduction angular velocity, both occurring over the whole of the stance phase. The direction of the differences was that the active tape condition reduced the peak adduction angular velocity with respect to the no tape condition with a magnitude of difference of 16%. The active tape condition also reduced the range of abduction-adduction angular velocity with respect to the no tape condition with a magnitude of difference of 25%. Furthermore, the current study shows that in symptomatic individuals, a significant difference was seen in the coronal plane in the second double support phase where the neutral tape condition reduced the peak adduction angular velocity with respect to the no tape condition by 31%. These significant findings suggest that both taping techniques had an impact on stability in the coronal plane and, if the MCID calculated from the work of Baldon et al (2014) is accepted, the threshold for establishing clinical importance is 10%. This means that all of these findings can be recognised as clinically important. The clinical importance of these results is that it could be argued that, alongside reducing pain which the taping conditions did, increasing the sideways stability of the patella by reducing the range of patellar abduction-adduction is an important target of an intervention for PFP and therefore the active tape technique could be a useful part of a PFP treatment programme.

When considering the tibial accelerations, no significant differences between taping conditions were found in any direction. This contrasts with the results from the previous study involving an asymptomatic cohort where there were significant findings in both the vertical accelerations and the anterior-posterior accelerations. However, for the patellar accelerations in the symptomatic cohort, the active tape condition significantly reduced the range of anterior-posterior acceleration, by 16% and 20% compared to the no tape and neutral tape conditions respectively over the whole of the stance phase. There was also a significant difference in the medial-lateral accelerations with the active tape condition reducing the peak lateral acceleration over the whole of the stance phase with a magnitude of difference of 35%. The reduction in the lateral patellar acceleration is an interesting finding as it suggests that there may have been a reduced lateral pull of the patellar which is consistent with there being reduced VL activity. It is plausible that the reduction in VL activity which was identified in chapter 8 but has not yet been discussed, may have induced a reduction in the lateral acceleration of the patella which implies that functionally, there was greater patellar stability with the active tape.

Relating the significant reduction in pain discussed above in section 9.3 to the other findings of the current study, it can be seen that there is a link between the reduction in pain and some of the movement control (kinematic) variables. As already highlighted and discussed, the active tape condition created increased stability of the patellar in the transverse and coronal planes and also increased stability of the tibia in the coronal plane where there was reduced ROM of abduction–adduction found. It is likely that the kinematic changes relate directly to the reduction in pain, with the reduced patellar and tibia angular velocities implying an increase in movement control. In the absence of mechanical changes, the likely mechanism for these findings is proprioceptive. Drawing on the work by Callaghan et al (2012, 2008 and 2002), which involved both asymptomatic (2012 and 2002) and symptomatic (2008) participants, it can be seen that taping has been shown to improve proprioception, especially where it was impaired to start with (Callaghan et al 2008 and 2002). This is supported by the work of Thijs et al (2010) who found that bracing had much the same effect, with their tight brace creating significantly greater sensorimotor cortex activation than their looser brace. These findings can be extrapolated and applied to the current study where the active tape would be the equivalent of the tighter brace and the neutral tape would be the equivalent of the looser brace. Impaired proprioception has been shown to be a feature of musculoskeletal injuries, not only by Callaghan et al but also by Abbasi et al (2020) who studied chronic low back pain, Alahmari et al (2020) who studied neck pain and Keenan et al (2017) who studied shoulder pain. However, in their respective studies, both Abbasi et al (2020) and Keenan et al (2017) found that their taping technique did not improve proprioception in their patient groups. This contrasts with the work of Callaghan et al highlighted above and with that of Alahmari et al (2020) who all found a significant improvement in proprioception with their taping techniques. Thijs et al (2010) proposed that their findings indicated that the intensity of proprioceptive stimulation is an important concept that can influence pain. Relating these findings to those of the current study, it could be argued that the active tape, which was applied with a great deal of tension, was therefore “tighter” than the neutral tape technique. Consequently, the active tape technique should therefore have had a greater proprioceptive effect. Therefore, it is possible that the symptomatic participants in the current study may have had impaired proprioception meaning that they could have benefitted more from the application of the tape, and that the active tape provided greater proprioceptive input. However, this will require future research to also measure proprioception alongside the variables included in the current study, with Clark et al (2015) suggesting that any clinical assessment of proprioception should include an assessment of joint position sense, kinaesthesia and force sense.

It is interesting that Lim et al (2020), who did not find any significant difference with the kinematics they explored, then raised the question of how their taping condition actually decreased the pain. Their conclusion was that the mechanism remained unclear. The results of Lim et al (2020) concur with those reported by

Greenwald et al (1996) who found that a patellofemoral brace reduced pain but had no effect on the biomechanical parameters they explored, and also those reported by Aminaka and Gribble (2008) who found no significant difference in the kinematics of the lower limb with patellar tape but did get a decrease in pain. This led Aminaka and Gribble to therefore conclude that changes in pain did not appear to influence hip/knee kinematics. However, these findings contrast with the current study where there were some kinematic differences with the different taping conditions.

Relating the perceived stability findings to the movement control variables measured in the current study, it can be argued, for example, that the reduced patellar angular velocities created by the active tape resulted in less patellar excursion which would result in the increase in the perceived stability that was reported by the participants. Likewise, the improvement in tibial control is also associated with the increase in perceived stability. The more dynamically stable the lower limb is, and both the tibial and patellar IMUs confirmed that in the active tape condition the lower limb was indeed more stable, the less symptomatic the participants became, which maybe as a result of the reduced patellar excursions creating less microtrauma in the patellofemoral joint and therefore less pain. Therefore, the perceived stability could have improved not only from the direct effects of the tape but also from the reduction in the pain-related changes noted above

9.7 Taping effects on Muscle Activity

The major finding for the effect of the taping conditions on muscle activity was that the active tape significantly decreased the average activity of VL during the single leg stance phase with respect to the no tape condition. This compares with the findings of both McCarthy Persson et al (2009) and Tobin and Robinson (2000), with both studies finding a significant reduction in VL activity with their active (tensioned) tape conditions. Although this does contrast with the findings of Janwantanakul and Gaogasigam (2005) who found no significant difference in VL activity, the taping technique they used to inhibit VL involved the application of elastic tape with full tension in the same direction as that recommended by McConnell and used by Tobin and Robinson and the current study but with no downward pressure exerted into the muscle and no furrow creation. Interestingly, the results of the symptomatic cohort also contrast with the results from the study on the asymptomatic cohort reported in this thesis, where neither taping technique showed any influence on muscle activity. This may be associated with differences in movement control between the two cohorts, with the symptomatic individuals showing greater instability which could arguably be associated with dysfunction during the step-down task on the high riser. This may indicate the symptomatic individuals required different muscle recruitment strategies, however this analysis was beyond the scope of this thesis.

It is an interesting finding that the active tape technique did indeed inhibit VL activity in the single leg stance phase. Although the active taping condition was not found to have inhibited VL in other phases or with other sEMG measurements, it was also responsible for a significant reduction in the reported pain. Similarly, it is again interesting that the neutral tape also induced a significant reduction in pain when compared to the no tape baseline condition. These results can be aligned with those of Cowan et al (2006) who found that whilst patellar taping did not have a significant effect on the relative magnitude of activation of VL and VM(O), it was responsible for a significant alteration in their participant's pain. Although it is difficult to directly compare patellar taping with the taping techniques used in the current study, it is relevant to consider all therapeutic taping as an intervention and therefore it is appropriate to compare findings from studies involving various taping techniques.

The decrease in the average activity of VL was seen during the single leg stance phase which is the most demanding of the stance sub-phases from a biomechanical perspective (Zachazewski et al 1993). This decrease in the activity of VL is a key finding as it suggests that tape can be used to inhibit the muscle and therefore re-balance the work done between VL and VM. Guner et al (2015) and Hug et al (2014) both identified the potential for using therapeutic taping techniques to address muscular imbalance issues, either by facilitating underactive muscles or, as in the case of VL here, inhibiting overactive muscles. VL being over-active with respect to VM is a widely accepted phenomenon in PFP (Chester et al 2008, Aminaka and Gribble 2005, Tang et al 2001), with the need to redress the balance between the two muscles being a clear goal of clinical interventions. Given that the literature regarding the ability to manipulate this imbalance by preferentially recruiting VM is ambivalent at best, finding an intervention that inhibits VL and is readily available to clinicians has the potential to change clinical practice and potentially enhance the outcomes for many people with PFP. Apart from the study by Singer et al (2015) where botulinum toxin injections, which are not readily available to most clinicians, were used to inhibit VL, the current study is the first one to the authors knowledge to investigate the use of tape to inhibit VL in a symptomatic cohort. Thus, the finding that VL can indeed be inhibited with tape represents a contribution to the PFP knowledge base. Furthermore, tape is a cheap and easy to use intervention that is readily available to most clinicians. Therefore, specific taping techniques, such as the active tape technique used in this thesis, can be introduced into clinical practice with little difficulty. Thus, the theoretical contribution to knowledge also becomes a potential practical addition to current best practice for treating PFP.

It is also an interesting finding that the change in VL that has been identified with the tape could be used in the rebalancing of VL to VM activity. However, this is not the only effect of the tape as it can also be related directly to the changes in dynamic stability and movement control that were detected with the IMUs. The current study was, to the authors knowledge, the first to investigate the effect of a VL inhibition taping technique on movement control as well as muscle activity. Thus, the finding that the active tape induced greater tibial stability in the coronal plane as well as improving the patellar stability in the coronal and transverse planes and reducing the anterior-posterior and medial-lateral patellar accelerations indicates an association between the tape and the movement control data that is a contribution to the knowledge base for PFP. Furthermore, the active tape also significantly decreased the pain and increased the perceived stability reported by the symptomatic cohort in this thesis. Thus, there appears to be an association between inhibiting VL, enhancing movement control and a positive impact on pain and perceived stability.

In the paper by Tobin and Robinson (2000), one of the key findings was that their placebo taping condition, which is comparable to the neutral tape condition in the current study, actually increased the activity of VL. Although this finding was not replicated in either of the studies comprising this thesis, it is a noteworthy finding that merits highlighting. Tobin and Robinson identified that the increase in VL activity with the neutral tape was a key finding because the two taping techniques, active and neutral, had opposite effects which has clear implications for application technique, i.e., if, for example, the active tape is applied with insufficient tension, it may actually increase the activity of VL, countering the original purpose of the tape. That there were no other taping effects on muscle activity is surprising, as it implies that there appears to have been no proprioceptive effect. This also contrasts with the findings of Selfe et al in their papers with both an asymptomatic sample (2008) and a symptomatic sample (2011), which have been discussed previously in section 6.2.2. It could be argued that the results of the current study therefore contradict the theory surrounding the proprioceptive effect of tape whereby taping over the skin can potentially stimulate cutaneous mechanoreceptors and boost afferent signals to the central nervous system for improved proprioception (Rőijezon et al 2015). However, given that the active tape did inhibit VL, the results of the current study may actually support the proprioceptive theory. Furthermore, it also appears that the results do support the nociceptive theory. According to the nociceptive theory, the application of tape can elicit changes in neural input through afferent receptors, such as those from cutaneous mechanoreceptors, which may be enough to block nociceptive input and cause neural inhibition via the large afferent fibres (Osorio et al 2013). This would then lead to an alteration in the muscle activity as detected by the sEMG, which is what was found in the single leg stance phase. Furthermore, it would also lead to the reduction in self-reported pain which was also found.

9.8 Study Limitations

As with the asymptomatic study, the current study also has limitations that should be acknowledged. Some are the same, including that it only involved a single task Brabants et al (2018), the lack of blinding which could unwittingly have introduced bias (Hickey et al 2016), and the data was again collected in one session so only the immediate effect(s) of the tape can be insinuated with any long-term effects being unknown (Aghakeshizadeh et al 2021). In order to be as pragmatic and real-life as possible, this study did not make any attempt to control the participant’s descent speed, which may affect the repeatability between conditions, and therefore the sensitivity to measure changes. The sample for this study was more diverse than that of the previous study as although it was again comprised of participants recruited from UCLan, there were also participants who were recruited from the local Park Run community. In addition, only a relatively small sample was recruited, and the target of 30 symptomatic participants was not reached due to the curtailment of recruitment due to the COVID-19 pandemic in 2020.

9.9 Implications for Clinical Practice and Future Research

A major implication of the results of the current study is the potential of both the active tape and neutral tape techniques to reduce the reported pain and improve the perceived stability associated with stair descent in a cohort of symptomatic PFP individuals. This offers a contribution to knowledge, as to the author’s knowledge, no other study has looked at these particular taping techniques on a symptomatic cohort. Although the active tape had the more dramatic effect on the reported pain levels, the fact that the neutral tape also reduced the reported pain creates an interesting clinical decision to be made; should a clinician choose the active tape condition to get the biggest reduction in pain and accept the discomfort that is associated with its application, or should a clinician choose the neutral tape condition which may not have the same level of effect but is not associated with any application discomfort? To aid the discussion, it is worth remembering that McConnell targets a minimum 50% reduction in symptoms following the application of tape to facilitate the performance of the necessary exercise programme (McConnell 1986). This may be achievable with the more comfortable neutral tape technique for some individuals, which may lead the clinician towards using it in preference to the active tape technique. However, Dye et al (1999) recommends working in a pain free envelope of function which would guide a clinician towards the greater pain relief afforded by the active tape. In addition, the active tape technique does inhibit VL which may possibly redress any imbalance between VL and VM while the neutral tape had no detectable effect on the muscle activity. However, this is an area that requires further research.

Another major implication of the results of the current study involves the finding that both the active tape technique and the neutral tape technique significantly improved the perceived stability of the knee for participants with PFP during stair descent. This creates a similar dilemma as discussed above in that the active tape technique had the greater effect, but its application is associated with a degree of discomfort, whereas the neutral tape technique had a lesser effect but doesn't engender the same discomfort. Thus, a clinician must decide, with the involvement of their patient, which of these two techniques they may wish to include in the patient's bespoke treatment programme. However, both of these taping techniques add to a clinician's arsenal of possible procedures they can utilise to effectively treat PFP.

A further major finding of this research is that the results of both studies confirm that IMUs can be used instead of expensive laboratory-based camera systems to capture kinematic information that is able to identify differences between riser heights as well as changes due to the taping techniques. IMUs are small, lightweight and relatively cheap meaning that they could conceivably be readily used in clinical settings (Al-Amri et al 2018). Budini et al (2018) found that IMUs detected clinically important changes in movement quality and postural control strategies in the lower limb. This is further supported by Costello et al (2020) who identified that small, low-cost wearable inertial sensors have become increasingly popular for collecting biomechanical data. Costello et al (2020) found an association between measurements taken from the inertial sensors and from a camera system, which confirms that both technologies are an appropriate way of collecting kinematic data. Interestingly, they found that the sensor they placed on the lateral thigh had less variability than the sensor they placed on the lateral lower leg. They postulated that this was possibly due to the thigh having less curvature along its length than the lower leg. Costello et al (2020) went on to report that a single appropriately placed sensor can quantify varus thrust across different walking speeds in patients with OA knees. Further support for the use of IMUs comes from Hu et al (2014) who identified that these small, lightweight wearable body sensors offer a user-friendly solution to the problems associated with camera systems as they minimise most of the constraints associated with them. They found that IMUs captured varus/valgus motion accurately with respect to a motion capture system. Finally, Saber-Sheikh et al (2010) also asserted that inertial sensors have the potential to be used for assessing human movement in various environments. In their study, they found that inertial sensors and electromagnetic motion tracking systems were comparable for measuring human movement.

9.10 Chapter Summary

In summary, this second study has again explored the effects of a specific VL inhibition therapeutic taping technique on various neuromuscular and biomechanical/kinematic parameters, this time in a symptomatic cohort. As all the participants had PFP, pain and perceived stability data were also collected and analysed. This cohort being symptomatic means that the clinical relevance of these results can be established more clearly than was possible with those of the asymptomatic cohort. Very few studies have explored inhibiting VL as a possible treatment technique for PFP, and to the authors knowledge, none have done so using therapeutic taping with symptomatic participants (Singer et al (2015) used botulinum toxin to inhibit VL)). Therefore, most of the current study's results represent a contribution to the knowledge as the study is presenting new and original work and findings. The reduction in pain, increase in perceived stability and reduction in VL activity in the single leg stance phase are all key findings. The level of statistical significance of the decrease in pain and the increase in perceived stability was matched by the clinical importance associated with these findings, which indicates the potential usefulness of these taping techniques in the management of PFP, with the active tape technique being responsible for the greatest effects. This implies that the addition of tension when applying the tape as a strategy to address PFP is supported by the data within this thesis. Thus, it is the active tape that should be most recommended for clinical use. The conclusion this taping technique could be used in clinical practice is important since, to the authors knowledge, there has been no previous evidence base for it. This is despite it being recommended for clinical use in cases where VM(O) is not responding well to attempts to rehabilitate it (McConnell 1995) and there being positive findings regarding its' potential efficacy from over twenty years ago, albeit in asymptomatic participants (Tobin and Robinson 2000), The data from both of the studies within this thesis add to the growing body of evidence that IMUs can be a practical alternative to laboratory-based camera systems when collecting movement control (kinematic) data. One of the key findings from this thesis is that the IMUs can measure important kinematic changes which can be related to the changes in pain and perceived stability. To the authors knowledge, this has not been done before and therefore represents another contribution to knowledge.

Chapter 10 Conclusions

This thesis centres around two separate studies; one involving an asymptomatic cohort and one involving a symptomatic cohort of people with PFP. The primary focus of the first study on the asymptomatic cohort was to investigate the efficacy of both a McConnell therapeutic taping technique designed to inhibit VL and also of a neutral taping technique, with the difference between the two taping techniques being the amount of tension the tape was applied with. Although the lack of VL inhibition means that the neuromuscular hypotheses for the asymptomatic study were rejected, there were numerous significant changes found in the lower limb movement control which were attributable to both the active and neutral taping techniques. These included the active taping condition increasing the tibial flexion and range of flexion-extension angular velocity in the sagittal plane in both the early stance phase and over the whole of stance phase. There were also increases in both the tibial and the patellar anterior-posterior accelerations, which were all attributable to the active tape condition, whilst the neutral tape condition increased the patellar abduction and range of adduction-abduction angular velocity in the early stance phase.

There were also significant changes in muscle activity and lower limb movement control which were attributable to the different riser heights. These included an increase in stance phase duration and VL and VM activity on the high riser, and previously unreported increases in the tibial and patellar kinematics with the high riser increasing acceleration and angular velocities in both the sagittal and the coronal planes.

The second study of this thesis involved a symptomatic cohort. The initial aims were similar to those of the first study but were also expanded to include being able to describe their clinical presentation using the KOOS-PF scores and their TIPPS classification, and to explore any associated changes in pain and perceived stability alongside muscle activity and lower limb movement control. In this study, where the KOOS-PF scores revealed a cohort with considerable impairment, there was evidence of VL inhibition seen with the active tape reducing VL activity in the single leg stance phase. There were also significant changes in the pain and perceived stability reported by the cohort, with both the pain and the perceived stability indicating statistically significant and clinically important improvements. As with the asymptomatic study, there were also lower limb movement control changes that were attributable to the taping techniques. These changes include the active tape increasing the tibial coronal plane stability by reducing the angular velocity, increasing the stability of the patella in the transverse and coronal planes again by reducing the angular velocities, and increasing the control of the patellar accelerations in an anterior-posterior and lateral direction.

With respect to the hypotheses for the study on the symptomatic cohort, the active tape condition did significantly reduce the sEMG activity of VL and therefore this hypothesis was accepted. However, as the active tape did not increase the activity of either VM or GM, and the neutral tape did not inhibit VL activity or increase either VM or GM activity, the other neuromuscular hypotheses were rejected. For the movement control results, the active tape increased the control of the lower limb in the coronal plane tibial angular velocity and also in the transverse and coronal plane patellar angular velocities allowing the relevant hypothesis to be accepted. However, this was not the case for the neutral tape, and thus the hypothesis that it would increase the movement control of the lower limb was rejected. Finally, the effect of the taping techniques on self-reported pain and perceived stability showed significant improvements which exceeded the threshold of a minimally important change, inferring that both taping techniques offer potential patient benefits with the active tape showing the greatest improvements and allowing the hypotheses that this is what would happen to be accepted.

This thesis demonstrated the efficacy and immediate effectiveness of these taping techniques, which to the author’s knowledge, is the first time this has been documented, indicating these have the potential to be a useful adjunct intervention in the management of PFP. Given the significant reductions in pain and increases in perceived stability, which can be linked directly with the kinematic changes induced, there is a case for making one or both techniques part of a PFP rehabilitation programme. However, further research is needed, both to confirm these results and to explore the longer-term effects of such taping techniques.

Chapter 11 References

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Chapter 12 Appendices

Appendix 1

8TH December 2014

Professor James Selfe, Professor Jim Richards & Sue Tobin
School of Sports, Tourism and the Outdoors
University of Central Lancashire

Dear James, Jim & Sue

Re: STEMH Ethics Committee Application Unique Reference Number: STEMH 283

The STEMH ethics committee has granted approval of your proposal application 'Alteration of the Vasti Muscles in Patellofemoral Pain'. Approval is granted up to the end of project date* or for 5 years from the date of this letter, whichever is the longer.

It is your responsibility to ensure that

- the project is carried out in line with the information provided in the forms you have submitted
- you regularly re-consider the ethical issues that may be raised in generating and analysing your data
- any proposed amendments/changes to the project are raised with, and approved, by Committee
- you notify roffice@uclan.ac.uk if the end date changes or the project does not start
- serious adverse events that occur from the project are reported to Committee
- a closure report is submitted to complete the ethics governance procedures (Existing paperwork can be used for this purposes e.g. funder's end of grant report; abstract for student award or NRES final report. If none of these are available use e-Ethics Closure Report Proforma).

Yours sincerely

Kevin Butt
Vice Chair
STEMH Ethics Committee

* for research degree students this will be the final lapse date

NB - Ethical approval is contingent on any health and safety checklists having been completed, and necessary approvals as a result of gained.

Appendix 2

PARTICIPANT INFORMATION SHEET

TITLE OF STUDY: Alteration of the Vasti Muscles in Patellofemoral Pain

RESEARCHER: Sue Tobin

SUPERVISORS: Professor James Selfe, Professor Jim Richards

STUDY AIMS: This study aims to address as yet unanswered questions about the function of the muscles on the front of the thigh and control of the knee joint in front of knee pain. This part of the study requires data to be collected from a healthy population of people with no known lower limb pathologies and no history of pain, pathology or surgery. The results of this part of the study will inform future research with a population of people with front of knee pain and assess the clinical applicability of a specific taping technique

WHAT IT INVOLVES: If you are eligible for this study and choose to participate, you will be asked to attend for only one testing session, which will be held in the Movement Analysis Laboratory in the Brook Building (BB021). Firstly, background demographic data will be collected including your age, gender, height and weight.

You will need to wear shorts for the data collection, and will have sensory electrodes placed on one of your buttock muscles, two on your front of thigh muscles, one on your kneecap and one on your shine bone. You will also have a sensor placed in the shoe of the leg the data is being collected from. These will be used to collect data and will not give any sensation to you. You will then be asked to descend two sets of steps five times under three test conditions; no tape and two with tape. The tape will be applied to your thigh, and will involve a layer of hypoallergenic tape to protect the skin and a layer of rigid tape. Although not a requirement, you will be given the opportunity to shave your leg if you choose to prior to the application of the tape.

After testing has finished, you will be asked to rate how much control you felt you had while descending each set of stairs under the three testing conditions.

POTENTIAL RISKS: It is important that you let the researcher know if you are allergic to, or have ever had any reaction to, adhesive tape. The application of one of the tape conditions and the removal of the both the tapes may cause slight discomfort. However, this discomfort should not last long.

POTENTIAL BENEFITS: Knee taping is frequently used in the treatment of pain at the front of the knee (patellofemoral pain). However, the efficacy of the particular taping technique being used in this research is as yet unknown. Although you may not benefit directly from participating in this research, if the results are favourable then this could benefit people who do have patellofemoral pain.

WITHDRAWAL
You will be free to withdraw at any time during your participation without the need to give a reason and without any adverse consequences.

DATA PROTECTION: Although there is an intention to use this research for publication in appropriate journals and at appropriate conferences, it will be impossible for you or your data to be identified. All data collected will be done so only by the researcher, and will be kept strictly confidential in line with the Data Protection Act (1998). Only the researcher and the project supervisors will have access to the data, and the data will be kept safely for five years before being destroyed. No information will be passed to third parties or commercial companies. Data collected will be stored separately from the consent forms.

FUNDING: This study is entirely independent and does not involve any funding issues.

STUDY APPROVAL: This study has been granted research approval by the University of Central Lancashire and has also been approved by the Science, Technology, Engineering, Medicine and Health (STEMH) Ethics Committee.

COMPLAINTS/PROBLEMS: Should you have any concerns about the way you are treated during this study or about potential harm you may suffer, you are invited to speak to the researcher or the project supervisors. If this does not resolve the issues, you are free to contact John Minton who is the Head of School.

QUESTIONS: If you have any questions, please do not hesitate to ask them

VOLUNTEERING: Having read this information sheet, if you wish to participate in this study please contact Sue Tobin at stobin@uclan.ac.uk or sue_tobin@hotmail.com or on 07837 390814.

Appendix 3

ASYMPTOMATIC PARTICIPANT CONSENT FORM

STUDY TITLE: Alteration of the Vasti Muscles in Patellofemoral Pain

RESEARCHER: Sue Tobin

SUPERVISORS: Professor James Selfe, Professor Jim Richards

REQUIREMENTS: This research will involve the attachment of various sensors to your leg in order to collect data from the performance of one of your buttock muscles, your front of thigh muscles, your knee joint and your shin bone while you descend stairs under three tests conditions. It will also involve the application of adhesive tape for two of the test conditions.

CONFIDENTIALITY: This research and any subsequent publication will provide complete anonymity for all participants.

SPECIFIC INFORMATION:

	YES	NO
I agree to wear shorts for this research.		
I confirm that I have no current or previous lower limb pain, and no history of pathology or surgery.		
I confirm that I have no known allergy to adhesive tape, and that I have been given the opportunity to shave my leg prior to the application of any tape.		
I confirm that I have been given, read and understood the participant information sheet, and have been given the opportunity to ask questions.		
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without my rights being affected.		
I agree to my anonymised data being used in this research and any subsequent publications.		
I agree to take part in this study.		

SIGNATURES:
Name of participant:

Signature:

Date:

Name of researcher:

Signature:

Date:

Appendix 4

MPHIL DEMOGRAPHIC DATA

Gender…………………….

Age…………………………

Height………………………

Weight……………………..

Test Code…………………

Appendix 5

University of Central Lancashire

5 October 2017

Jim Richards/Sue Tobin
School of Health Sciences
University of Central Lancashire

Dear Jim and Sue

Re: STEMH Ethics Committee Application Unique Reference Number: STEMH 283 _amendment

The STEMH Ethics Committee has approved your proposed amendment to your application 'Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent'.

Yours sincerely

William Goodwin

Will Goodwin
Deputy Vice Chair
STEMH Ethics Committee

Appendix 6

PhD PARTICIPANT INFORMATION SHEET – Version 3 (04/08/18)

TITLE OF STUDY: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

STUDY AIMS: This study aims to address as yet unanswered questions about the function of the muscles on the front of the thigh and control of the knee joint in front of knee pain. It also aims to assess the clinical applicability of a specific taping technique, which includes assessment of pain levels, during stair descent.

WHY HAVE I BEEN ASKED TO PARTICIPATE? You have identified that you have pain at the front of your knee(s).

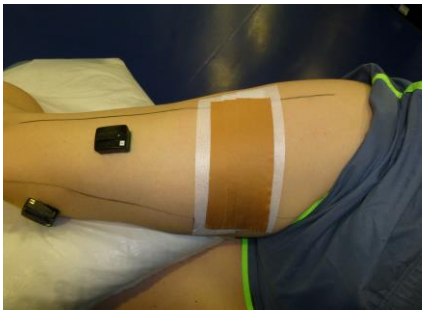
WHAT IT INVOLVES: This study requires data to be collected from people with pain in the front of the knee(s) but with no known other lower limb pathologies or history of lower limb surgery. There is a pre-assessment screening checklist to be gone through before you can participate. This is to ensure you have the particular knee condition that is being researched and this can be conducted over the 'phone.

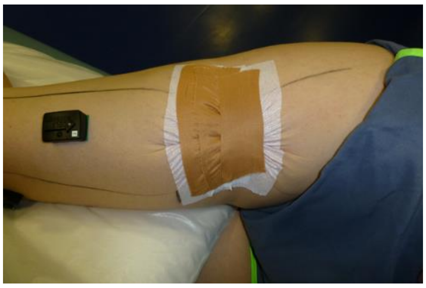
If you are eligible for this study and choose to participate, you will be asked to attend for only one assessment/testing session, which will be held in the Movement Analysis Laboratory in the Brook Building (BB021) at the University of Central Lancashire. This session will last no more than 2 hours.

You will need to wear shorts and trainers/flat shoes for the pre-testing assessment and the data collection. Firstly, you will be asked another series of questions designed to ensure that your symptoms fit with the set criteria of the study. Once this is established, you will be asked to sign a consent form and then you will undergo a series of quick tests to establish some baseline recordings regarding your knee condition. Background demographic data will then be collected including your age, gender, height and weight. You will also be asked to complete two questionnaires designed to assess the severity of your symptoms. You will then have sensory electrodes placed on one of your buttock muscles, two on your front of thigh muscles, one on your kneecap and one on your shine bone. You will also have a sensor placed on the soul of the foot the data is being collected from (see picture below).

These sensors will be used to collect data and will not give any sensation to you. You will then be asked to descend one set of steps five times under three test conditions; one with no tape and two with different tape applications.

The tape will be applied to your thigh, and will involve a layer of hypoallergenic tape to protect the skin and a layer of rigid tape (see pictures below). Although not a requirement, you will be given the opportunity to shave your leg if you choose to prior to the application of the tape.





After testing has finished under each condition, you will be asked to rate how much pain you felt while descending the stairs and how stable or unstable your knee felt.

POTENTIAL RISKS: It is important that you let the researcher know if you are allergic to, or have ever had any reaction to, adhesive tape. The application of one of the tape conditions and the removal of the both the tapes may cause slight discomfort. However, this discomfort should not last long.

POTENTIAL BENEFITS: Knee taping is frequently used in the treatment of pain at the front of the knee (patellofemoral pain). However, the efficacy of the particular taping technique being used in this research is as yet unknown.

WITHDRAWAL
You will be free to withdraw at any time during your participation without the need to give a reason and without any adverse consequences. However, once you have left the university, it will not be possible to identify your data and therefore not possible to withdraw it.

DATA PROTECTION: Although there is an intention to use this research for publication in appropriate journals and at appropriate conferences, it will be impossible for you or your data to be identified. All data collected will be done so only by the researcher, and will be kept strictly confidential in line with the Data Protection Act (1998). Only the researcher and the project supervisors will have access to the data, and the data will be kept safely for five years before being destroyed. No information will be passed to third parties or commercial companies. Data collected will be stored separately from the consent forms.

FUNDING: This study is entirely independent and does not involve any funding issues.

STUDY APPROVAL: This study has been approved by the University's ethics committee.

COMPLAINTS/PROBLEMS: Should you have any concerns about the way you are treated during this study or about potential harm you may suffer, you are invited to speak to the researcher or the project supervisors. If this does not resolve the issues, you are free to contact the Research Officer or the University (OfficerForEthics@uclan.ac.uk).

QUESTIONS: If you have any questions, please do not hesitate to ask them at any stage during the process.

VOLUNTEERING: Having read this information sheet, if you wish to participate in this study please contact Sue Tobin at stobin@uclan.ac.uk or sue_tobin@hotmail.com or on 07837 390814.

Appendix 7

PhD PARTICIPANT INCLUSION/EXCLUSION CRITERIA SCREENING SHEET

TITLE OF STUDY: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

Question	Yes/No
Have you had pain at the front of your knee(s) for more than 3 months?	
Are you aged between 18 and 39 years old?	
Are you willing to attend an assessment/testing session at the University of Central Lancashire (which will last approximately 2 hours)?	
Do you have any known allergy to adhesive tape?	
Do you have any other medical conditions?	
Are you currently having treatment for any lower limb or back condition?	
Have you had any previous lower limb problems?	
Do you have a history of your knee(s) giving way or locking?	
Have you had any lower limb surgery?	
Are you waiting surgery for another lower limb problem?	

Participant code:

Researcher:

Researcher Signature:

Date:

Appendix 8

PhD PARTICIPANT CONSENT FORM – Version 3 (04/08/18)

STUDY TITLE: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

CONFIDENTIALITY: This research and any subsequent publication will provide complete anonymity for all participants.

	YES (Initials)	NO (Initials)
I agree to wear shorts for this research.		
I confirm that I have no known allergy to adhesive tape, and that I have been given the opportunity to shave my leg prior to the application of any tape.		
I confirm that I have been given, read and understood the participant information sheet (Version 3 – 04/08/18), and have been given the opportunity to ask questions.		
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without my rights being affected.		
I agree to my anonymized data being used in this research and any subsequent publications.		
I agree to my anonymized data being used for teaching and other research purposes.		
I agree to take part in this study.		

Name of participant:

Signature:

Date:

Name of researcher:

Signature:

Date:

Appendix 9

PhD DEMOGRAPHIC DATA

STUDY TITLE: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

Gender…………………….

Age…………………………years

Height………………………metres

Weight…………………….. kg

Participant Code…………………

Affected side…………………….

Test Order………………………..

Date:……………………………

Appendix 10

PhD PATELLOFEMORAL PAIN ASSESSMENT RECORDING SHEET

TITLE OF STUDY: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

Numeric Pain Rating Scale (NPRS)

What has been your <u>usual or average level</u> of pain in your knee in the past week?

Please put an X through a number

No Pain   Worst pain
imaginable

0	1	2	3	4	5	6	7	8	9	10

	Yes/No
Do you have front of knee pain during/after squatting	
Do you have front of knee pain during/after prolonged sitting	
Do you have front of knee pain during/after stair ascent	
Do you have front of knee pain during/after stair descent	
Do you have front of knee pain during/after running	
Do you have front of knee pain during/after kneeling	
Do you have front of knee pain during/after hopping/jumping	
Patellofemoral pain on palpation of the medial and lateral borders of the patella	
Patellofemoral pain during /after resisted isometric quadriceps contraction	

Participant Code:

Researcher:

Signature:

Date:

Appendix 11

KOOS Patellofemoral subscale (KOOS-PF)

Participant Code:

Researcher: Sue Tobin

This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to do your usual activities.
Please answer every question by ticking the appropriate box, only one box for each question.
If you are unsure about how to answer a question, please give the best answer you can.

Stiffness

The following question concerns the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or slowness in the ease with which you move your knee joint.

PF1. How severe is your knee stiffness after exercise?

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Pain

The following questions concern your knee pain over the past week. PF2. How often do you experience knee pain after stopping activity?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

PF3. How often does pain limit your activity?

Never	Monthly	Weekly	Daily	Always
☐	☐	☐	☐	☐

What amount of knee pain have you experienced in the last week during the following activities?

- Please give the best answer you can, even if you are unsure about an item
- If you haven't done this activity because of medical advice or pain, please tick "EXTREME"

PF4. Rising from sitting (including getting out of the car)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF5. Kneeling

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF6. Squatting

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF7. Heavy household activities (including carrying and lifting)

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF8. Hopping/jumping

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF9. Running/jogging

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

PF10. After sport and recreational activities

None	Mild	Moderate	Severe	Extreme
☐	☐	☐	☐	☐

Quality of life

The following question concerns your quality of life over the past week

PF11. Have you modified your sport or recreational activities due to your knee pain?

Not at all	Mildly	Moderately	Severely	Totally
☐	☐	☐	☐	☐

Appendix 12

PhD TIPPS ASSESSMENT RECORDING SHEET

TITLE OF STUDY: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

SUPERVISORS: Professor Jim Richards and Dr Jessie Janssen

Quadriceps muscle tightness in degrees (use max value)			
Gastrocnemius muscle tightness in degrees (use max value)			
Quadriceps muscle weakness in kg (use max value)			
Hip abductors muscle weakness in kg (use max value)			
Medial-lateral patella displacement in mm		XXXXXX	XXXXXX

The following are all scored from -2 to +2

Talar head position	
Supra and infra lateral malleolar curvature	
Calcaneal frontal plane position	
Prominence in the region of the talonavicular joint	
Congruence of the medial longitudinal arch	
Abduction/adduction of the forefoot on the rearfoot	

Participant Code:

Researcher:

Signature:

Date:

Appendix 13

PhD POST DATA COLLECTION PAIN RECORDING SHEET

TITLE OF STUDY: Investigating the Effect of Taping to Manipulate Quadriceps Muscles Activity and Knee Control in Participants with Patellofemoral Pain during Stair Descent

RESEARCHER: Sue Tobin

Jim Richards and Dr Jessie Janssen

	0-10
Pain on stair descent with no tape	
Pain on stair descent with un-tensioned tape	
Pain on stair descent with tensioned tape	

Perceived stability on stair descent with no tape (please circle one response)

Very unstable Unstable Neither stable nor unstable Stable Very stable

Perceived stability on stair descent with un-tensioned tape (please circle one response)

Very unstable Unstable Neither stable nor unstable Stable Very stable

Perceived stability on stair descent with tensioned tape (please circle one response)

Very unstable Unstable Neither stable nor unstable Stable Very stable

Participant Code:

Researcher:

Signature:

Date:

Appendix 14

UNIVERSITY OF CENTRAL LANCASHIRE

Targeted Intervention for Patellofemoral Pain Syndrome

TIPPS

Therapist Manual

Grant Reference: 19950

INTRODUCTION

This manual should be used in conjunction with the therapist recording sheets and is designed to assist you in collecting standardised data for this research project. If you have any questions please do not hesitate to contact

James Selfe at UCLan on 01772 894571 jselfe1@uclan.ac.uk

Prior to starting the assessment please double check the study eligibility and then ensure that the patient is wearing shorts. This will help their legs adjust to room temperature which is important later. Please also check the patient is eligible to take part in study using the criteria listed below.

Inclusion criteria: based on Syme et al (2009) & Cook et al (2010)

Males and females age 18-39 years able to give informed written consent
Clinical diagnosis of unilateral or bilateral patellofemoral pain longer than three months
Willing to attend a physiotherapy clinic for a research assessment
Anterior or retropatellar pain reported on at least two of the following activities: prolonged sitting, ascending or descending stairs, squatting, running, kneeling, and hopping/jumping
In addition to the above, at least two of the three following clinical examination findings: • pain during resisted isometric quadriceps contraction • pain with palpation of the medial & lateral facets of the patella • pain during squatting

Exclusion criteria: based on Syme et al (2009)

Previous knee surgery & subjects awaiting surgery for another lower limb joint problem(s).
Ligamentous instability and/or internal derangement. Subjects should be referred for arthroscopy or Magnetic Resonance Imaging (Acton and Craig 2000)
History of patella subluxation or dislocation
Joint effusion when the mid-patellar girth is 5% or more than the non involved knee
True knee joint locking and/or giving way
Coexistent acute illness or chronic disease
Bursitis, patella or iliotibial tract tendinopathy, Osgood Schlatter's disease, Sinding-Larsen Johansson Syndrome, muscle tears or symptomatic knee plicae
Subjects already involved in active lower limb training programs.
Pregnancy or breast feeding.

Please note the therapist recording sheets are divided into 3 sections. Sections 1&3 should be completed by the physiotherapist. Section 2 should be completed by the patient.

Patient characteristics**:** The first page of the recording sheets focus on information that will help to describe whether the patients in this study are similar to those in other studies. <u>When a patient has bilateral patellofemoral pain, the most affected side must be considered when filling in the recording sheets.</u>

There then follows a series of 8 brief questionnaires (estimated time to complete: 15-20mins) that may also help us to understand differences between potential sub-groups. Previous studies have used some of these tools and suggest that patellofemoral patients have higher than expected levels of disability associated with activity limitation, however no other study has attempted to systematically investigate these issues in the comprehensive manner proposed here.

Numeric Pain Rating Scale (NPRS): Commonly used to assess baseline pain and response to intervention. NPRS has widely been used in PFP studies.

International Physical Activity Questionnaire (IPAQ): This is a well recognised tool for assessing activity.

Modified Functional Index Questionnaire (MFIQ): A PFP specific index consisting of 10 closed-ended questions; developed using an NHS population of patients. The MFIQ assesses two domains pain and function during the previous 24hours.

Short-Form McGill Pain Questionnaire-2 (SF-MPQ-2): Measures the major symptoms of both neuropathic and non-neuropathic pain.

Leeds Assessment of Neuropathic Symptoms and Signs (S-LANSS): The S-LANSS identifies pain of predominantly neuropathic origin, as distinct from nociceptive pain, without the need for a clinical examination.

World Health Organisation Disability Assessment Scale (WHODAS 2.0): Provides a generic assessment of health and disability.

EQ-5D-5L: Is a standardised health measurement instrument often used to assess the outcome of an intervention. We are thinking of using this in a later phase of this research programme so are initially testing it here.

Hopkins Symptom Checklist-25 (HSCL-25): Is a symptom inventory which measures symptoms of anxiety and depression.

The Movement Specific Reinvestment Scale: Measures the propensity for movement-related self-consciousness and for conscious processing of movement.

Self-reported indicators of cold knees: PFP patients with cold knees appear to form a distinct ischaemic sub-group with differing characteristics to those without cold knees. The cold knees of this group are not wholly explained by variations in ambient temperature (question 1) and seem to be a local problem not associated with general circulatory disturbance of the lower limb (question 2). The questions in this survey focus on the knee for which the patient is seeking attention for.

Leg Length

Clinical test: Leg Length Measurement (Beattie et al 1990)

Equipment required: Tape measure

Subject position: Subject in supine lying with the legs extended in the neutral anatomical position with feet near mid-line

Therapist procedure: Leg Length Measurement

Stand on the side which you are about to measure and position the subject's lower extremities in neutral hip rotation with the medial malleoli together so that they meet in approximately the mid-line of the body. Position one end of the tape measure on <u>the inferior portion of the ASIS</u>. Guide the tape measure down the anteromedial aspect of the subject's thigh, patella, and lower leg until the point where the <u>medial malleolus slopes inferiorly and laterally</u>. Hold the tape measure taut and record the value in centimetres (Fig 1).

Fig 1:

Ischaemia

Clinical tests: Digital thermometry of skin temperature and skin fold thickness using callipers

Equipment required: Digital thermometer, Room Thermometer, Skin fold callipers, Tape measure

Subject position: Subject in supine lying with the legs extended in the neutral anatomical position

Therapist procedure: Temperature measurement.

(i) Locate the centre of the patella and mark the skin at this spot. Place tip of digital thermometer over centre of patella (Fig 2) and record skin temperature. Repeat this three times on each side.

(ii) Locate the muscle belly of tibialis anterior 10 cm distal to the tibial tubercle and 2cm lateral to the anterior border of the tibia (Fig 3) and mark this spot. Place tip of digital thermometer over this spot. Record skin temperature and repeat this three times on each side.

(iii) Record ambient room temperature

Fig 2: Centre of Patella

Fig 3: Tibialis Anterior muscle belly

Therapist procedure: Skin fold measurement

A horizontal patella skin fold is measured over the centre of the patella with the knee in full extension. With the dominant hand grasp the skin fold at 90 degrees to the long axis of the leg between thumb (superior) and index finger (inferior) and take the measurement using the skin fold callipers in the non-dominant hand (Fig 4). If the measurement is in the middle of two data points (eg 3 or 4 mm) take the highest number. Repeat this three times on each side and please ensure the patient flexes their knee between each measurement.

Fig 4: Skin fold measurement

Use of digital inclinometer: The inclinometer (Fig 5) can give readings in Degrees, Slope % or pitch make sure it is reading degrees by pressing the ^{O}%IN/FT button. The inclinometer will have been supplied to you with a battery installed and already calibrated, if the battery needs replacing or there is an issue with calibration, for example if the inclinometer has been accidentally dropped then please contact me.

The inclinometer reads and records angles between 0 degrees and 90 degrees; it will provide an audible alarm when either of these 2 positions are attained if the speaker button is switched on. When any of the target angles/positions have been reached press the hold button, which will lock the display which makes it much easier to read and then record the display. When attaching the inclinometer to the subject ensure the base is in contact with the medial border of the tibia.

Fig 5: Base (surface with line) and front (surface with control buttons) view of the digital inclinometer

Lower Limb Biarticular Muscle Tightness

Quadriceps

Clinical test: Prone Knee bend method (Witvrouw et al 2000)

Equipment required: Digital inclinometer, strapped to medial side of shin

Starting position: The subject lies prone and the foot on the non-involved side is placed on the floor in a 90 degree hip flexion position (Fig 6). The tested leg is positioned with the knee at 90 degrees of knee flexion (Fig 7). In this position the digital inclinometer will read approximately 90 degrees. Instruct the subject to verbalise when he/she is experiencing pain or discomfort at the front of the leg or in the knee.

Procedure: The knee is passively maximally flexed by the therapist (Fig 8). End position is reached when the patient is feeling pain or discomfort at the front of the leg or in the knee. The angle of the tibia at the maximum knee flexion angle is recorded using the digital inclinometer. Note that as the heel moves towards the buttock the angle being read by the inclinometer will reduce from 90 towards zero, therefore the nearer to zero the inclinometer reading the more flexible the quadriceps. Repeat this three times.

Fig 6: Patient starting position

Fig 7: Therapist starting position

Fig 8: Therapist finish position

Lower Limb Biarticular Muscle Tightness

Hamstrings

Clinical test: Passive knee extension method (adapted from Youdas et al 2005)

Equipment required: Stabilisation strap, Digital inclinometer, strapped to medial side of shin

Starting position: The subject lies supine on a plinth. The lower limb not being tested is positioned in hip neutral and knee extension and strapped to the plinth. The strap is positioned approximately 10 cm proximal to the patella.
The therapist positions the hip and knee of the tested side in 90° of flexion, thus marking the starting position for the test (Fig 9). In this position the digital inclinometer will read approximately zero. Instruct the subject to verbalise when he/she is experiencing pain or discomfort at the back of the leg or in the knee.

Procedure: With 1 hand supporting the participant’s distal thigh and the other hand cupping the heel, the therapist passively extends the knee until firm resistance is elicited or the patient is feeling pain or discomfort at the back of the leg or in the knee. (Fig 10). At this point the angle of the tibia is recorded with the digital inclinometer. During this manoeuvre the reading on the inclinometer will increase from zero degrees towards 90 degrees, therefore the closer to a reading of 90 degrees the more flexible the hamstrings. Repeat this three times.

Fig 9: Starting position

Fig 10: End position

Lower Limb Biarticular Muscle Tightness

Gastrocnemius

Clinical test: Standing method (Witvrouw et al 2000)

Equipment required: Tape measure, Digital inclinometer, strapped to shin

Starting position: The subject leans on a solid support 0.6m away with the tested leg parallel with and posterior to the non-involved leg, so that the toes of the tested leg are level with the heel of the non-involved leg (Fig 11). In this position the inclinometer will read approximately 90 degrees. Instruct the subject to verbalise when he/she is experiencing pain or discomfort at the back of the leg or in the knee.

Procedure: Keeping the knee of the tested leg extended the subjects are instructed to maximally flex their tested ankle while keeping their heel on the floor. To ensure the heel does not lift a piece of paper can be placed under the heel which the therapist should not be able to remove (Fig 12). End position is reached when the patient is feeling pain or discomfort at the back of the leg or in the knee or when patient lifts his/ her heel. The angle of the tibia is measured relative to vertical with a digital inclinometer. During the manoeuvre as the subject flexes their ankle the reading will decrease towards zero therefore the lower the number recorded the more flexible the gastrocnemius. Repeat this three times.

Fig 11: Starting position

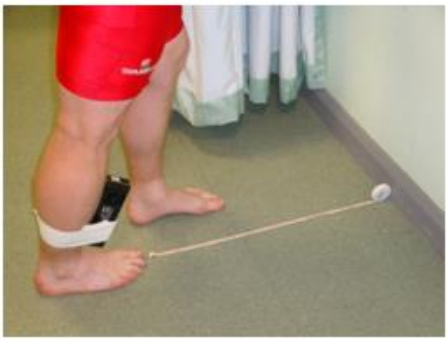


Fig 12: End position

Limb Muscle weakness

Quadriceps

Clinical test: Portable dynamometry

Equipment required: Tape Measure, Hand Held Dynamometer (HHD), Stabilisation Strap

Starting position: Subject in a seated position over the side of a plinth with the knee flexed at 90 degrees and the HHD mounted under the stabilisation strap positioned <u>perpendicular</u> to the tibia just proximal to the malleoli (Fig 13).

Subject procedure: The subject is instructed to apply a maximum force against the HHD. This is recorded by the HHD in Kilograms (Kg). Subjects can hold the sides of the plinth for their stability when extending the knee. Three measurements are required to later calculate the average. A rest period of 20s should be allowed between each test.

Therapist procedure: To record the length of the moment arm the therapist records the distance in metres (m) from the level of the HHD on the tibia to the centre of the knee joint (assumed to coincide with the most prominent point on the femoral epicondyle identified via palpation) (Fig 14).

Fig 13: HHD position measurement

Fig 14: Therapist

Lower Limb Muscle weakness

Hip Abductors

Clinical test: Portable dynamometry

Equipment required: Tape Measure, Hand Held Dynamometer (HHD), Stabilisation Strap

Starting position: Subject in side lying with the legs in the neutral anatomical position and the HHD mounted under the stabilisation strap positioned perpendicular to the side of the leg at a level just above the knee joint (Fig 15).

Subject procedure: The subject is instructed to ensure their toes are pointing horizontally during the contraction and then they will be asked to abduct their leg sideways towards the ceiling to apply a maximum force against the HHD. This force is recorded by the HHD in Kilograms (Kg). Three measurements are required to later calculate the average. A rest period of 20s should be allowed between each test.

Therapist procedure: To record the length of the moment arm the therapist records the distance in metres (m) from the adduction/abduction axis of the hip joint, (level with the proximal part of the greater trochanter) to the level of the HHD on the thigh (Fig 16).

Fig 15: HHD position measurement

Fig 16: Therapist

Local Patellar Factors

Clinical test: Total manual medial and lateral displacement of the patella (Witvrouw 2005)

Equipment required: Tape measure and pen

Starting position: Supine lying with the quadriceps relaxed and the knees in extension.

Procedure: The therapist will apply a medially directed force to the lateral border of the patella and the maximum displacement of the pole of the patella marked on the skin with a pen. This will be followed by a laterally directed force to the medial border of the patella and the maximum displacement of the pole of the patella marked on the skin with a pen (Fig 17).

Measurement: The distance between medial displacement skin mark and the lateral displacement skin mark will be recorded in mm to give the total displacement of the pole of the patella in the coronal plane (Fig 18).

Fig 17: Skin marking displacement of the pole of the patella

Fig 18: Measurement of total patellar displacement

Distal (Foot) Factors

Problem: Foot Pronation

Clinical test: Foot Posture Index (FPI) (Redmond 1998)

(Reproduced with permission of Anthony Redmond 2010)

Test Threshold: A pronation score of +7 or more

Individual test items:

1. Talar head position
2. Supra and infra lateral malleolar curvature
3. Calcaneal frontal plane position
4. Prominence in the region of the talonavicular joint
5. Congruence of the medial longitudinal arch
6. Abduction/adduction of the forefoot on the rearfoot

Equipment required: Ruler

Starting position: Relaxed standing in double limb support

Calculation: Each foot should be scored independently. Each of the component tests or observations are graded 0 for neutral, with a score of -2 for clear signs of supination, and +2 for positive signs of pronation. Unless the criteria outlined for each of the features are clearly met then the more conservative score should be awarded. When the scores are combined, the aggregate value gives an estimate of the overall foot posture. High positive aggregate values indicate a pronated foot posture, significantly negative aggregate values indicate a supinated overall foot posture, while for a neutral foot the final FPI aggregate score should lie somewhere around zero.

1. Talar Head Palpation

(Palpation for talo-navicular congruence)

This is the only scoring criterion that relies on palpation rather than observation. The head of the talus is palpated on the medial and lateral side of the anterior aspect of the ankle, according to the standard method described variously by Root, Elveru and many others. Scores are awarded for the observation of the position as follows.

Diagram showing the position of the fingers when palpating of the head of the talus. The circles indicate the precise point of palpation on the medial and lateral side.

Score	-2	-1	0	1	2
	Talar head palpable on lateral side but not on medial side	Talar head palpable on lateral side/slightly palpable on medial side	Talar head equally palpable on lateral and medial side	Talar head slightly palpable on lateral side/ palpable on medial side	Talar head not palpable on lateral side but palpable on medial side

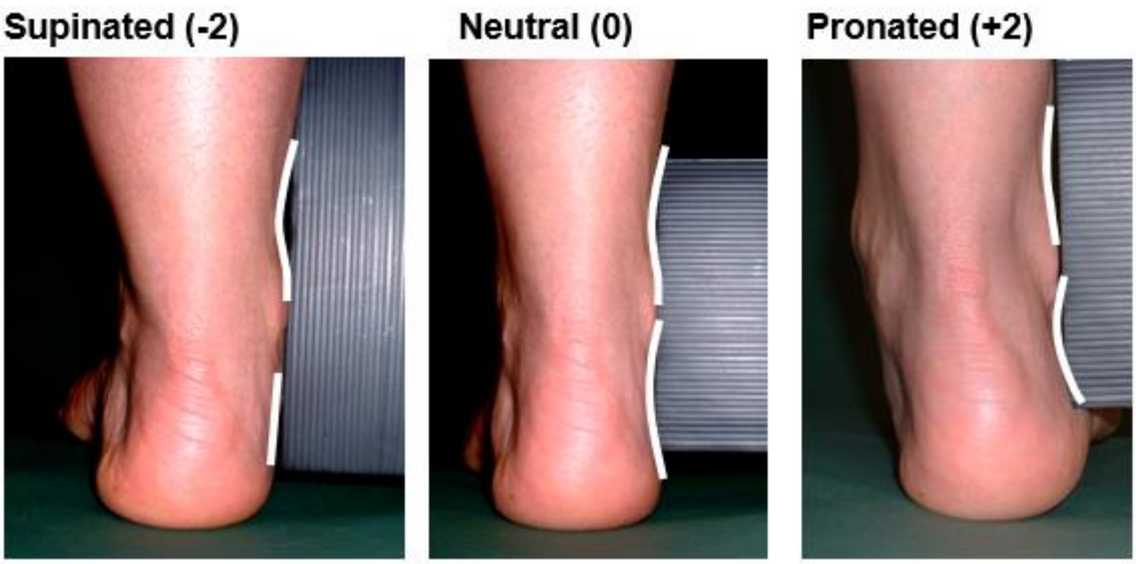
Clinical note: This is not an attempt to determine the so-called subtalar neutral position. For the FPI measure the subtalar joint is not manipulated into the position where the head of the talus is in maximal congruence with the navicular. For the FPI measure the head of the talus is simply palpated in the relaxed stance position and the talar head orientation reported.

It may however be useful in some cases to move the foot into inversion and eversion while palpating for the talar head as this can aid in determining wether the head is still palpable in individuals on the border between 1&2 or –1&-2.

2. Supra and infra lateral malleolar curvature

(Observation and comparison of the curves above and below the lateral ankle malleoli)

In the neutral foot it has been suggested that the curves should be approximately equal. In the pronated foot the curve BELOW the malleolus will be more acute than the curve above due to the abduction of the foot, and eversion of the calcaneus. The opposite is true in the supinated foot.



Score	-2	-1	0	1	2
	Curve below the malleolus either straight or convex	Curve below the malleolus concave, but flatter/ more shallow than the curve above the malleolus	Both infra and supra malleolar curves roughly equal	Curve below malleolus more concave than curve above malleolus	Curve below malleolus *markedly* more concave than curve above malleolus

Clinical note 1: For estimating malleolar curvature, it may be helpful to use a straight edge for reference. This can be a set square, ruler or even a pen according to availability.

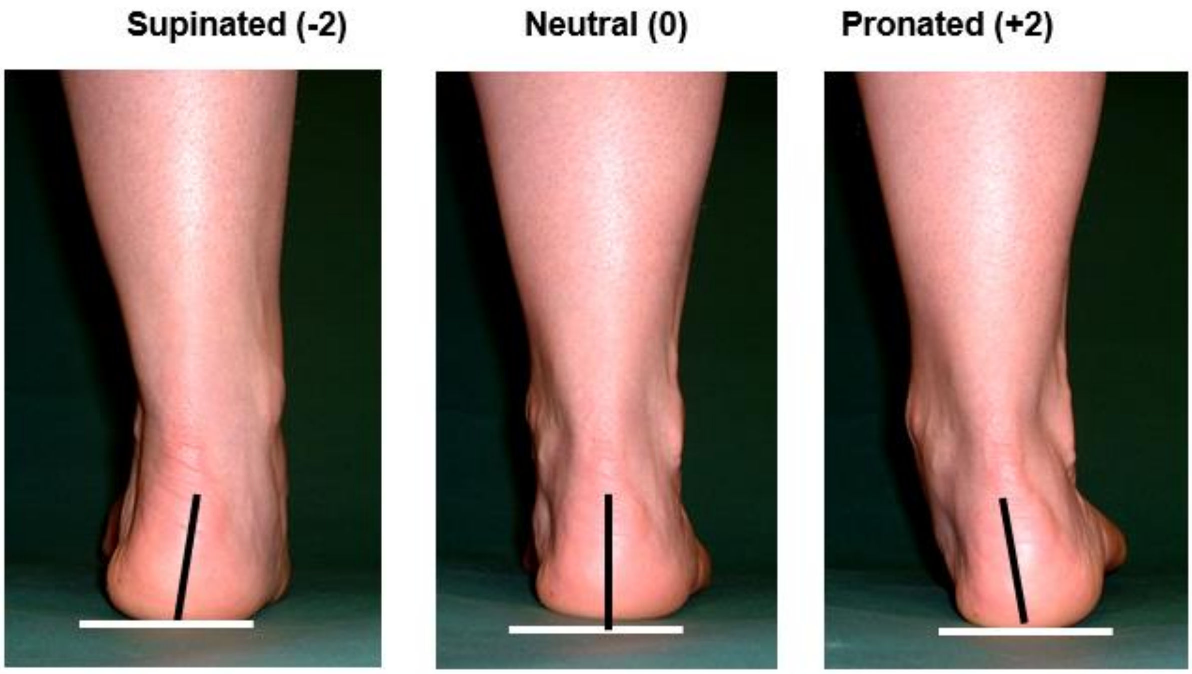
Clinical note 2: Where oedema or obesity obscures the curvature this measure should be either scored at zero or removed from the assessment and indicated as such.

3. Calcaneal frontal plane position

(Inversion / eversion of the calcaneus)

This is an observational equivalent of the measurements often employed in quantifying the relaxed and neutral calcaneal stance positions. With the patient standing in the relaxed stance position, the posterior aspect of the calcaneus is visualised with the observer in line with the long axis of the foot.

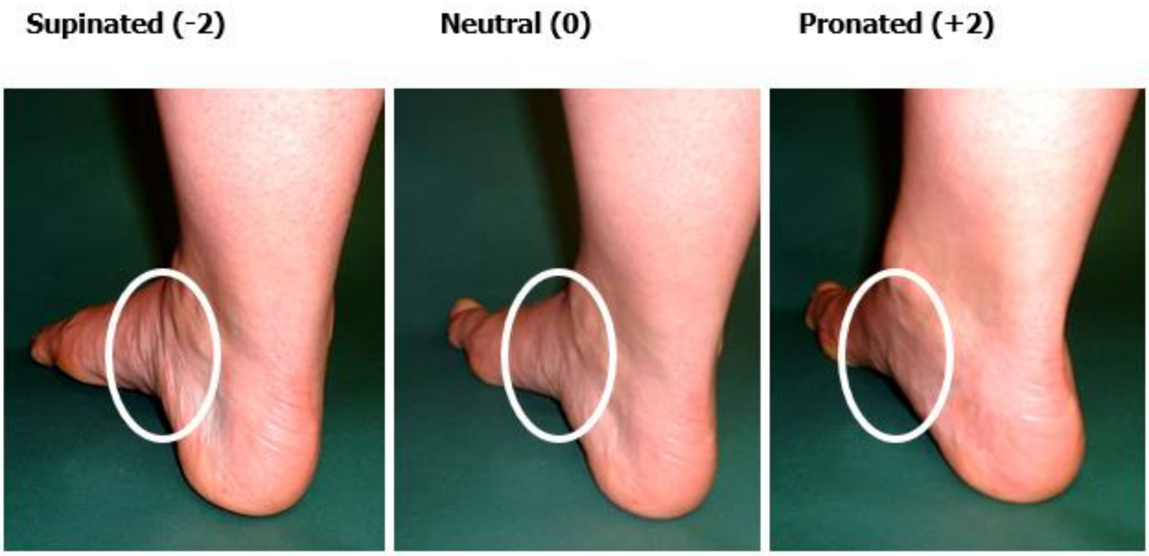
Angular measurements are not required for the FPI, the foot is graded according to visual appraisal of the frontal plane position.



Score	-2	-1	0	1	2
	More than an estimated 5° inverted (varus)	Between vertical and an estimated 5° inverted (varus)	Vertical	Between vertical and an estimated 5° everted (valgus)	More than an estimated 5° everted (valgus)

4. Bulging in the region of the talo-navicular joint (TNJ)

In the neutral foot the area of skin immediately superficial to the TNJ will be flat. The TNJ becomes more prominent if the head of the talus is adducted in rearfoot pronation. Bulging in this area is thus associated with a pronating foot. In the supinated foot this area may be indented



Score	-2	-1	0	1	2
	Area of TNJ markedly concave	Area of TNJ slightly, but definitely concave	Area of TNJ flat	Area of TNJ bulging slightly	Area of TNJ bulging markedly

Clinical note: Bulging of the TNJ area is a common finding in pronated feet. However, true convexity of the area is usually only seen with highly supinated postures.

Unless there is a definite indentation, assigning negative scores to this observation should be undertaken judiciously.

5. Height and congruence of the medial longitudinal arch

While arch height is a strong indicator of foot function, the shape of the arch can also be equally important. In a neutral foot the curvature of the arch should be relatively uniform, similar to a segment of the circumference of a circle. When a foot is supinated the curve of the MLA becomes more acute at the posterior end of the arch. In the excessively pronated foot the MLA becomes flattened in the centre as the midtarsal and Lisfranc's joints open up.

This observation should be made taking both the arch height and the arch congruence into consideration

Neutral (0)

Supinated foot (-2)

Pronated foot (+2)

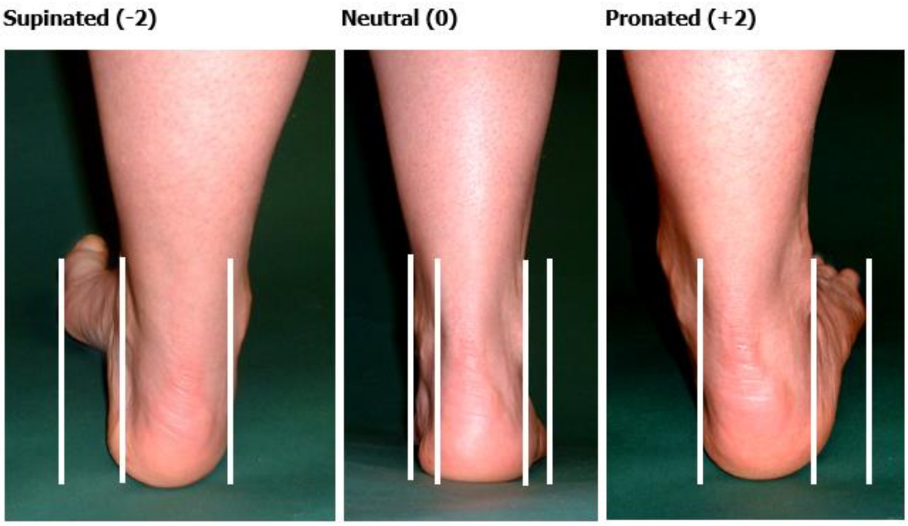
Clinical note: While simple arch height will usually be the more readily apparent of the two components of this measure, arch congruence is probably more subtle and informative.

Careful observation of the arch congruence should be the main element of this measure with arch height factored in secondarily.

Score	-2	-1	0	1	2
	Arch high and acutely angled towards the posterior end of the medial arch	Arch moderately high and slightly acute posteriorly	Arch height normal and concentrically curved	Arch lowered with some flattening in the central portion	Arch very low with severe flattening in the central portion – arch making ground contact

6. Abduction/ adduction of the forefoot on the rearfoot.
(Too many toes sign)
When viewed from directly behind, and in-line with the long axis of the **heel** (not the long axis of the whole foot), the neutral foot will allow the observer to see the forefoot equally on the medial and lateral sides. In the supinated foot the forefoot will adduct on the rearfoot resulting in more of the forefoot being visible

on the medial side. Conversely pronation of the foot causes the forefoot to abduct resulting in more of the forefoot being visible on the lateral side.



Score	-2	-1	0	1	2
	No lateral toes visible. Medial toes clearly visible	Medial toes clearly more visible than lateral	Medial and lateral toes equally visible	Lateral toes clearly more visible than medial	No medial toes visible. Lateral toes clearly visible

Clinical note: This measure should be treated with caution where there is a fixed adduction deformity of the forefoot on the rearfoot in the non-weight bearing state.

Normally it is possible to see the toes by the observer raising their angle of view slightly. If the toes are obscured by other structures the mtp joints or more proximal structures can be used as a guide