ANALYSIS OF THE VERTICAL GROUND REACTION FORCES IN SPORTS PARTICIPANTS WITH ADDUCTOR-RELATED GROIN PAIN: A COMPARISON STUDY

This thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Physiotherapy (Structured) OMT at Stellenbosch University

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Declaration Page

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Abstract

Objectives: The objective of this study was to describe the differences in vertical ground reaction forces (VGRF) in male sports participants with adductor-related groin pain, compared to matched asymptomatic controls.

Design: A descriptive observational study with cross-sectional time frame was conducted.

Setting: Laboratory based setting at the 3D Human Biomechanics Central Analytical Facility were implemented.

Participants: A consecutive sample of twenty-six active male sports participants, thirteen subjects with adductor-related groin pain (unilateral and bilateral) and thirteen matched asymptomatic controls were included.

Main Outcome Measures: Three outcome measures were used: time to peak landing force, peak landing force and time to lowest vertical position of the pelvis.

Results: Greater differences were seen in time to peak landing force and peak landing force in the unilateral pain group versus the matched controls. No statistical or clinical differences were found in either of the three outcome measures ($p>0.05$) between the subjects and their matched controls.

Conclusions: This study demonstrates similar VGRFs between subjects with and without chronic adductor-related groin pain and that changes in VGRF might not result from adductor-related groin pain. Clinically, teaching appropriate landing strategies to decrease VGRF may not be useful in male sports participants with chronic adductor-related groin pain.

Keywords: *groin pain, kinetics, landing, VGRF*

Opsomming

Doel: Die doel van hierdie studie was om veranderinge in vertikale grond reaksie-kragte (VGRK) te bepaal in manlike sport deelnemers met adduktor-verwante liespyn en dit te vergelyk met ‘n nie-symptomatiese kontrole groep.

Ontwerp: ‘n Beskrywende waarnemeingstudie is uitgevoer.

Omgewing: Labratorium-gebaseerde studie by die 3D Menslike Biomeganika sentrale analiserings fasiliteit is geimplementeer.

Deelnemers: ‘n Groep van ses-en-twintig aktiewe manlike sport deelnemers is agtereenvolglik gewerf. Die groep het bestaan uit dertien deelnemers (unilaterale en bilaterale) met adduktor-verwante liespyn en dertien ooreenstemmende, nie-simptomatiese kontroles.

Uitkomsmetings: Drie uitkomsmetings was gebruik: tyd tot pieklandingskrag, pieklandingskrag en tyd tot die laagste vertikale posisie van die pelvis.

Resultate: Groter verskille is waargeneem in tyd tot pieklandingskrag en pieklandingskrag in die unilateral pyn groep in vergelyking met die ooreenstemmende kontrole groep. Geen statistiese of kliniese verskille is gevind tussen die twee groepe in enige van die drie uitkomsmetings nie ($p>0.05$).

Gevolgtrekking: Hierdie studie toon ooreenstemmende VGRK tussen deelnemers met en sonder adduktor-verwante liespyn en dat veranderinge in VGRK moontlik nie ‘n resultaat is van adduktor-verwante liespyn nie. Klinies impliseer dit dat die aanleer van effektiewe landings stratigieë om VGRK te verminder nie van waarde mag wees in manlike sportdeelnemers met adduktor-verwante lies pyn nie.

Sleutel woorde: *liespyn, kinetika, landing, VGRK*

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List of abbreviations

3D	Three Dimensional
ACL	Anterior Cruciate Ligament
CAF	Centre analytical facilities
Cm	Centimeter
EMG	Electromyography
FAI	Femoral Acetabular Impingement
FP	Force Plate
GRF	Ground Reaction Force
Hz	Hertz
Kg	Kilogram
LF	Landing Force
N	Newton
NSAIDS	Non-steroidal Anti-inflammatory Drugs
ROM	Range of Motion
SD	Standard Deviation
SIJ	Sacroiliac Joint
VAS	Visual Analog Scale
VGRF	Vertical Ground Reaction Force

List of definitions

Kinetics	"A push or a pull exerted by one object or substance on another" (Norkin & Levangie 2011)
Kinematics	"The displacement (change in position over time) or motion of a segment without regard to the forces that cause the movements" (Norkin & Levangie 2011)
Newton's Third Law	For every contact force one object exerts on a second object, there is an equal and opposite force acting on the second object. The size of the force on the one object, equals the size of the force on the other object (Reiser et al., 2006)
Ground Reaction Forces	The forces being applied to the foot by the ground when a person makes contact with the ground. (Norkin and Levangie 2011)

CHAPTER 1: Introduction

Groin pain in athletes is a major concern in sports medicine (Hölmich, Larsen, Krogsgaard & Gluud 2010). Groin-related injuries have a high recurrence rate and can lead to prolonged symptoms (Hölmich, Thorborg, Dehlendorff, Krogsgaard & Gluud 2014) and time away from sport (Almeida, Silva, Andriolo, Atallah & Peccin 2013). Soccer, rugby and ice hockey are listed as the sporting activities that typically cause long-standing groin injuries (Paajanen, Ristolainen, Turunen & Kujala 2011). Amongst rugby players, the risk of a player sustaining a groin injury is 23% per season (O'Connor, 2004) and in soccer, groin injuries account for 12–16% of all seasonal injuries (Werner, Hägglund, Waldén & Ekstrand 2009). Overuse is considered the main cause for groin injuries (Sedaghati, Alizadeh, Shirzad & Ardjmand 2013), but often multiple causal factors, including age and repeated injury, can be identified (Hölmich et al., 2010). Recurrent groin injuries result in a significantly longer absence from sport compared to first-time injures (Werner et al., 2009). If groin pain becomes chronic, it is more difficult to successfully treat (Weir, Jansen, van de Port, Van de Sande, Tol & Backx 2011).

The groin region has a complex anatomy and consists of a large number of potential pain-generating structures (Serner, van Eijck, Beumer, Hölmich, Weir & de Vos 2015). Possible structures resulting in groin pain include the hip joint, the sacroiliac joint, the obturator nerve, the iliopsoas muscle and the adductor longus muscle (LeBlanc & LeBlanc 2003; Hölmich, 2007; Paajanen et al., 2011; Drew et al., 2014). Inadequate differential diagnosis and confusion with regards to the clinical presentation of different types of groin pain can result in inappropriate management and re-injury (Drew, Osmotherly & Chiarelli 2014). Common clinical tests have been proven to be reliable in differentiating between different groin pathologies (Drew et al., 2014). Groin pain resulting from a strain to the adductor longus muscle is the most common cause of groin pain compared to all other causes of groin injuries (Hölmich et al., 2014).

The typical clinical presentation of adductor-related groin pain is described as pain that is located at the proximal attachment of the adductor muscles on the pubic bone during sporting activities (Hölmich, 2007), pain that can be reproduced on palpation of the proximal attachment of the adductor muscles (Weir et al., 2011) and pain with resisted adduction (Hölmich, Hölmich & Bjerg 2004; O'Connor, 2004). The function of the adductor muscle group is adduction of the hip in an open kinematic chain motion and stabilisation of the lower extremity and pelvis in a closed kinematic chain motion. The adductor longus has been identified as the most commonly injured muscle of the adductor group (Tyler, Silvers, Gerhardt & Nicholas 2010). Weakness of the adductor muscle group has been linked to being a risk factor for the development of chronic groin pain (Maffey & Emery 2007).

A prospective study demonstrated that restricted overall hip range of motion may be a risk factor for the development of chronic groin injury (Verrall, Slavotinek, Barnes, Esterman, Oakeshott & Spriggins 2007). Other risk factors include previous injury (Hölmich et al., 2014), greater abductor-to-adductor strength ratios and decreased levels of pre-season sport-specific training (Maffey & Emery 2007). It is proposed that modifiable risk factors can be addressed and altered to reduce injury rate through the implementation of injury prevention strategies (Maffey & Emery 2007; Hölmich et al., 2010; Esteve, Rathleff, Bagur-Calafat, Urrútia & Thorborg 2015). In an attempt to decrease the amount of groin injuries the risk factors, mechanisms of injury and play situations need to be addressed (Paajanen et al., 2011). Preventing these types of injuries would be beneficial for athletes, as treatment may take months and can be costly (Hölmich et al., 2010).

There is currently moderate evidence for both conservative and surgical treatment of athletes with chronic adductor-related groin pain (Serner et al., 2015). Although Almeida *et al.,* (2013) concluded that evidence for the conservative treatment of chronic adductor-related groin pain is insufficient to decide on any specific conservative modality, they found that strengthening of hip and abdominal muscles may improve short-term outcomes and return to sport. Serner *et al.,* (2015) suggested that there is moderate evidence that active exercises improved treatment success compared to passive treatments and that adding manual therapy techniques can shorten the time to return to sport when compared to only using active exercise therapy. Injury prevention strategies are also being implemented with the emphasis on strengthening and coordination exercises of the adductor and abdominal muscles (Esteve et al., 2015), but no significant preventative program has been identified (Van Beijsterveldt, van de Port, Krist, Schmikli, Stubbe, Frederiks & Backx 2012; Esteve et al., 2015).

Observation of injury mechanisms or risk factors relating to groin strain injury have not been thoroughly identified so that injury prevention strategies can be scientifically implemented and evaluated (Maffey & Emery 2007). Many sporting activities require landing following a jump and is considered as an essential motor skill (Reiser, Rocheford & Armstrong 2006). During a sporting activity, bilateral landing during a jump results in peak forces and produces a large amount of stress in the joints of the lower limbs (Ortega, Bies & De La Rosa 2010). These forces during landing have been implicated as potential risk factors for injury in the lower limb (McNair, Prapavessis & Callender 2000; Ortega et al., 2010). Maffey & Emery (2007) suggested that a large percentage of groin pain may actually be due to inadequate absorption of vertical ground reaction forces (VGRF) through eccentric attenuation of the knee muscles during the landing phase. VGRF during landing can be a determining factor of injury, especially if frequent jumps occur and the ground reaction forces (GRF) are high (McNair, Prapavessis & Callender 2000).

To be able to land in a stable and balanced position from a jump, muscle activity must be generated and coordinated by the three major lower limb joints (McNair et al., 2000). During a jump the interaction between muscle recruitment, kinematics and kinetics are complex (Reiser et al., 2006) and it is proposed that VGRF can be increased or decreased by muscle and joint activity (McNair et al., 2000). During training it is common in many sports to perform loaded and unloaded jumps to increase height and explosive strength, however not many athletes are trained on how to land during jumps (Ortega et al., 2010).

It has been suggested that the overuse of the groin area results from an alteration in motor control strategies for load transfer between the pelvis and lower limbs (Morrissey et al., 2012). Morrissey *et al.,* (2012) found significant reductions in the activation ratio of gluteus medius and adductor longus muscles in football players with chronic adductor-related groin pain during standing hip flexion on the weight bearing leg. These biomechanical changes can have an effect on the VGRF (McNair et al., 2000).

Several studies have focussed on VGRF in other pathologies in relation to forces applied to the lower limbs. (Hewett et al., 2005). Measurements derived from GRF provide a means of quantifying bilateral symmetry in limb loading (McCrory, White & Lifeso 2001). Hewett *et al.,* (2005) demonstrated that female athletes who sustained an anterior cruciate ligament (ACL) injury had a 20% higher peak VGRF and Caulfield & Garrett (2004) found important changes in timing of peak VGRF in subjects with functional instability of the ankle joint compared to asymptomatic controls. These findings can lead to repeated injury due to significant increases in stress on the ankle joint and suggested that they are most likely to result from deficits in feed-forward motor control (Caulfield & Garrett 2004). To date, no studies have been conducted to explore the VGRF in sports participants presenting with chronic adductor-related groin pain. The purpose of this study was to explore the VGRF in active soccer and rugby players with chronic adductor-related groin pain compared to asymptomatic controls.

CHAPTER 2: Literature review

2.1 Introduction

The following literature review aims to provide an overview of current literature on chronic groin pain in sports participants. The prevalence, differential diagnosis, risk factors, and treatment of groin pain will be reviewed. The effect of vertical ground reaction forces (VGRF) on the lower kinematic chain during double leg jump will also be investigated.

The following Stellenbosch University electronic databases were searched for relevant articles: *PubMed, Google Scholar, PEDro, Science Direct, Scopus, Cinahl* and *Cochrane*. Search terms in different combinations included: "*groin pain", "chronic groin pain", "adductor-related", "ground reaction forces", "biomechanics", "kinematics", "kinetics", "jumping", "double-leg jump", "landing", "lower limb biomechanics", "soccer", "rugby", "sport injuries", "prevention strategies", "force plate", "three-dimensional motion analysis"* and *"prevalence"*. The literature review was conducted between February 2014 and September 2015.

2.2 Groin injuries in sport

Groin injuries are particularly common in sports that require kicking, running and sharp cutting movements (LeBlanc & LeBlanc 2003; Paajanen et al., 2011). Soccer, being a sport that involves repeated kicking and change of direction places great stress upon the adductors resulting in an increased risk of these muscles being injured (Hölmich et al., 2014).

Groin-related injuries have a high recurrence rate and can lead to prolonged symptoms (Hölmich et al., 2014) and time away from sport (Almeida et al., 2013). Soccer, rugby and ice hockey are listed as the sporting activities that typically cause long-standing groin injury (Paajanen et al., 2011). In a prospective study by O'Connor, (2004), one-hundred asymptomatic rugby league players were monitored over a two year period; the risk of sustaining a groin injury was reported as 23% per season. A prospective study conducted over seven consecutive years on professional soccer players showed 12-16% of all injuries per season is groin-related with adductor-related injuries being the most prevalent (three-quarter of all injuries) followed by iliopsoas muscle injuries (Werner et al., 2009). Both acute and chronic groin injuries are more common in male than female players (Paajanen et al., 2011).

Sports-related groin injuries can be placed into two main categories: acute groin injuries and chronic groin pain (Werner et al., 2009). Acute groin injuries are fairly common in sports-related activities and it is estimated that one out of ten soccer players will sustain an acute injury per season (Paajanen et al., 2011). Acute injuries generally have a good prognosis and are expected to resolve within 4-6 weeks of conservative management (LeBlanc & LeBlanc 2003; Arnason, Sigurdsson, Gudmundsson, Holme, Engebretsen & Bahr 2004). Acute injuries do not always develop into a chronic disorder (Paajanen et al., 2011), but if the groin pain persists and becomes chronic, it is more difficult to treat (Weir et al., 2011)

2.3 Differential diagnosis of chronic groin pain

Determining the exact cause of groin pathology in athletes presenting with on-going complaints of groin pain may be more difficult due to the lengthy differential diagnosis possibilities (LeBlanc & LeBlanc 2003). The groin region has a complex anatomy and consists of a large number of potential pain-generating structures (Serner et al., 2015). The complexity of this region and its overlapping anatomy and interdependence of structures imply that the diagnosis cannot be confirmed by only using one specific clinical test (Drew et al., 2014). Inadequate differential diagnosis and confusion with regards to clinical presentation of groin pain is likely to result in inappropriate management and re-injury for athletes (Drew et al., 2014).

Adductor-related groin injuries have been shown to be the most common of all groin injuries (Werner et al., 2009; Hölmich et al., 2014). However in recent years femoral acetabular impingement (FAI) and labral tears have gained interest as a potential source for groin pain (Werner et al., 2009). FAI is an intra-articular pathology and occurs when a bony abnormality of the proximal femur or acetabulum causes damage to the acetabular labrum and articular cartilage in the hip (Philippon, Schenker, Briggs & Kuppersmith 2007). FAI presents primarily as groin pain and effects sporting abilities, but impingements tests were found to be 99% sensitive to distinguish FAI from other groin injuries (Philippon et al., 2007). Osteitis pubis is known to be an overuse injury of the pubic symphysis and presents as anterior and medial groin pain (Hiti, Stevens, Jamati, Garza & Matheson 2011). Currently the literature is not in agreement with the definition relating to the term osteitis pubis (Hölmich, 2007). Hiti et al., (2011) describes the aetiology of osteitis pubis as a bony stress injury, rather than an inflammatory disease and it is more accurate to describe the condition with the term "*pubic bone stress injury*". Specificity of the test to differentiate for osteitis pubis is unknown and it is suggested that it should rather be a diagnosis by the exclusion of other pathologies (Hiti et al., 2011).

Other possible structures resulting in groin pain include sacroiliac joint (SIJ) pathology, entrapment of the obturator nerve, sports-man's hernia (disruption of the posterior wall of the inguinal canal), inguinal hernia, the iliopsoas muscle, prostatitis or a stress fractures (Hölmich, 2007; Paajanen et al., 2011; Sedaghati et al., 2013; Drew et al., 2014). A review by Drew *et al.,* (2014) concluded that commonly used clinical tests are reliable and can guide treatment progression, but that more work is required to examine the properties of the currently used diagnostic test.

2.3.1 Adductor-related groin pain

If an adductor strain is treated improperly it can become chronic and possibly career threatening (Tyler et al., 2010). The adductor group consists of six muscles: the adductor longus, magnus and brevis, the gracilis, obturator externus and pectinius (Tyler et al., 2010). Of these, the adductor longus muscle is the most commonly injured muscle of the group with the lack of mechanical advantage making it more susceptible to strain (Tyler et al., 2010). The main function of the adductor muscle group is adduction of the hip in an open kinematic chain movement and to stabilise the lower limb and pelvis in a closed kinematic chain motion (Nicholas & Tyler 2002). Common symptoms arising from the adductor muscle group are pain and tenderness on palpation of the pubis symphysis and tubercle and/or tenderness of the adductor and abdominal muscles, as well as pain with resisted adduction (Hölmich et al., 2004; O'Connor, 2004).

2.4 Risk factors related to groin pain

Identifying individual risk factors for groin injury is an important basis for the development of preventative strategies and protocols (Arnason et al., 2004). Exact incidence of adductor muscles strains in most sports is unknown as sports participants often play through minor groin pains and the injury goes unreported, also overlapping diagnosis can skew the incidence (Tyler et al., 2010)

In a prospective study done by Hölmich *et al.,* (2014) that included 998 sub-elite male soccer players during a full 10-month season had shown that age (p=0.05) and previous groin injury (p=0.0068) were the most significant risk factors for sustaining a groin injury. Arnason *et al.,* (2004), in a study of 306 male soccer players also concluded that older players, between the ages of 29 to 38 years were significantly at higher risk for suffering a groin injury. The reason for older age being a risk factor for sustaining a groin injury is suggested to be due to the body's collagen tissue changes that renders the body less adaptable to quick force changes or fatigue (Hölmich et al., 2014).

A prospective study, where rugby players were monitored for two seasons, demonstrated that overall restriction of hip range of motion may also be a risk factor for the development of chronic groin injury (Verrall et al., 2007). Arnason *et al.,* (2004) further confirmed a decrease in hip range, especially in abduction, as a predictor for a new injury to the groin. Another identified risk factor is a greater abductor to adductor strength ratio (Tyler et al., 2010). In a review by Maffey & Emery (2007) which included 11 studies, there was consistent evidence that greater abductor to adductor strength ratios and previous injury were risk factors. They identified that a lack or decrease level of pre-season sport-specific training posed greater chances of sustaining a groin injury and there was some suggestion that core muscle weakness or a delay in onset of transverse abdominal muscle recruitment increases the risk of groin injury

The risk factors for sustaining a groin injury listed above, all have the potential to effect a sports participant's ability to attenuate forces when landing from a jump, thus suggesting that changes when landing from a jump, can occur.

2.5 Treatment for groin pain

Acute groin injuries are fairly common in sports-related activities and usually resolve within 4-6 weeks of conservative management (LeBlanc & LeBlanc 2003). Conservative management protocols include rest, ice and non-steroidal anti-inflammatory drugs (NSAIDs) (LeBlanc & LeBlanc 2003). Some injuries can result in longer rehabilitation time and may become chronic and be resistant to many treatment options such as active exercises and multimodal treatments (Serner et al., 2015).

2.5.1 Treatment for chronic adductor related pain

A systematic review by Serner *et al.,* (2015), showed moderate evidence for the treatment of adductor-related groin pain with active exercises compared to passive treatments, but that the inclusion of manual therapy techniques could shorten the time to return to sports. The authors included 72 studies with mainly soccer players, but also included rugby players. Only 6% of the studies were of high methodological quality. The studies with lower methodological quality generally obtained more favourable outcomes. The review confirmed a lack of consensus between researchers when it comes to the diagnosis of groin pain and that most studies included different treatments, thus they cannot support any single treatment option.

In a Cochrane review conducted by Almeida *et al.,* (2013) they reviewed two studies (Hölmich et al., 1999; Weir et al., 2011) for the treatment of adductor-related groin pain and found that the available evidence was insufficient to advise on a specific treatment option. The best evidence from one trial (Hölmich et al., 1999) supported the use of exercise therapy above any passive modalities. The authors also commented on the low evidence of the trials and concluded that future research on adductor-related groin pain should evaluate whether athletes demonstrate functional limitations during sporting activities and not only the presence of pain when they return to sport in an attempt to improved treatment strategies.

2.5.2 Preventative treatment programs

Esteve *et al.,* (2015) conducted a meta-analysis on data from preventative treatment protocols for groin injuries and reported a potential clinical reduction of 19% in sport-related groin injuries, but no statistical significant reduction could be noted. They included seven trials with a total of 4191 participants, who were mostly soccer players. All intervention programs were conducted over one season and included various protocols. Prevention protocols were mainly aimed at strengthening and eccentric training of the adductor muscles, balance and proprioception training and core strengthening. The authors concluded that future studies may need to consider prevention strategies other than those aiming only to improve hip and core strength and lower limb coordination such as early groin symptom identification and monitoring and managing the amount of load a player takes per season.

2.6 Vertical ground reaction forces and double leg landing

In recent literature, jump tests have been used to evaluate speed and power ability of athletes in a variety of sports (Mackala, Stodölka, Siemienski & Coh 2013). The double-leg jump can be defined as a complex series of ballistic multi-joint actions where the surrounding muscles of the hip, knee and ankle collectively work together to produce patterns of movement (Mackala et al., 2013). During the landing phase, at the moment of contact, the GRF builds up from zero, rising quickly to levels developed by countermovement and propulsion, before returning to body weight (Reiser et al., 2006). The combination of these peak forces and the high frequency of landing during sport, produce a large amount of stress in the joints of the lower limbs (Ortega, et al., 2010). The VGRF during the landing action is commonly used to examine various parameters including maximum force and time to maximum force (Walsh et al., 2006) and indicates the intensity and duration of stress that the body is subjected to during contact with the ground (Bressel & Cronin 2005).

Ortega *et al.,* (2010) differentiates between two types of jumps during bilateral landing, landing with flat feet and landing with the forefoot first and then making contact with the rear foot. Forefoot landing is more common when landings are made consciously and the VGRF here is smaller compared to flat feet landing. Different strategies has been proposed to decrease the impact forces during double leg landing (McNair et al., 2000). Effective strategies included instruction on how to land such as increasing the landing time (McNair et al., 2000). It is possible to increase landing time by increasing flexion at the hip, knee and ankles with proper coordination (Ortega et al., 2010). By flexing these joints, landing forces can be better absorbed compared to abruptly stopping the movement (Reiser et al., 2006).

2.7 Vertical ground reaction forces and sport

GRF has been used to quantify abnormal limb loading in individuals and provide indirect information about internal joint loading and can also give an indication to unequal limb loading (McCrory et al., 2001). VGRF has been studied in conjunction with the amount of stress placed on joints during landing (Ortega et al., 2010).

Large VGRF generated over a short period of time have been associated with an increase in anterior cruciate ligament (ACL) injury risk (Olsen, Myklebust, Engebretsen & Bahr 2004). In a study by Hewett *et al.,* (2005), they found that the peak VGRF were 20% greater in females who sustained ACL injuries than in uninjured females. Significant differences were detected in VGRF immediately post-impact in patients with chronic ankle instability in comparison to controls, suggesting deficits in feed-forward motor control of the ankle joint (Caulfield & Garrett 2004). Maffey & Emery (2007) suggested that a large percentage of groin pain may be due to inadequate absorption of VGRF through eccentric attenuation of the knee muscles during the landing phase. VGRF during landing can be a determining factor of injury, especially if frequent landings occur and the GRF are high (McNair et al., 2000).

2.8 Conclusion

Groin injuries are particularly common in sports that require kicking, running and sharp cutting movements (LeBlanc & LeBlanc 2003; Paajanen et al., 2011). Adductor-related groin injuries have been shown to be the most common of all groin injuries (Werner et al., 2009; Hölmich et al., 2014). The association between groin pain and lower limb biomechanical risk factors such as VGRF are still unclear. Measurements derived from GRF provide a means of quantifying bilateral symmetry in limb loading (McCrory et al., 2001) and unilateral groin pain or bilateral groin pain could influence this symmetry. To date, no studies exploring the VGRF in athletes presenting with adductor-related groin pain has been investigated. Therefore this study describes the VGRF in male, active sports participants presenting with chronic unilateral and bilateral adductor-related groin pain in comparison to matched asymptomatic controls.

CHAPTER 3: The Manuscript

This manuscript is to be submitted to the Physical Therapy in Sport Journal. The Journal guidelines are included in Appendix A.

ANALYSIS OF THE VERTICAL GROUND REACTION FORCES IN SPORTS PARTICIPANTS WITH ADDUCTOR RELATED GROIN PAIN: A COMPARISON STUDY

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Abstract

Objectives: The objective of this study was to describe the differences in vertical ground reaction forces (VGRF) in male sports participants with adductor-related groin pain, compared to matched asymptomatic controls.

Design: A descriptive observational study with cross-sectional time frame was conducted.

Setting: Laboratory based setting at the 3D Human Biomechanics Central Analytical Facility were implemented.

Participants: A consecutive sample of twenty-six active male sports participants, thirteen subjects with adductor-related groin pain (unilateral and bilateral) and thirteen matched asymptomatic controls were included.

Main Outcome Measures: Three outcome measures were used: time to peak landing force, peak landing force and time to lowest vertical position of the pelvis.

Results: Greater differences were seen in time to peak landing force and peak landing force in the unilateral pain group versus the matched controls. No statistical or clinical differences were found in either of the three outcome measures ($p>0.05$) between the subjects and their matched controls.

Conclusions: This study demonstrates similar VGRFs between subjects with and without chronic adductor-related groin pain and that changes in VGRF might not result from adductor-related groin pain. Clinically, teaching appropriate landing strategies to decrease VGRF may not be useful in male sports participants with chronic adductor-related groin pain.

Keywords: *groin pain, kinetics, landing, VGRF*

1. INTRODUCTION

Groin pain in athletes is a major concern in sports medicine (Hölmich, Larsen, Krogsgaard & Gluud 2010); these injuries have a high recurrence rate and can lead to prolonged symptoms (Hölmich, Thorborg, Dehlendorff, Krogsgaard & Gluud 2014) and time away from sport (Almeida, Silva, Andriolo, Atallah & Peccin 2013). Groin injuries are particularly common in sports that require kicking, running and sharp cutting movements (LeBlanc & LeBlanc 2003; Paajanen, Ristolainen, Turunen & Kujala 2011). Soccer, rugby and ice hockey are listed as the sporting activities most typically associated with long-standing groin injuries (Paajanen et al 2011). Amongst soccer and rugby players, groin injuries respectively account for 12% to 23% of all seasonal injuries (O'Connor, 2004; Werner, Hägglund, Waldén & Ekstrand 2009).

The groin region has a complex anatomy and consists of a large number of potential pain-generating structures (Serner, van Eijck, Beumer, Hölmich, Weir & de Vos 2015). Overuse of the adductor muscle group has been considered the main cause for groin injuries (Werner et al., 2009; Sedaghati, Alizadeh, Shirzad & Ardjmand 2013; Hölmich et al., 2014). The typical clinical presentation of adductor-related groin pain is pain located at the proximal attachment of the adductor muscles on the pubic bone during sporting activities, such as running or changing of direction (Hölmich, 2007). This pain can be reproduced on palpation of the proximal attachment of the adductor muscles (Weir, Jansen, van de Port, Van de Sande, Tol & Backx 2011) and with resisted adduction (Hölmich, Hölmich & Bjerg 2004; O'Connor, 2004).

Currently there is moderate evidence for both conservative and surgical treatment of athletes with chronic adductor-related groin pain (Serner et al., 2015). Injury prevention strategies are also implemented with the emphasis on strengthening and coordination exercises of the adductor and abdominal muscle groups (Esteve, Rathleff, Bagur-Calafat, Urrútia & Thorborg 2015), however no preventative program has shown to be effective (Van Beijsterveldt, van de Port, Krist, Schmikli, Stubbe, Frederiks & Backx 2012; Esteve et al., 2015).

Although weakness of the adductor muscle group, previous injury, a greater abductor-to-adductor strength ratio and decrease levels of pre-season sport-specific training have been identified as risk factors for the development of groin pain, the ineffective implementation of injury prevention strategies could be due to the lack in successfully identifying these risk factors (Maffey & Emery 2007; Hölmich et al., 2014). Many sport activities require landing following a jump and it is considered to be an essential motor skill (Reiser, Rocheford & Armstrong 2006). During a sporting activity, the landing phase of a jump results in peak vertical ground reaction forces (VGRF) and the combination of these forces and the frequency of landings, produces a large amount of stress in the joints of the lower limbs (Ortega, Bies & De La Rosa 2010). VGRF gives an indication of the amount and duration of stress that the body is subjected to during contact with the ground (Bressel & Cronin 2005). These forces have been implicated as potential biomechanical risk factors for injury in the lower limb (McNair, Prapavessis & Callender 2000; Ortega et al., 2010). Maffey & Emery (2007) suggested that a large percentage of groin pain may be due to inadequate absorption of VGRF through eccentric attenuation of the knee muscles during the landing phase. VGRF during landing can be a determining factor of injury, especially if frequent landings occur and the GRF are high (McNair et al., 2000). During a jump the interaction between muscle recruitment, kinematics and kinetics are complex (Reiser et al., 2006) and it is proposed that VGRF can be increased or decreased by changing muscle and joint activity (McNair et al., 2000).

It has been suggested that the overuse of the groin area results from an alteration in motor control strategies for load transfer between the pelvis and lower limbs (Morrissey, Graham, Screen, Sinha, Small, Twycross-Lewis & Woledge 2012). During testing of the muscle activation patterns of the pelvis and lower limbs in soccer players during standing hip flexion, Morrisey *et al*., (2012) found significant reductions in the activation ratio of glutes medius and adductor longus muscle during the weight bearing phase in soccer players with adductor-related groin pain compared to controls. These changes in muscle activation can have an effect on the VGRF as the control over the joint motion is controlled by the muscles (McNair et al., 2000). Measurements, such as peak forces and time to peak forces, derived from VGRF provide a means of quantifying bilateral symmetry in limb loading (McCrory, White & Lifeso 2001). Several studies have focussed on VGRF in knee and ankle pathologies in relation to forces applied to the lower limbs. (Caulfield & Garrett 2005; Hewett, et al., 2005). To date, no studies have explored the VGRF in individuals presenting with chronic adductor-related groin pain. The aim of this study was to describe the VGRF in active male sports participants with chronic adductor-related groin pain compared to asymptomatic controls.

2. METHODS

2.1 Ethical Considerations

Institutional ethical approval was obtained from the Health Research Ethics Committee of Stellenbosch University (ethics number S12/10/265) (Appendix B). After recruitment, all participants provided written informed consent.

2.2 Study design and setting

A descriptive observational study with cross-sectional time frame was conducted at the 3D Human Biomechanics CAF (Central Analytical Facilities), at Stellenbosch University.

2.3 Sample recruitment and eligibility criteria

Twenty six male participants between the ages of 18 and 40 years were consecutively recruited from soccer, rugby and running clubs in the Western Cape, South Africa in 2012 (18 participants) and 2015 (8 participants) (Appendix C).

Eligibility criteria for subjects participating in the study was unilateral or bilateral adductor-related groin pain persisting for longer than three months and a positive adductor squeeze test as described by Delahunt, Kennely, McEntee, Coughlan & Green (2011). Participants still had to be actively participating in their sport. Included subjects were matched with asymptomatic controls according to age, build and sport. Controls were eligible to partake in the study if they had no history of groin pain in the last year and a negative adductor squeeze test. Potential participants were excluded if they had 1) any previous orthopaedic surgery, 2) any diseases that could influence body function, 3) a history of spinal, pelvis or lower limb pathologies other than groin pain, 4) symptoms of prostatitis or urinary tract infection or 5) a palpable inguinal or femoral hernia. Participants were recruited and screened by two experienced musculoskeletal physiotherapists according to the inclusion and exclusion criteria.

2.5 Instrumentation

A floor embedded force plate (FP9060-15, Bertec Corporation, USA) was used to measure VGRF during the landing phase of the double leg jump. The force plate was synchronized with an eight camera T-10 Vicon (MX T-series, Vicon Motion Systems

Ltd, UK) system, with Nexus 1.4 116 software. Walsh, Ford, Bangen, Myer & Hewett (2006) established high reliability in using the Bertec force plate to measure peak force (0.95-0.98) and time to peak force (0.86-0.92) during landing and jumping activities.

2.4 Double leg jumping task

The participants were instructed to jump from a starting position (measured and indicated individually for each participant) that was marked on the floor and land flat on both feet simultaneously. The distance for the double leg jump was calculated by measuring each individual's full leg length from the anterior superior iliac spina to the medial malleoli with a tape measure. Only one foot landed on the force plate per trial. The landing position had to be kept for three seconds. Participants were instructed to jump as high as possible, land on flat feet and were not given any instructions on how to initiate the jump or what to do with their arms.

2.6 Kinetic outcomes

The following outcomes were used: 1) time (in milliseconds) from foot contact to peak landing force; 2) peak landing vertical force (in Newton) normalised to body weight; and 3) time (in milliseconds) to the lowest vertical position of the centre of the pelvis (Abbasi et al., 2011; Ortega et al., 2010). The centre of the pelvis was determined by the midpoint between the two pelvic marker placements. Foot contact was defined as the moment in time when the foot first made contact with the force plate and registered a force greater than 0 N.

2.7 Procedures

Each participant attended the 3D Human Biomechanics CAF on appointment for approximately 90 minutes. Participants were asked to dress appropriately in training shorts to expose their torso, legs and feet. On arrival, all participants were familiarised with the procedure and equipment. A physical examination (included in Appendix D) was performed on all participants by the same two experienced musculoskeletal therapists: one therapist performed the testing, while the other took down the measurements to ensure consistency. The examination included range of motion measurements with a goniometer (Roach, Juan, Suprak & Lyda 2013) of all the lower limb joints using the same bony landmarks and repeating each measurement three times to obtain an average, leg dominance (participants were asked which was their dominant leg) and current pain as measured by the visual analogue scale (VAS) (Bijur, Silver & Gallagher 2001). These measurements were taken and kept on file with the purpose that if there were any outliers or inconsistent data points, that this information could be used to explain and interpret these data points in terms of abnormalities in range of motion or pain. Anthropometrics were again measured by the same two therapists and included weight, height, leg length (as measured from the anterior superior iliac crest to the medial malleoli) and knee and ankle width. Participants were fitted with retro-reflective markers on the bony landmarks of the pelvis (Figure 1a and 1b) directly over the left and right anterior superior iliac spines.

Figure 1a and 1b: Retro-reflective marker placement on participant (anterior and posterior)

The Vicon system was calibrated for each participant according to standard procedures and model calibration (standard dynamic wand-wave calibration using passive, 5-marker wand) (Barker, Freedman & Hillstrom 2006). The double leg jump was demonstrated once by another (third) physiotherapist and each participant was given one opportunity to practice on each leg. The starting leg was randomly allocated by a coin toss. Instructions were given as “Ready and Jump” and counted down for three seconds after the landing. The landing was considered a fail if the participants landed off the force plate or if they lost their balance (shifting their feet after the land, or stepping forward). Three successful landings for each leg were recorded for each participant. The same physiotherapist repeated the testing procedure for all participants to ensure consistency (Appendix E).

2.8 Data processing

Gap filling was performed using the standard Wolt ring filter supplied by Vicon. The events for foot contact and lowest vertical position of the pelvis were calculated automatically using Matlab Version R2012b. Segment and joint kinematics were calculated using the PIG-model and filtered with a 4th-order Butterworth filter at a 10Hz cut-off frequency. Data was exported to Matlab to extract the parameters of interest.

2.9 Sample size calculation

Post hoc sample size calculation was done using the G-Power Version 3.1 statistical power analysis program. A large effect size of at least 1 (alpha value 0.05) was considered and the sample size of 18 (including nine participants and nine matched controls) in the unilateral group, gave 97% power.

In the bilateral pain group, considering a large effect size of at least 1 (alpha 0.05), six participants (three subjects and three controls), gave 50% power.

2.10 Sample size

Twenty six active male sport participants (13 subjects and 13 controls) formed part of this study (See Figure 2).

2.11 Data analysis

The subjects were divided into two subgroups: unilateral pain and bilateral pain. For the unilateral pain group, the data obtained from landing on the injured leg was compared to 1) the data obtained from landing on the unaffected leg and 2) the data obtained from landing on the same-sided leg of the matched control. The most affected and least affected legs of the bilateral pain group were individually compared to the same-sided legs of the matched control. For the subjects with bilateral groin pain, they were able to indicate which side of the groin was most affected.

Descriptive statistical data of demographics (mean, range and SD) were used to indicate variability between the subjects and controls. A two-tailed Student's *t-test* was performed to determine significant differences between subjects and controls. Statistical significance was set at $p>0.05$

3. RESULTS

3.1 Sample description

The sample of twenty six males consisted of 18 rugby players (69.2%), four soccer players (15.4%) and four runners (15.4%). All subjects were still actively participating in his sport and had a positive squeeze test in 45^0 of hip flexion. The demographics of the participants are displayed in Table 1. No significant differences in age, weight or height were noted between the subjects and controls in either of the two sub-groups.

Table 1: Demographics of participants (mean, SD)

	Age (years)	Height (cm)	Weight (kg)
Unilateral pain group (n=18)			
Subjects (n=9)	24.8 (5.8)	178.3 (7.9)	85.0 (19.9)
Controls (n=9)	23.7 (3.0)	178.2 (8.7)	89.9 (18.4)
Bilateral pain group (n=8)			
Subjects (n=4)	25.8 (9.7)	177.3 (10.3	88.6 (14.0)
Controls (n=4)	23.3 (5.7)	172.3 (6.1)	76.2 (11.1)

Due to technical errors, the data from three participants (two with unilateral groin pain and one control) could not be used in the analysis. This resulted in the sample size of 14 participants (seven subjects and seven controls) in the unilateral pain group when compared to the uninjured side and 16 participants (eight subjects and eight controls) when compared to the matched control. In the bilateral pain group six participants (three subjects and three controls) were analysed (refer to Figure 2).

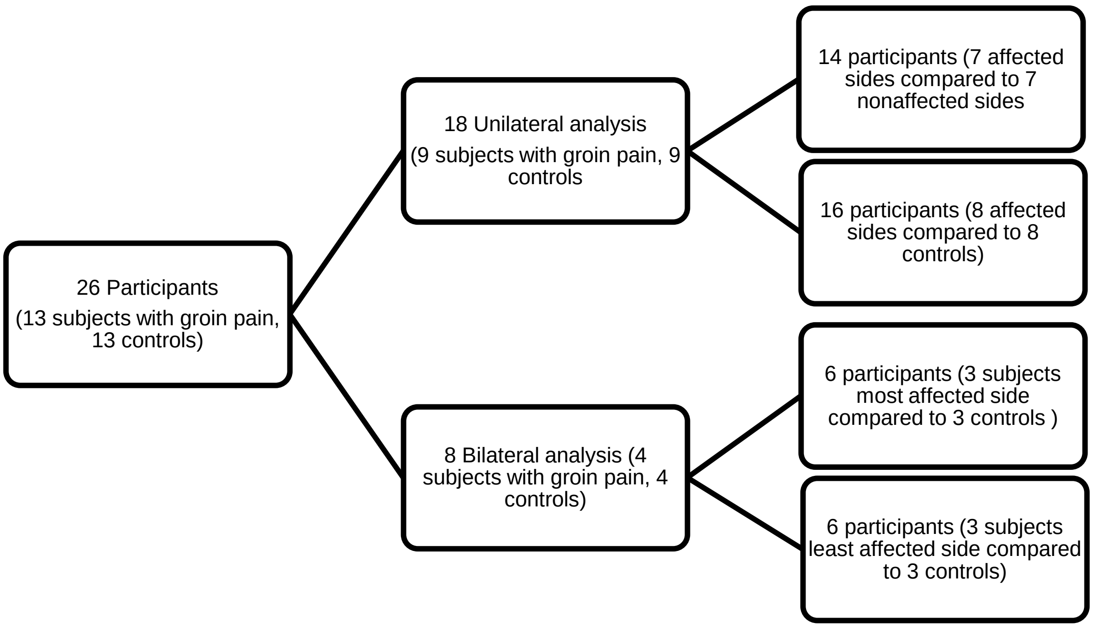

Figure 2: Sample description for analysis

3.2 Kinetics of the unilateral groin pain group

Greater differences in time to peak force and peak landing force were seen in the analysis of the subjects affected side versus the matched controls compared to the analysis of the subjects' unaffected side versus the affected side. The opposite was seen in the time to the lowest vertical position of the pelvis, where a greater difference was noted in the analysis of the subjects' affected side versus the unaffected side. No significant differences in all three outcome measures were however found between the unilateral groin pain subjects when compared to their unaffected side or to their matched controls (Table 2).

Table 2: Unilateral groin pain subjects compared to unaffected side and same side control (mean, SD

	Time to peak LF (ms)	Peak LF (kg/ N)	Time to lowest vertical position of pelvis (ms)
Subjects affected side (n=8)	52.4 (±7.2)	2.9 (±1.2)	200.5 (±87.8)
Subjects unaffected side (n=8)	51.1 (±17.1)	3 (±1.3)	164.5 (±58.4)
p Value	p=0.86	p=0.83	p=0.39
Subjects affected side (n=9)	57.7 (±16.5)	2.8 (±1.2)	189.2 (±87.3)
Controls (n=9)	46.9 (±18.1)	2.5 (±1.9)	169.9 (±37.3)
p Value	p=0.23	p=0.79	p=0.58

LF – landing force, ms – milliseconds, kg/N – kilogram/Newton

Figure 3 and 4 illustrates the time to peak force (not normalised to body weight) and shows that both the participants' unaffected side (Figure 3) and the matched control (Figure 4) reached the peak landing force sooner compared to the participants affected side.

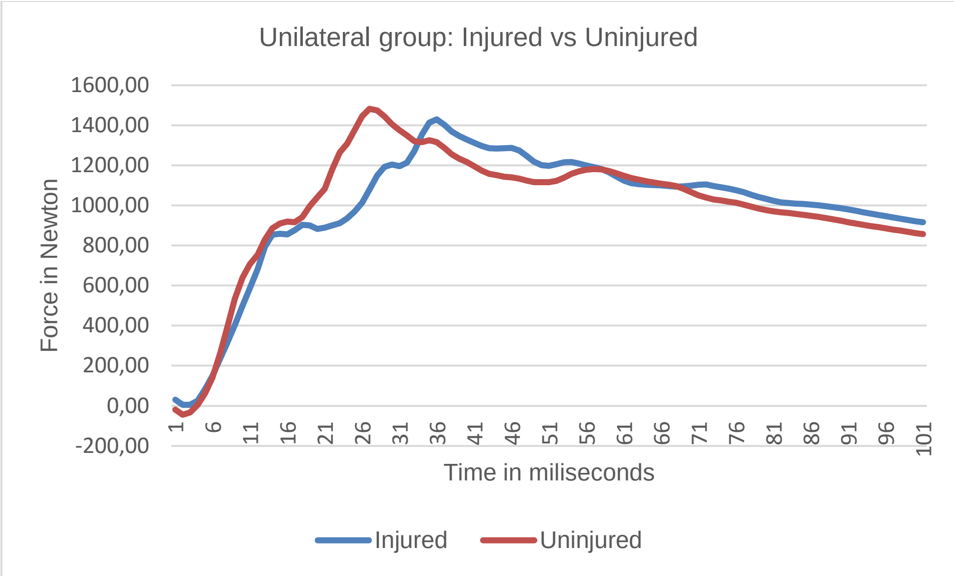

Figure 3: Force diagram of unilateral groin pain subjects illustrating the time (in milliseconds) to peak force (in Newton) for subjects' injured side compared to their own non-injured side.

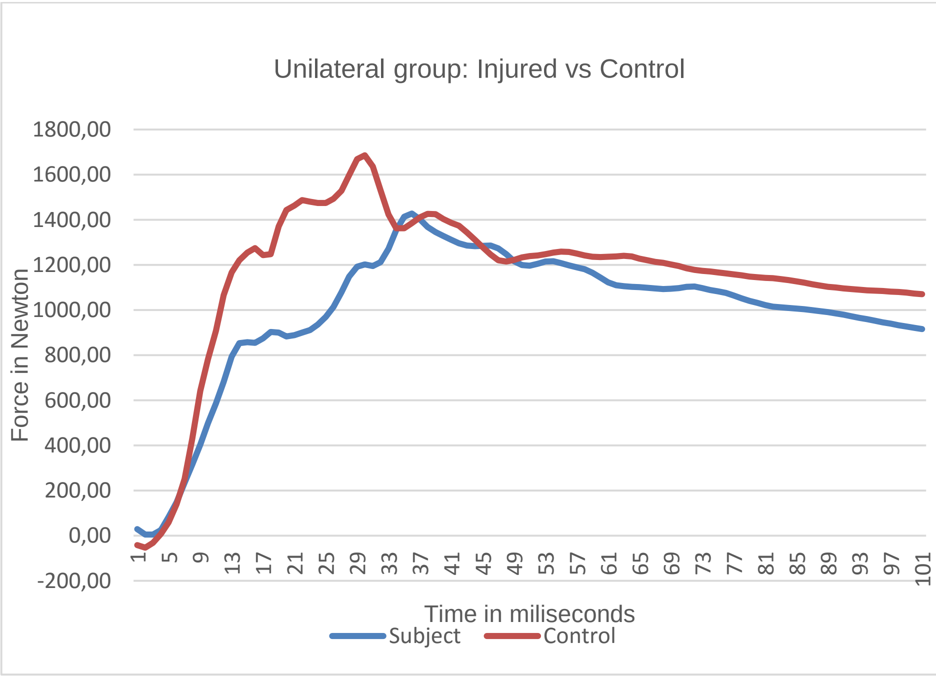

Figure 4: Force diagram of unilateral groin pain subjects illustrating the time (in milliseconds) to peak force (in Newton) compared to same-side controls.

3.3 Kinetics of the bilateral groin pain group

Greater differences were seen in the analysis of time to peak force and time to lowest vertical position of the pelvis where the subjects most affected side was compared to the control versus when the least affected side is compared to the controls. The opposite is true for peak landing force where a greater difference is seen when the subjects least affected side is compared to the controls. No significant differences could however be depicted between the most affected and least affected sides of the bilateral groin pain group compared to the same sided controls.

Table 3: Bilateral groin pain, most affected side and least affected side compared to control (mean, SD)

	Time to peak LF (ms)	Peak LF (kg/N)	Time to lowest vertical position of pelvis (ms)
Subjects most affected groin (n=3)	50.8 (±4.2)	2.4 (±1.0)	161.7 (±33.3)
Controls (n=3)	40.8 (±8.5)	2.7 (±2.2)	149.4 (±74.2)
p Value	p=0.14	p=0.83	p=0.81
Subjects least affected groin (n=3)	53.3 (±30.9)	2.5 (±0.9)	176.1 (±35.1)
Controls (n=3)	36.7 (±8.8)	2.9 (±2.4)	176.7 (±97.1)
p Value	p=0.42	p=0.81	p=0.99

LF – landing force, ms – milliseconds, kg/N – kilogram/Newton

Figure 5 and 6 illustrates the time to peak landing force (not normalised to bodyweight) when participants with bilateral groin pain most affected (Figure 5) and least affected side (Figure 6) is compared to a matched control. The different patterns seen (as compared to figures 3 and 4) could be attributed to the small sample size (n=3) and the large variability (large SD in the least affected groin pain group) between the different participants within this subgroup.

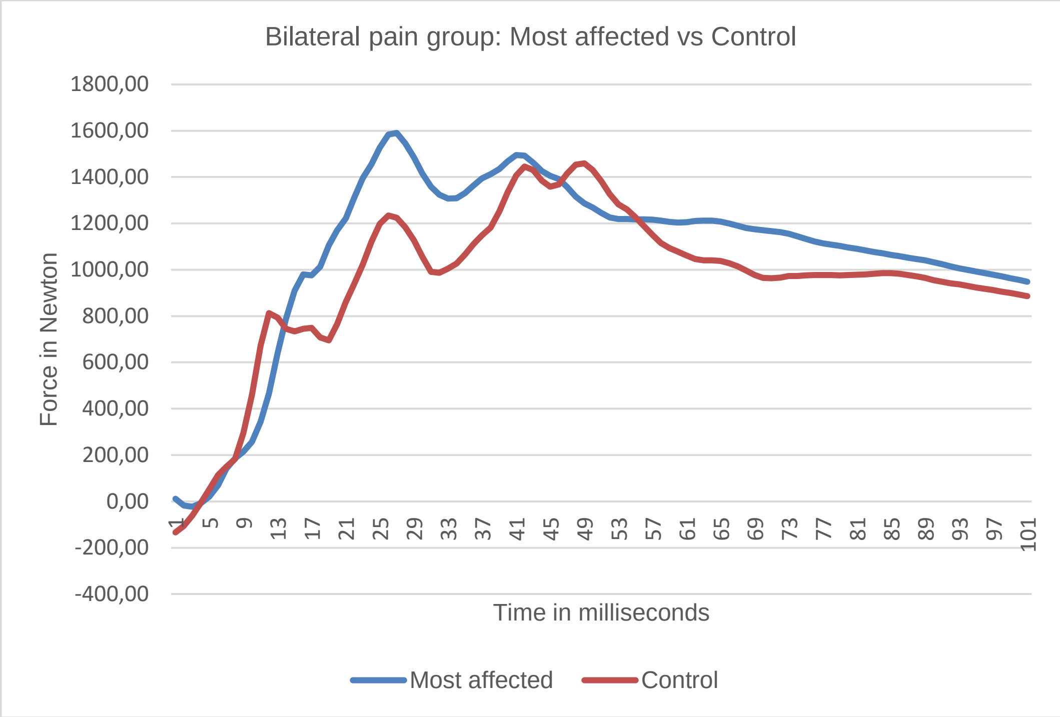

Figure 5: Force diagram illustrating time (in milliseconds) to peak force (in Newton) in the bilateral pain group. The most affected side is compared to the same side control.

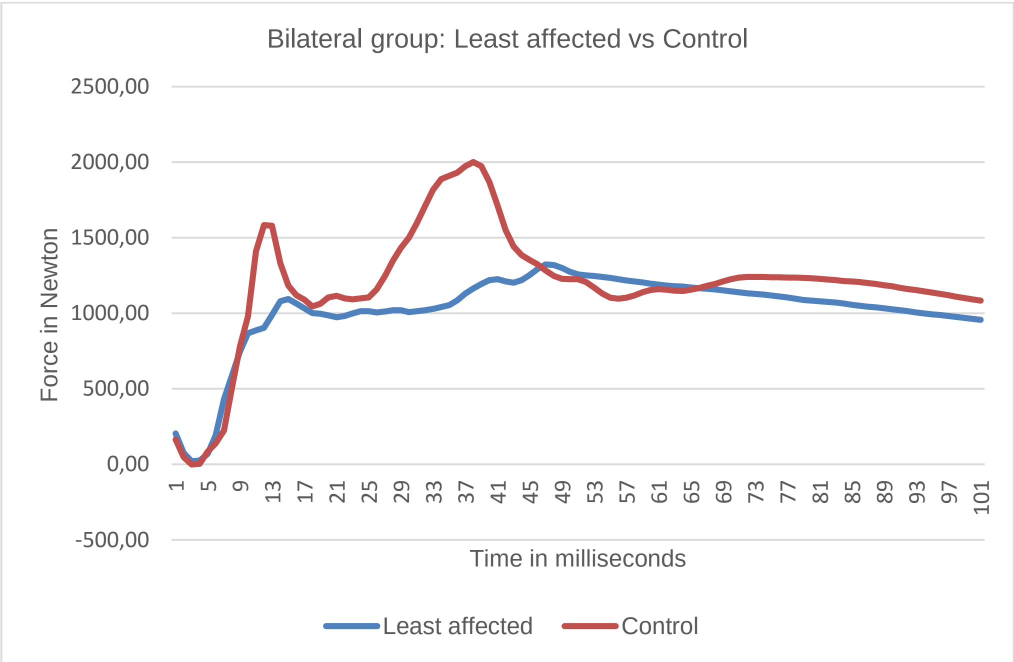

Figure 6: Force diagram illustrating time (in milliseconds) to peak force (in Newton) in the bilateral pain group. The least affected side is compared to the same side control.

4. DISCUSSION

This study aimed to determine whether differences occur in the VGRF of male sports participants with chronic adductor-related groin, compared to matched asymptomatic controls. Participants were divided into two subgroups, unilateral- and bilateral groin pain for analysis. No statistical difference were found in either time to peak force, peak force normalised to body weight or time to lowest vertical position of the pelvis in either subgroup.

Differences in time to peak vertical force are noted in the literature (Decker, Torry, Wyland, Sterett & Steadman 2003; Ortega et al., 2010). Our findings correlate with Decker *et al*., (2003) who measured time to peak landing force of 40ms in healthy male sports participants, compared to Ortega *et al.,* (2010) who reported time to peak landing force of 140ms in healthy semi-professional male participants. This group described by Ortega *et al*., (2010) took approximately two thirds longer than the average landing time for our participants. This difference could be contributed to the different landing strategies described in the studies since literature has shown that different jump techniques influence the VGRF (Ortega et al., 2010). Two types of landings are described in the literature, one that is made with feet flat where the VGRF are usually greater and one where contact is first made with the forefoot and then with the rear foot (Bressel & Cronin 2005; Ortega et al., 2010). Increased landing time through forefoot landing results in a smaller peak force (Bressel & Cronin 2005). Our participants landed with their feet flat; whereas in the study done by Ortega *et al.,* (2010) participants were instructed to land firstly with their forefeet, explaining the differences in findings. The landing technique of participants in our study could have influenced our findings.

Bressels & Cronin (2005) reported that the VGRF can be as high as 18 times body weight during sporting activities such as landing in adouble back summersault in gymnastics. The lower the VGRF, the more optimal the landing strategy of the participant is (Abbasi, Tabrizi, Sadeghi, Sarvestani & Bagheri 2011). In our study no significant differences were found in the peak vertical landing force when unilateral or bilateral adductor-related groin pain subjects were compared to controls. Our findings for peak vertical landing forces in both symptomatic and asymptomatic participants during a double leg landing correlate with values reported in studies of asymptomatic participants by Decker *et al.,* (2003) and Abassi *et al.,* (2011). This indicates an equal weight distribution between the affected and non-affected side during the landing phase.

No significant differences were found in the time to the lowest vertical position of the pelvis when the unilateral or bilateral subject groups were compared to controls. The unilateral and bilateral groups' time difference also showed no statistical differences. Limited evidence is found in the literature for normative values and could thus not be adequately compared and interpreted.

Similar VGRF between the subjects and controls of this study may indicate that no modification in the landing techniques/strategies were implemented by participants with unilateral or bilateral adductor-related groin pain or that chronic adductor-related groin pain alone does not influence landing strategies. Another possibility for this occurrence might be that since changes in peak vertical landing forces are mainly influenced by changes in the amount of hip flexion, knee flexion and ankle dorsiflexion (Ortega et al., 2010; Abassi et al., 2011). It is feasible that our subjects with chronic adductor-related groin pain may already have adopted different joint angle ranges or muscle activation patterns during landing due to the chronicity of the pain. Other possible reasons for no significant differences in VGRF may include that the VGRF is evenly distributed between the lower limb joints i.e. hip, knee and ankle, thus making no statistical difference. These findings may be supported by Decker et al., (2003) who demonstrated no energy absorption differences (p>0.05) between the lower limb joints during a landing task. Or it can support findings of Abbasi *et al.,* (2011) that the knee joint is the primary shock absorber of the lower limb during landing. The measurement of joint kinematics or muscle activation patterns however were beyond the scope of this study.

The adductor muscle group's function in a closed kinematic chain motion is to stabilise the pelvis and the lower limb. Although weakness of this muscle has been identified as a risk factor for adductor-related groin pain (Maffey & Emery 2007; Tyler, Silvers, Gerhardt & Nicholas 2010), the muscle strength of the adductor muscle group was not tested in this study. Therefore the results of this study might suggest that there was no difference in the adductor muscle strength between the subjects and controls and that this muscle group provided equal stability to the pelvis and the lower limb in bilateral and unilateral pain groups of participants when landing from a double leg jump. This can suggest that there is no difference in pelvis stability in participants with unilateral or bilateral groin pain group and that other muscles surrounding the pelvis is responsible for stability in a closed kinematic chain motion. Furthermore muscle fatigue in sports participants leads to an increased need for neuromuscular control (Kuni et al., 2014). Kuni *et al.,* (2014) has shown that dynamic postural control in landing from a jump is impaired directly after a 30-minute run and risk of injury and changes in VGRF could be greater under fatigue conditions. In this study, all subjects were still actively participating in sport and the effect of fatigue was not measured. This leaves the question that if the participants were fatigued prior to data capture, would larger differences in VGRF be noted due to pain or decreased neuromuscular control? Adductor-related groin pain is known to be typically exacerbated by sporting activities (Sedaghati et al., 2013) and muscle control, flexibility and fatigue are all known risk factors for the development of chronic adductor-related groin pain (Maffey & Emery 2007; Sedaghati et al., 2013).

Our study sample represented male participants with an average age of 25.1 years (SD=6.8). Arnason, Sigurdsson, Gudmundsson, Holme, Engebretsen & Bahr (2004) stated that older players, between the ages of 29 to 38 years had a significant higher risk for a groin injury. Only three subjects of our study fell in that range. Thus our findings cannot be generalised to sports participants with adductor-related groin pain of all ages.

It is important to note that different biomechanical factors can influence VGRF associated with the double leg landing. Limitations to our study include the lack in measuring electromyography (EMG) of the muscles around the hip and pelvis, the lack of including kinematics of the lower limb and pelvis and the small sample size. Clinical implication for our findings may suggest that inadequate absorption of VGRF alone may not be associated with adductor related groin pain and that specific landing-technique training alone, may not be effective in our sample population.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

Future research should include fatiguing of participants before testing and exploring kinematics of the lower limbs during initial contact of the double leg landing to establish if subjects do adapt their landing strategy. EMG can also be included to ascertain which muscles are mainly responsible for stabilising the pelvis and hip in a closed kinematic chain action. Inclusion of a larger sample size, a wider age distribution and bigger population may also be warranted.

6. CONCLUSION

The aim of this study was to describe whether any differences in VGRF exists between male sports participants with adductor-related groin pain compared to asymptomatic controls during the landing phase of the double leg jump. No significant differences were noted in the time to peak landing force, peak landing force or time to lowest vertical position of the pelvis in unilateral or bilateral groin pain subjects compared to controls. VGRF has not previously been studied in participants with groin pain. This study illustrates that VGRF is similar in subjects with adductor-related groin pain and asymptomatic matched controls. Clinical application may indicate that landing strategies alone aimed at decreasing VGRF in sports participants with adductor-related groin pain may not be useful.

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van Beijsterveldt, A. M., van de Port, I. G., Krist, M. R., Schmikli, S. L., Stubbe, J. H., Frederiks, J. E., et al. (2012). Effectiveness of an injury prevention programme for adult male amateur soccer players: A cluster-randomised controlled trial. *British Journal of Sports Medicine, 46*(16), 1114-1118.

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CHAPTER 4: Conclusion, limitations and recommendations

The landing phase of a jump results in peak vertical ground reaction forces (VGRF) and it has been proposed that a combination of these forces with the frequency of landings produce a large amount of stress in the joints of the lower limbs (Ortega et al., 2010). As these forces have been implicated as potential biomechanical risk factors for injury in the lower limb (McNair et al., 2000; Oretaga et al., 2010), the aim of this study was to determine whether differences exist in VGRF in male sports participants with chronic adductor-related groin, compared to matched asymptomatic controls. This was the first study to report on VGRF in sport participants with adductor-related groin pain.

No statistical or clinical difference were found in either time to peak force, peak force normalised to body weight or time to lowest vertical position of the pelvis in either of the two subgroups. The information gathered in this study might suggest that there are no difference in the VGRF in male runners, rugby-, and soccer players in the Western Cape metropole with unilateral of bilateral adductor-related groin pain when landing from a double leg jump.

Most research on VGRF focusses on knee and ankle pathology, especially anterior cruciate ligament (ACL) injuries (Olsen et al., 2004; Hewett et al., 2005). Limited research has been done regarding changes in VGRF in subjects with hip pathologies. However a study on changes in VGRF during walking in patients after hip arthroplasty has indicated great asymmetry. Subjects continued to favour the unaffected leg compared to controls for as long as six months follow-up (McCrory et al., 2001). This indicates that uneven limb loading due to a hip pathology can be detected in closed kinematic chain movements through studying VGRF.

Previous research have found significant reductions in the activation ratio of glutes medius and adductor longus muscles during one leg stance in the weight bearing phase of the symptomatic leg of soccer players with adductor-related groin pain compared to controls (Morrisey et al., 2012). These changes in motor control affects kinematics (McNair et al., 2000). These findings may lead to the assumption that there should be changes in VGRF in patients with adductor related groin pain. With our findings it leaves the question of which biomechanical changes did the subjects make to accommodate for these changes in muscle activation around the pelvis. Whether it is a change in the joint angles of the lower limbs or if other muscle groups around the pelvis and hip play a bigger role in the stability of the pelvis and lower limb. The inclusion of kinematics and electromyography (EMG) of these muscles are a limitation to this study and is warranted in further research. The analysis of joint kinematics during foot contact can ascertain whether there is a difference in maximum hip, knee or ankle flexion in symptomatic subjects compared to controls and analyzing EMG of the lower limbs and pelvis can ascertain which muscles in symptomatic subjects provide stability to the pelvis and lower limbs compared to controls.

Other limitations to this study is the sample size, as the small size limits the level of confidence in the findings of the study. The sample group also only included male participants, with an average age of 25.1 years (SD=6.8) and is not inclusive of the whole population of sports participants with groin pain, as Anason *et al*., (2004) stated that older players, between the ages of 29 to 38 years had a significant higher risk for a groin injury. Consecutive sampling was used during recruitment for this study. It is recommended that further research use random sampling, include a bigger sample size and include male and female participants in a wider age group to better demonstrate the demographics of adductor-related groin pain. To include subgrouping of participants according to range of motion (ROM) and visual analogue scale (VAS) findings were beyond the scope of this study and the small sample size does not allow for this, however including these outcomes in future studies is warranted as it has the potential to influence the findings of future studies.

The participants in this study were not fatigued before the commencement of the study. Fatigue is proven to have an adverse effect on kinetics (Kuni et al., 2014), it is thus recommended that further research should include fatiguing of participants before the commencement of testing. Another limitation to this study is that it was laboratory based and does not reflect real-life activity. The double leg landing is a bilateral activity and load can be equally absorbed, during sporting activities landing might be bilateral or unilateral. Unilateral landing studies may reveal different kinetic results. During testing, participants were only instructed to jump as high as possible and land with feet flat, thus it is not possible to determine whether a maximum effort was given by all participants and participants could have utilized different jumping techniques.

Some treatment strategies for adductor-related groin pain include instruction on landing aiming to increase landing time (McNair et al., 2000; Bressels & Cronin 2005). It is possible to increase landing time by increasing flexion at the hip, knee and ankles with proper coordination (Ortega et al., 2010). By flexing these joints landing forces can be better absorbed compared to halting the movement (Reiser et al., 2006). Our findings suggest that the implementation of landing strategies in treatment or prevention programs may deem unnecessary as no differences in VGRF were seen in sports participants with unilateral of bilateral groin pain when they were compared to matched, asymptomatic controls in a double leg landing.

The field of adductor-related groin pain still warrant more research as currently there is no effective treatment strategy (Serner et al., 2015) or prevention protocol (Esteve et al., 2015). Our study adds to the opinion that associative factors still need to be better established (Arnason et al., 2004) to provide clear answers and direction for treatment.

Conclusion

The aim of this study was to determine differences in VGRF between male sports participants with adductor-related groin pain compared to asymptomatic controls during the landing phase of the double leg jump. No significant statistical differences were noted in the time to peak landing force, peak landing force or time to the lowest vertical position of the pelvis in unilateral or bilateral groin pain subjects compared to controls. VGRF has not previously been studied in participants with groin pain. This study illustrates that changes in VGRF may not be associated with adductor-related groin pain in male sports participants in the Western Cape metropole. Clinical application may indicate that landing strategies alone, aimed at decreasing VGRF in male sports participants with adductor-related groin pain, may not be warranted.

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The following information of the Author designated as corresponding Author must be stated: E-mail address; full postal address; Telephone and fax numbers; all necessary fields have been uploaded; Keywords; All figure captions; all tables (including title, description, footnotes)

At the end of the paper (before the references) three statements must be provided:

- Ethical Approval: The organisation providing ethical approval and ethics protocol reference number where appropriate.
- Funding: any sources of funding should be stated.
- Conflict of Interest: Disclosed conflicts will be published if they are believed to be important to readers in judging the manuscript. If there are no conflicts of interest, authors should state that there are none.

Format/Preparation Guidelines

The article should be typed on A4 paper, double-spaced with margins of at least 3cm. All pages must be numbered consecutively beginning with the title page. Papers should be set out as follows, with each section beginning on a separate sheet: **Title page; abstract; keywords, text, and references.**

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- Title page must consist of the following:
    - *Title.* Concise and informative. Titles are often used in information-retrieval systems. Avoid abbreviations and formulae where possible.

- *Author names and affiliations*. Present the authors' affiliation addresses (where the actual work was done) below the names. Indicate all affiliations with a lower-case superscript letter immediately after the author's name and in front of the appropriate address. Provide the full postal address of each affiliation, including the country name, and, if available, the e-mail address of each author.
- *Corresponding author.* Clearly indicate who is willing to handle correspondence at all stages of refereeing and publication, also post-publication. Ensure that telephone and fax numbers (with country and area code) are provided in addition to the e-mail address and the complete postal address.
- *Present/permanent address*. If an author has moved since the work described in the article was done, or was visiting at the time, a 'Present address' (or 'Permanent address') may be indicated as a footnote to that author's name. The address at which the author actually did the work must be retained as the main, affiliation address. Superscript Arabic numerals are used for such footnotes.

• An abstract of the manuscript, summarizing the content in no more than 200 words, should be provided. Abstracts should follow a structured format. For empirical studies, this will usually involve these headings: Objectives, Design, Setting, Participants, Main Outcome Measures, Results, and Conclusions. For other types of study, contributors may adapt this format, but should retain the idea of structure and headings.

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All references cited in the text must be present in the reference list (and vice versa). Avoid using references in the abstract. Avoid citation of personal communications or unpublished material. A citation to material "in press" is acceptable and implies that the item has been accepted for publication. Citation of material currently under consideration elsewhere (e.g. "under review" or "submitted") is not.

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Ethics

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- **Patient Anonymity:** Studies on patients or volunteers require ethics committee approval and informed consent which should be documented in your paper. Patients have a right to privacy. Therefore identifying information, including patients images, names, initials, or hospital numbers, should not be included in videos, recordings, written descriptions, photographs, and pedigrees unless the information is essential for scientific purposes and you have obtained written informed consent for publication in print and electronic form from the patient (or parent, guardian or next of kin where applicable). If such consent is made subject to any conditions, Elsevier must be made aware of all such conditions. Written consents must be provided to Elsevier on request. Even where consent has been given, identifying details should be omitted if they are not essential. If identifying characteristics are altered to protect anonymity, such as in genetic pedigrees, authors should provide assurance that alterations do not distort scientific meaning and editors should so note. If such consent has not been obtained, personal details of patients included in any part of the paper and in any supplementary materials (including all illustrations and videos) must be removed before submission.

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APPENDIC B: Ethical approval

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Ethics Letter

26-Jan-2015

Ethics Reference #: S12/10/265
Clinical Trial Reference #:
Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Ms Tracy MORRIS,

The HREC approved your application for a Protocol Amendment dated 2 October 2014.

Approval was also granted for the new research team for the extended study namely:

Principal Investigator:
PROF Q LOUW

M Students:
ERNESTINE BRUINDERS
WENDY-LYNN MOODIEN
ANICA COETSEE
CHARIS WHITEBOOI
CATHRINE DU PLESSIS

Supervisors:
DR SJAN MARI VAN NIEKERK
DR YOLANDI BRINK
MS GAKEEMAH INGLIS JASSIEM
MR JOHN COCKCROFT
DR MARIANNE UNGER
MS MARLETTE BURGER
MS LEONE WILLIAMSWILLIAMS

If you have any queries or need further assistance, please contact the HREC Office 219389156.

Sincerely,

REC Coordinator
Franklin Weber
Health Research Ethics Committee 1

Approval Notice

New Application

03-Dec-2012
MORRIS, Tracy Louise
Ethics Refernce #: S12/10/265

Title: Exploration of Biomechanics during functional Activities in Adults Sports participants with Chronic Groin Pain

Dear Ms Tracy MORRIS,

The New Application received on 22-Oct-2012, was reviewed by Health Research Ethics Committee 1 via Committee Review procedures on 28-Nov-2012 and has been approved. Please note the following information about your approved research protocol:

Protocol Approval Period: 28-Nov-2012 -28-Nov-2013

Present Committee Members:
Kinnear, Craig CJ
Seedat, Soraya S
Mukosi, M
Theunissen, Marie ME
Kearns, E
Meintjes, WAJ Jack
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Rohland, Elvira EL
Theron, Gerhardus GB
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Please remember to use your protocol number (S12/10/265) on any documents or correspondence with the HREC concerning your research protocol.

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

After Ethical Review:

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

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of

Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of

Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit: www.sun.ac.za/rds

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

Included Documents:
Checklist
Application Form
Investigators declaration
Protocol

Sincerely,

Franklin Weber
HREC Coordinator
Health Research Ethics Committee 1

APPENDIX C: Recruitment

Rugby and soccer clubs in the Western Cape were contacted via email inviting them to partake in the study. If they did not respond they were followed up telephonically. All clubs who was willing to partake in the study and had candidates who they thought were suitable were visited. A time was scheduled where the participant would be available and two of the researchers screened the participants for eligibility. If they were found to meet the inclusion criteria a suitable control was selected from the same club. They were then invited to form part of the study and a time and date were agreed on with the lab to do the testing.

APPENDIX D: Physical evaluation form

Height: ____

Weight: ____

Leg length: L ____________________ R ________________________

Leg dominance: ____

Anthropometric measurements:

Knee: L _________________________R________________________

Ankle: L _________________________R _______________________

Hip	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Extension								
Flexion								
Abduction								
Adduction								
Internal Rotation								
External Rotation								

Knee	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Extension								
Flexion								

Ankle	Left1	Left2	Left3	**Mean**	Right1	Right2	Right3	**Mean**
Dorsiflexion								
Plantar flexion								
Inversion								
Eversion								

Special test:

SIJ Faber

P4

Gaenslen’s Test

Palpation of LDL

Hip FAI

Faber

Fitzgerald

Ankle Anterior Drawer

APPENDIX E: Procedure on day of testing

Step 1: The participant was welcomed at the door and shown the lay out of the lab and was introduced to the lab personal and physiotherapists conducting the tests.

Step 2: The participant was taken to the back room where they were given time to dress in appropriate attire of shorts to expose their legs and torso. The following measurements was done in this particular order.

- VAS (at that current time)
- Height
- Weight
- ROM (left and right)
    - Hip (flexion, extension, internal rotation, external rotation, abduction, adduction
    - Knee (Flexion, extension)
    - Ankle (Dorsiflexion, plantarflexion, inversion, eversion)
    - Leg length
- Anthropometric measurements
    - Knee (femoral condyles)
    - Ankle (malleoli)
- Shaving of appropriate areas
- Participants were asked to sign consent to take photographs of marker placements.

Step 3: The participant was taken to the testing area where they were fitted with the marker placements. Skin preparation was done by cleaning areas with alcohol and scrubbing of to activate the skin.

Step 4: The participants were asked to stand in the middle of the force plate facing forwards for 5 seconds for calibration.

Step 4: The participant was instructed on how to do the double leg jump.

- The test was demonstrated once by the physiotherapist
- The participant was instructed to give a maximum effort jump as high as possible and after landing with the feet flat to hold the position for three seconds
- No additional information was be given on what to do with their arms
- The participant got one chance to practice the jump with each leg landing on the force plate
- The instructions was given as "Ready and jump" … "Three, two, one and relax"
- The jump was repeated three times and then again three times to land with the other leg on the force plate
- Loosing balance and stepping forward with either leg, or moving the feet before the three seconds was over was considered as a fail

Step 7: The participant was asked to repeat the VAS score to see if it has changed.

APPENDIX F: Adductor squeeze test

The adductor squeeze test as described by Delahunt *et al*., (2011) was used as a pain provocation test to identify participants with adductor related groin pain. The adductor squeeze test as a pain provocation test has shown to be positive in predictive value of chronic groin pain (Crow, Pearce, Veale, Van der Westhuizen, Coburn, & Pizzari 2010). Participants were positioned supine with the hips flexed at 45^0 of flexion. In this position the adductor muscle indicated the greatest amount of activity and may replicate the initial load bearing phase in dynamic weight bearing activity during which the adductor muscles are required to perform both a stabilising and movement function (Delahunt et al., 2011). For testing the participant was instructed to squeeze as hard as possible and maintain the squeeze for 10 seconds before returning to a relaxed position. A positive test was if the contraction reproduced the participants familiar groin pain at the adductor muscle insertion or over the muscle belly (Hölmich et al., 2004; O'Connor, 2004). The test was repeated three times.

APPENDIX G: Participant screening form

What sport do you play	Rugby	Soccer
How many hours do you spend training and participating in your sport per week		
Have you ever had any pain over your groin area?	YES	NO
Has the groin pain been there for longer than three months?	YES	NO
Is the groin pain currently stopping you from participating in sport?	YES	NO
Which side is your pain? **(It can be on both sides)**	LEFT	RIGHT
Do you feel generally healthy?	YES	NO
Do you have a history of neck, back, pelvis or limb injuries? If YES, please state	YES Types of injuries:___________	NO
Have you suffered from any of the symptoms related to prostatitis or urinary tract infection, as listed adjacently? **YES/ NO**	Pain and tenderness in upper back and sides.	Rectal pain.
	Pain in the pelvis, genitals, lower back and buttocks.	Discomfort in the perineal area (area between the scrotum and the anus)
Have you had symptoms associated with nerve entrapment syndrome in your legs (tingling, pins and needles, numbness or burning pain)?	YES	NO
Have you undergone any orthopaedic surgery, as listed adjacently in the last 12 months? **YES/ NO**	Lumbar spine	Pelvis
	Hip Joint	Knee joint
	Ankle joint	Foot
Have you been diagnosed with any of the following illnesses? **YES/ NO**	Ankylosing Spondylosis;	Scheuerman's disease
	Rheumatoid Arthritis;	Muscular Dystrophy
	Paget's disease	