A CROSS SECTIONAL STUDY TO DETERMINE WHETHER THERE ARE CENTRAL NERVOUS SYSTEM CHANGES IN FOOTBALL PLAYERS WHO HAVE SUSTAINED RECURRENT LATERAL ANKLE INJURIES USING THE LATERALITY JUDGEMENT TASK, TWO POINT DISCRIMINATION TEST AND LIMB PERCEPTION TESTING

RASHAAD JAKOET

THIS THESIS IS PRESENTED FOR THE DEGREE OF MASTER OF PHILOSOPHY IN SPORTS PHYSIOTHERAPY IN THE DEPARTMENT OF HEALTH AND REHABILITATION SCIENCES

UNIVERSITY OF CAPE TOWN

FEBRUARY 2016

SUPERVISORS

ASSOCIATE PROFESSOR ROMY PARKER

DR THERESA BURGESS

DEPARTMENT OF HEALTH AND REHABILITATION SCIENCES

FACULTY OF HEALTH SCIENCES

UNIVERSITY OF CAPE TOWN

SOUTH AFRICA

Declaration

I, Rashaad Jakoet, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

Signed by candidate

(Signature)

15/02/2016

(Date)

Acknowledgements

I would like to take the opportunity to thank the following people, as without their participation and support, this study would not have been possible.

1. Dr Theresa Burgess: for giving me the opportunity to complete my thesis and act as supervisor for this study.

2. Associate Professor Romy Parker: my supervisor, for her continuous and patient support and prompt feedback.

3. Dr James Brown: for his invaluable assistance with the statistical analysis of data

4. Vasco Da Gama Football Club for allowing me to use their premises and test their professional players, with a special mention to the assistant coach, Keenan Lesch, for conveying my request to the club.

5. Nicole Faulman: the physiotherapist looking after the team for making sure they attended the testing sessions.

6. My family, friends and colleagues for their sustained encouragement.

Your assistance in this study is greatly appreciated.

Thank you.

Table of Contents

List of Abbreviations

FIFA: International Federation of Association Football (*Fédération Internationale de Football Association)*

CAI: Chronic Ankle Instability

CRPS: Complex Regional Pain Syndrome

ATFL: Anterior Talofibular Ligament

CTFL: Calcaneal Talofibular Ligament

PTFL: Posterior Talofibular Ligament

IL-1: Interleukin-1

RICE: Rest, Ice, Compression, Elevation

CNS: Central Nervous System

IASP: International Association for the Study of Pain.

fMRI: Functional magnetic resonance imagery

List of Definitions

Football: refers to Association Football (American Soccer) as played under FIFA rules

Re-injury: an injury of the same nature and location as the previous injury

Injury: defined as one sustained during training or competition and which prevented the injured player from participating in normal training or competition for more than 48 hours (Woods et al. 2003)

Severity of injury:

- Slight : 2 – 3 days (absence from training)
- Minor: 4 – 7 days
- Moderate: 1 – 4 weeks
- Major: > 4 weeks (Woods et al. 2003)

Chronic Ankle Instability : repetitive bouts of lateral ankle instability resulting in numerous ankle sprains (Hiller, Kilbreath, et al. 2011)

Mechanical instability: pathologic ligamentous laxity about the ankle joint complex (Hiller, Kilbreath, et al. 2011)

Proprioception: The unconscious perception of movement and spatial orientation arising from stimuli within the body itself (Stedmans Medical Dictionary)

Conscious effort:	to be fully aware of or sensitive to something while performing a task

List of Tables

List of Figures

Abstract

Background: A chronic ankle sprain injury is a condition that affects professional, amateur and social football players globally. Despite a large amount of research into the medical management of this condition, it remains one of the most frequently experienced injuries in professional football. A previous ankle sprain is a recognised risk factor for future lateral ankle sprain injury. No previous study has investigated the effects of chronic lateral ankle sprains on the cortical representation of the ankle in the brain.

Aim: To determine if there are any changes in the primary and secondary somatosensory cortices of football players who have a history of recurrent ankle sprain injuries

Methods: 25 professional male football players (13 previously injured, 12 non-injured) with an average age of 24.9y (+/- 4.49y) from a national first division club were recruited for the study. . All players included in the study completed an informed consent form before participation in the study and were declared fit to play by the clubs medical staff. Player demographics and training history were collected by means of a questionnaire followed by anthropometric measurements being taken. Tests used in the assessment of complex regional pain syndrome (Laterality Judgement Task recognition, two point discrimination and limb perception drawing) were used to assess for cortical representation changes in both limbs of injured players and uninjured players.

Results: There were no differences found between the injured and uninjured limb in the previously injured football player population in any of the tests administered. There were no significant differences found between groups when testing for Laterality Judgement Task recognition times or with the limb perception drawing tests. Significant differences were found between the previously injured and uninjured populations in the two point discrimination test anteriorly (p=0.02) and 2 cm proximal to the lateral malleolus (p=0.05) and a near significant finding inferior to the lateral malleolus (p=0.06).

Conclusion: Significant differences found with the results of the two point discrimination test indicate impaired sensation around the lateral ankle and are suggestive of cortical representation changes in professional football players with recurrent ankle sprain injuries. Further studies of this nature should include a larger sample population and possibly testing during the symptomatic phase of injury, which could lead to more significant findings, adding to our understanding of how central nervous system changes occur as a result of a chronic lateral ankle sprain injury.

Clinical implications: Based on the findings of this study, the effect of a chronic ankle sprain injuries on central nervous system changes should be investigated with every ankle injury and techniques used in the treatment of complex regional pain syndrome should be included in the comprehensive management of chronic ankle sprain injuries

Key words: chronic ankle sprain, complex regional pain syndrome, two point discrimination

Chapter 1- Introduction and Scope of Thesis

A chronic ankle sprain is a common condition which has considerable impact on a football player's career. It is a condition that affects professional, amateur and social football players worldwide. A primary concern of a lateral ankle sprain is that once having had one, there is an increased chance of having a recurrence (Arnason 2004).

A considerable amount of literature has been published on the treatment and prevention of lateral ankle sprains, yet despite all this literature, a lateral ankle sprain is still one of the most frequently experienced injuries in professional football. No previous study has investigated the effects of chronic lateral ankle sprains on the cortical representation of the ankle in the brain, although some studies investigating proprioception training on joint injury recurrence have hinted at a possible mechanism for re-injury and successful management. Current methods of treatment have proven to be inadequate in significantly reducing injury recurrence and debate continues about the best strategies for the management of this injury(Kim et al. 2014; De Vries et al. 2011; Dubin et al. 2011; Kemler et al. 2011)

The objective of this research is to determine whether there are any changes in the somatosensory representation in football players suffering from chronic ankle sprains by comparing them to a group of uninjured professional football players by using methods used to assess and treat patients suffering from a range of chronic pain conditions such as complex regional pain syndrome (CRPS).

Chapter 2 – Literature Review

Introduction

Considering the prevalence of ankle injuries in football players(Woods et al. 2003) and the difficulty in managing recurrent ankle injuries, a literature review was conducted. To inform the literature review, a literature search was conducted using the PubMed, Cochrane Collaboration, FIFA and Google Scholar databases. Literature on chronic lateral ankle sprains in football and CRPS was obtained by using the following search terms: football injuries, lateral ankle instability, lateral ankle sprain, chronic ankle instability (CAI), chronic lateral ankle instability, ankle instability, residual ankle instability, chronic instability, recurrent instability, recurrent lateral ankle instability, chronic ankle sprain, proprioception, complex regional pain syndrome, and chronic pain.

Epidemiology

Globally over 240 million people in 207 member associations, regularly participate in playing football. These football players are accompanied by close to five million referees, assistant referees and other officials involved in the game. This is according to a global survey launched by the International Federation of Association Football (FIFA) (Kunz 2007). According to FIFA's "Big Count", this number had grown to 265 million in 2006 with 1.46 million registered members and approximately three million unregistered football players in South Africa (Anon 2006).

Ankle sprains are common injuries that are well known to medical professionals, coaches and athletes supporting and competing in various sporting codes, including football. An epidemiological study of 837 Brazilian college athletes over a 20 year period from 1993 – 2013 found that the ankle was the second most injured area (12.3%) among 13 different sporting codes (Rosa et al., 2014). According to an audit of ankle injuries in professional English football conducted by FIFA, ankle injuries account for 17% of all injuries in the sport (the third most common injury after the thigh and groin) (Woods et al. 2003). Of these ankle injuries, 77% occur on the lateral side involving the anterior talofibular ligament (ATFL) and 9% reoccur in the same football playing season. The majority of these injuries occur during matches, with 40% arising from non-contact trauma. The average time lost to ankle injuries in professional English football was 19 days and four matches (Woods et al. 2003).

In a recently published research paper on a single South African premier league football club, it was found that 21% of all injuries sustained during a professional season were to the ankle, with the average time lost to injury being eight days. This was found to be the main cause of injury, along with injuries to the thigh (n=27). Of these ankle injuries (n=27), 12% of these were recurrent (Calligeris et al. 2015).

At the New South Wales Institute of Sport at Concord Hospital, Sydney, a study on inversion sprain injuries from 1999 to 2002 found that 74% of study participants who have had inversion ankle sprain injuries still had persisting symptoms up to four years post-injury (Anandacoomarasamy & Barnsley, 2005). Patient ages ranged from 13 – 28 years, included both sexes and competed in a variety of sport. These persisting symptoms did not prevent them from returning to sport; however, the study was questionnaire-based and did not assess whether athletes returned to their previous level of competition (Anandacoomarasamy & Barnsley 2005).

Given that ankle injuries are so common in the sport of football it is relevant to explore why this joint is vulnerable. The anatomy, of the joint and the phases of healing will be briefly reviewed to provide context for this injury.

Anatomy

For the purpose of this dissertation, when referring to the ankle joint, we will be referring to the talocrural and subtalar joints. A brief description of each will be provided, as well as an overview of the surrounding musculature and the lateral ligament complex, which is the most common site of ankle injury in professional football players (Woods et al. 2003).

Joint Structure

The talocrural joint is formed by the articulation of the dome of the talus, the medial malleolus, the tibial plafond, and the lateral malleolus (the distal end of the fibula). The shape of the talocrural joint allows torque to be transmitted from the lower leg (internal and external rotation) to the foot (pronation and supination) during weight bearing. This joint may be thought of as a hinge joint that allows the motions of plantar flexion and dorsiflexion (Hertel 2002).

The subtalar joint is formed by the articulations between the talus and the calcaneus and, like the talocrural joint; it converts torque between the lower leg and the foot. The subtalar joint allows the motions of pronation and supination (Hertel 2002).

Surrounding muscles

The muscles around the ankle joint generate stiffness when contracted leading to dynamic protection of the joints. The peroneas longus and brevis muscles are important in the control of supination of the rearfoot and provide protection against lateral ankle sprains (Ashton-Miller 1996). In addition, the muscles of the anterior compartment of the lower leg (anterior tibialis, extensor digitorum longus, extensor digitorum brevis, and peroneus tertius) may also contribute to the dynamic stability of the lateral ankle complex by contracting eccentrically during forced supination of the rearfoot. Specifically, these muscles may be able to slow the plantar flexion component of supination and thus prevent injury to the lateral ligaments (Sinkjaer T, Toft E, Andreassen S 1988).

Lateral Ligaments

The lateral ligaments of the ankle consist of five ligaments: (1) anterior talofibular ligament (ATFL), (2) calcaneofibular ligament (CFL), (3) posterior talofibular ligament (PTFL), (4) cervical ligament, and (5) lateral talocalcaneal ligament.

The ATFL is really a thickening of the tibiotalar capsule that originates from the anterior border and tip of the lateral malleolus and runs anterior to insert on the neck of the talus. It is 6 mm to 10 mm wide, 20 mm long and 2 mm thick. It runs almost parallel to the axis of the neutral foot, except when the foot is in plantar flexion, the ligament courses parallel to the axis of the leg.

Most sprains occur when the foot is in plantar flexion, making this ligament the most frequently injured in inversion sprain injuries (Renström & Lynch 1998).

Hertel et al (Hertel 2002)reported that in vitro kinematic studies have shown that the ATFL prevents anterior displacement of the talus from the ankle mortise and excessive inversion and internal rotation of the talus on the tibia (Hertel 2002). The strain in the ATFL increases as the ankle moves from dorsiflexion into plantar flexion. The ATFL demonstrates lower maximal load and energy to failure values under tensile stress as compared with the PTFL, CFL, anterior inferior tibiofibular ligament, and deltoid ligament. This may also explain why the ATFL is the most frequently injured of the lateral ligaments (Cass & Harry Settles 1994). The reader is referred to page 274 of Sobatta: Atlas of Human Anatomy Volume 2 for a diagram of the ankle and its supporting ligaments.

It is not only the anatomy of a joint which may predispose to injury and re-injury. In particular, in the case of recurrent injuries, it is essential to consider injury healing processes to develop insight into factors which may contribute to re-injury or delayed healing.

Injury/wound healing

Wound healing begins at the moment of injury and the healing thereof can be loosely summarized into four phases (Diegelmann & Evans 2004) , although some group haemostasis in the acute phase and not as a phase on its own (as in the table below) (Stadelmann et al. 1998). These mechanisms are initiated at the time of physical injury and proceed continuously throughout the repair process and sometimes overlap when transitioning form one phase to the next. The phases and their physiological processes are described in the table (Table 1) below:

Table 1: Phases of healing

	Acute	Subacute/fibroblastic	Remodelling
Physiological processes	Haemostasis, inflammatory mediators and phagocytosis (neutrophils, macrophages)	Epithelialization, fibroplasia and angiogenesis	Collagen cross linking and modelling
Clinical symptoms	Increased temperature, swelling, pain, erythema, decreased ROM	Increased ROM, decreased pain, decreased erythema, discolouration (blue, green, yellow)	Resolution of acute and subacute symptoms
Approximate time	0 – 7 days	3 days – 3 weeks	3 weeks – 2 y

Acute Phase

Immediately after injury, coagulation and haemostasis take place in the wound. The principal aim of these mechanisms is to prevent exsanguination. A second aim is a long-term one, which is to provide a matrix for invading cells that are needed in the later phases of healing (Broughton et al. 2006). The neutrophils begin to be attracted to the wound site within 24 – 36 h of injury. Once in the wound environment, neutrophils phagocytose foreign material and bacteria. In the late inflammatory phase, 48 – 72h after injury, macrophages appear in the wound and continue the process of phagocytosis. The last cells to enter the wound site in the late inflammatory phase are lymphocytes, attracted 72 h after injury by the action of interleukin-1 (IL-1). The IL-1 plays an important role in collagenase regulation, which is later needed for collagen remodelling, production of extracellular matrix components and their degradation. When ongoing injury has ceased, haemostasis has been achieved and an immune response successfully set in place, the acute wound shifts toward tissue repair (Velnar & Bailey 2009).

The subacute phase

The proliferative phase starts on the third day after wounding and lasts for about 2-3 weeks thereafter. Fibroblasts first appear in the wound on the third day after injury. Wound contraction, which is an important event in the reparative process that helps to approximate the wound edges, then takes place as these cell extensions retract. Collagens are an important component in all phases of wound healing and are synthesized by fibroblasts. Modelling and establishment of new blood vessels is critical in wound healing and takes place concurrently during all phases of the reparative process (Velnar & Bailey 2009).

Remodelling phase

As the final phase of wound healing, the remodelling phase is responsible for the development of new epithelium and final scar tissue formation. This phase may last up to one or two years. The remodelling of an acute wound is tightly controlled by regulatory mechanisms with the aim of maintaining a delicate balance between degradation and synthesis, leading to normal healing. The tensile strength of the wound increases progressively in parallel with collagen collection. Collagen fibres may regain approximately 80% of the original tensile strength compared with unwounded tissue, Stadelmann et al reports that the wound only regains about 70% of the undamaged tissue (Stadelmann et al. 1998) while Diegelmann et al reports approximately 80% (Diegelmann & Evans 2004). The acquired final strength depends on the localization of the repair and its duration, but the original strength of the tissue can never be regained (Velnar & Bailey 2009). Synthesis and breakdown of collagen as well as extracellular matrix remodelling take place continuously and both tend to equilibrate to a steady state about three weeks after injury. Following injury, the healing time may be shorter when there is less injured tissue (Velnar & Bailey 2009)

As can been seen from the approximate injury healing times and the underlying physiology, most ankle sprains should be completely asymptomatic within a few weeks of the injury incident, yet some still experience symptoms, such as pain and functional impairment, more than a year after injury (Anandacoomarasamy & Barnsley 2005). This makes finding the cause of symptoms very difficult for the clinician, especially if there is no obvious anatomical abnormality. Assuming the physiological phases of healing occur optimally without disruption, the factors contributing to the latent symptoms and the risk of re-injury may therefore not only be related to the anatomical site of injury. The factors contributing to risk of re-injury may therefore be related to the management of the injury.

Conventional management of lateral ankle sprains

Conventional treatment for ankle sprains includes relative rest, ice, compression, elevation (RICE), immobilization, ultrasound, acupuncture, electrotherapy, laser therapy, joint mobilization, soft tissue mobilization, proprioception training, concentric and eccentric strengthening of the peroneal muscles, bracing and taping (Kim et al., 2014; Dubin, Comeau, McClelland, Dubin, & Ferrel, 2011; Js et al., 2011; Kemler, Van de port, Bacx, & van Dijk, n.d). In a recent review of literature, the use of RICE and immobilisation was found to be useful during the inflammatory phase, bracing and exercise therapy was seen as beneficial, while manual therapy, ultrasound, electrotherapy and laser seemed to add no value (Kerkhoffs et al., 2012). Rehabilitation programmes that included balance and co-ordination training reduced the likelihood of recurrence during the first 12 months (Verhagen et al. 2004; Mcguine & Keene 2006; McKeon et al. 2008).

The same review found that a disturbance in proprioception caused by lateral ankle injury seemed to be occurring in the central nervous system above the level of the spinal reflex. Further, two separate studies found similar results with balance and postural control impaired following an ankle sprain (Akbari, Karimi, Farahini, & Faghihzadeh, 2006; Steib, Zech, Hentschke, & Pfeifer, 2013). Akbari et al concluded that balance problems occur after an ankle injury due to deficits in proprioception, and that the unconscious, reflexive aspect of proprioception is more affected than the conscious aspect. This conclusion was reached after evaluating ankle sprain injuries using the star excursion test and functional reach with eyes open, then closed and comparing results. The assumption was that balance control requires an integration of the vestibular system, somatosensory and visual stimulus and that by removing the visual stimulus, the person's ability to maintain balance then relies solely on the vestibular and somatosensory systems. Thus, rehabilitation focussing on balance and proprioception training affects several central nervous system (CNS) circuits including the somatosensory cortices (Akbari et al., 2006).

In a randomized controlled trial investigating the effect of a balance training program on the risk of ankle sprain injuries in high school athletes, it was found that the inclusion of a balance training program reduced the risk of injury by 56% (Mcguine & Keene 2006). Similarly, a 2005 study found that the incidence of ACL rupture decreased by 88% and 74% in a one and two year follow up respectively, following the implementation of a proprioceptive and neuromuscular training program of 1885 female football players (Mandelbaum et al. 2005), emphasizing the role proprioception training has on reducing the incidence of recurrent lower limb injuries.

The results of a study of eight right chronic ankle instability participants and 10 control participants that underwent functional magnetic resonance imaging to detect cortical activation in sensorimotor areas while performing an ankle tracking task and using electromagnetic motion capture during a step down task support that processing differences exist at the cortical level between chronic ankle instability and healthy control participants and that motor performance differences are also present (Anderson 2008).

Despite this large list of treatment options, and studies exploring a multitude of intrinsic (such as career duration, mechanical instability and increased age) and extrinsic factors (such as playing surface and low training to match ratio) thought to increase risk for ankle sprains, a previous sprain still appears to be the main predictor of the likelihood of a future ankle injury (Arnason, 2004). Arnason et al also states, "…a multivariate model is needed to examine the contribution of the various factors in injury etiology and to explore their interrelationship". Chronic ankle injuries have also been referred to as: lateral ankle instability, chronic ankle instability (CAI), chronic lateral ankle instability, ankle instability, residual ankle instability, chronic instability, recurrent instability, recurrent lateral ankle instability and chronic ankle sprain (Hiller, Kilbreath, et al. 2011).

A Cochrane review found that 10% to 20% of people will develop chronic ankle instability after an ankle sprain (De Vries et al. 2011) and the likelihood of developing impairment and active limitation is independent of the severity of the initial injury and is not confined to the injured limb. Symptoms have also been reported in the contralateral ankle of 85% of people who develop CAI, after a unilateral sprain (Hiller et al., 2011).

Chronic Ankle Instability (CAI) – two different types

Impairments associated with CAI include increased ligament laxity and proprioceptive deficits. Two main subgroups of CAI are widely accepted: 1) mechanical instability (resulting from a ruptured ATFL/grade 3 lateral ankle injury); and 2) functional instability, thought to result from functional insufficiencies such as impaired proprioception and neuromuscular control which is the focus of this study (Hiller et al., 2011).

An assessment technique that evaluates multiple insufficiencies is the Star Excursion Balance Tests. These tests are a series of dynamic postural-control tasks that require stabilization on one lower limb and a functional reach with the contralateral lower limb in different directions. Adequate postural control, strength, and range of motion must be present to optimally execute these tasks. Olmsted et al demonstrated impairment in performance on the Star Excursion Balance Tests among a group of athletes with chronic ankle instability (Olmsted et al. 2002). This finding complements a previous paper (using EMG and vibration sensation testing), which concluded that both local sensory and proximal muscle function changes are associated with a unilateral ankle sprain (Bullock-saxton 1994). It was also found in a systematic review of eight studies that evidence suggests that using an ankle brace or ankle tape has no effect on proprioceptive acuity in participants with recurrent ankle sprain or who have functional ankle instability (Raymond et al. 2012). This also suggests that a lateral ankle instability is not as a result of a mechanical abnormality.

Wikstrom et al (Wikstrom et al. 2010) also found that postural control differs between those with and those without chronic ankle instability and between copers (individuals who return to high level activity without recurrent injury or loss of function) and non-copers (individuals who develop CAI). Furthermore, it was found that fatigue negatively affects dynamic postural control in individuals suffering from chronic ankle instability when comparing them against healthy controls (Gribble et al. 2004). This indicates a neuromuscular impairment as a result of an association between CAI and fatigue, i.e., it is possible that some athletes suffering from CAI require a conscious effort to prevent recurrence of an ankle sprain injury and are at a higher risk of re-injury when fatigue affects concentration during activity.

In a review of 20 trials comparing surgical to conservative management of acute lateral ligament injuries (clinical injury grades not mentioned), there was evidence of longer recovery times, higher incidences of ankle stiffness, impaired ankle mobility and complications following ankle surgery compared to a non-operative management approach (Kerkhoffs et al. 2010). This suggests that surgical intervention may not be indicated in the treatment of chronic ankle instability in professional football players and that proprioception training is more beneficial to the management of chronic ankle instability than other more conventional physiotherapy treatment modalities. This finding was similar to that of De Vries et al who also came to the conclusion that there is currently insufficient evidence to support surgical intervention (De Vries et al. 2011).

The absence of any distinct anatomical abnormalities in functional CAI in the literature above points to a possible different cause of recurrent lateral ankle sprain that has not been investigated before in professional football players with chronic ankle instability. This cause could be a possible distortion of body image, similar to that which occurs in patients with complex regional pain syndrome.

Complex Regional Pain Syndrome

Complex regional pain syndrome (CPRS) has been known by many names, but most commonly as reflex sympathetic dystrophy, Sudecks Atrophy and causalgia. After much debate in the literature and at scientific meetings, the name was ultimately changed to complex regional pain syndrome at a consensus workshop in Orlando, Florida, in 1994, with the new name and diagnostic criteria codified by the International Association for the Study of Pain (IASP).

It is a painful disease with clinical features that include pain, sensory, sudomotor and vasomotor disturbances, trophic changes and impaired motor function (Mos et al. 2007). The disease varies from a relatively mild and self-limiting condition to a chronic disease with a high impact on daily functioning and quality of life (Galer et al. 2000). Usually, symptoms appear in one extremity, sometimes resulting from a relatively mild trauma, or surgery, but symptoms have also been described after varicella zoster infection and myocardial infarction (Merritt 2005).

Complex regional pain syndrome describes an array of painful conditions that are characterized by a continuing (spontaneous and/or evoked) regional pain that is seemingly disproportionate in time or degree to the usual course of any known trauma or other lesion. The pain is regional (not in a specific nerve territory or dermatome) and usually has a distal predominance of abnormal sensory, motor, sudomotor, vasomotor, and/or trophic findings. The syndrome shows variable progression over time (Harden et al. 2007).

The diagnosis of CRPS is based on the findings during the history and physical examination, for which diagnostic criteria have been developed. A workshop in Budapest, Hungary, in 2003 was held by 35 professionals from seven countries to discuss the diagnostic criteria (Harden et al. 2007) which led to the Budapest criteria being the most commonly used diagnostic criteria set used for the diagnosis of complex regional pain syndrome. In the past, it was diagnosed using a variety of non-standardized and idiosyncratic diagnostic systems, each of which was derived solely from the authors' clinical experiences and none of which achieved wide acceptance.

The clinical diagnostic criteria of the Budapest group are summarized below. To make the clinical diagnosis, the following criteria must be met:

1. Continuing pain, which is disproportionate to any inciting event;
2. Must report at least one symptom in three of the four categories listed in Table 2 (below);
3. Must display at least one sign at the time of evaluation in two or more of the categories in listed in Table 2 (below); and
4. There is no other diagnosis that better explains the signs and symptoms.

Table 2: Diagnostic categories for CRPS

Categories	**Sensory**	**Vasomotor**	**Sudomotor/Oedema**	**Motor**
Symptoms	Hyperesthesia, allodynia	Temperature , colour or sweating asymmetry	Oedema, sweating asymmetry or sweating changes	Decreased range of motion, weakness, tremor, dystonia, motor dysfunction or trophic changes (hair, nails, skin)

There is a growing body of evidence that suggests that perceived body image is distorted in the presence of pain, which can disrupt tactile perception (Lotze & Moseley, 2007). Pain, as the unavoidable result of movement, inhibits motor function, impairs proprioception, and restricts physiologic movement (Bank et al. 2013). The result is a dysfunctional movement pattern that reinforces musculoskeletal pain through improper weight-bearing. Over time, however, many symptoms result from a reorganization of the brain. Complex regional pain sufferers must concentrate on the affected extremity in order to use it, so that perception of body symmetry shifts to the affected side. The visual perception of the affected extremity is that of being too large (Moseley 2005) and somatosensory perception of the affected arm is delayed (Moseley et al. 2009) .

Further evidence of the adaptation of the central nervous system to pain is provided by magnetencephalography and fMRI. It has been demonstrated in a study of 10 CRPS patients that the representation of the affected extremity in the primary somatosensory cortex is altered and that a reduction of pain in the affected body part reverses it (Maihofner et al. 2004).

Maihofner et al also found that patients with allodynia have a stronger activation of the gyrus cinguli, while those with motor deficits have a stronger activation of the parietal lobe as seen on fMRI (Maihofner et al. 2007). In cases of chronic pain, a reduction in grey matter in a sample of CRPS patients was observed in the right insular cortex, the nucleus accumbens, and the ventromedial prefrontal cortex—regions important for stress processing (Geha et al. 2009). This same study concluded that while regional grey matter atrophy relates to pain intensity and duration, the strength of bidirectional connectivity between the atrophied regions relates to anxiety. These abnormalities encompass emotional, autonomic, and pain perception regions, implying that they likely play a critical role in the global clinical picture of complex regional pain syndrome. As the above literature is evidence of neuroplasticity of the central nervous system, verified by fMRI and magnetencephalography, treatment of the condition needs to involve both the affected limb and the central nervous system to restore normal somatosensory representation in the somatosensory cortex (Pleger et al. 2005). The role of the primary somatosensory cortex in CRPS is well described in a review by Pietro et al and beyond the scope of this dissertation (Pietro et al. 2013).

Behavioural treatment implemented up to a six-month period consisting of pain-adapted sensorimotor treatment protocols led to a persistent decrease in pain intensity, which was accompanied by a restoration of the impaired tactile discrimination and regaining of cortical map size in the contralateral primary and secondary somatosensory cortex. This was done in the absence of any adjustments to pain medication (Pleger et al. 2005). This suggests that the reversal of tactile impairment and cortical reorganization in CRPS is associated with a decrease in pain and that altered representation in the somatosensory cortex is associated with worse sensitivity on two point discrimination testing. No reliability or validity data was provided in the article for the treatment protocols which decreases the reliability and generalization of the results (Pleger et al. 2005).

In a study of 135 patients with complex regional pain syndrome, it was found that physiotherapy, and to a lesser extent occupational therapy, were helpful for reducing pain and improving active mobility in patients (Oerlemans et al. 1999). A review by Birklein et al (Birklein 2005) identified the following physiotherapy interventions as being beneficial, in addition to behavioural therapy components:

- *Mirror therapy*.

  The therapeutic process is based on the mirror image of the healthy extremity being seen in place of the affected extremity and as a result the functional impairment will be reduced. This is most effective in patients with acute CRPS.
- *Graded motor imagery*.

  This therapeutic approach involves first recognizing the right and left extremities. In a second step, imagined movement is introduced, and finally mirror therapy is conducted.
- *Pain-exposure physical therapy/graded exposure in vivo*.

  Pain-exposure physical therapy is a progressive-loading physical exercise program and management of pain-avoidance behaviour.

> Graded exposure in vivo first reduces irrational disease-related fears (e.g., worsening by movement) and identifies the most "dangerous" or "threatening" practice tasks, which then have to be faced step by step by the patients until fear and anxiety is reduced. (Birklein 2005)

Methods to assess for cortical distortion of perceived body image

Functional MRI (fMRI) has the capacity to measure hemodynamic responses to changing stimulus or task conditions with a high spatial and temporal resolution (Friston et al. 1998). While a participant performs a cognitive task, using fMRI we can obtain estimates of local blood flow (a proxy for neural processing) from tens of thousands of neuroanatomical locations in the brain in a matter of seconds. This helps our understanding of what information is represented in different brain structures, how that information is processed and how the information is transformed at different stages of processing (Norman et al. 2006). As previously discussed, CRPS sufferers have a significant reorganization of cortical activity during certain activities involving the symptomatic limb (Maihofner et al. 2007; Maihofner et al. 2004). However, fMRI is a costly method of assessment and as a result, different assessment techniques commonly used to assess and treat CRPS were identified to assess for any cortical reorganization in football players with chronic ankle sprain injuries. The assessment techniques are discussed below with motivation for the inclusion of the assessment technique in the study.

Laterality Judgement Task Perception

Changes in laterality judgement task perception and two point discrimination threshold are associated with recorded changes in bodily representation in the primary and secondary somatosensory cortices (Moseley et al. 2005; Moseley 2008). The laterality judgement task test evaluates the ability of a person to recognise whether an image projected on a screen is of the left or right foot. Altered representation in the somatosensory cortex is associated with longer recognition time and a greater number of errors on the affected side (Moseley et al. 2005; Reinersmann et al. 2010). Three levels of difficulty have been developed for the test with images increasing in complexity from images with neutral backgrounds, to images in context and finally to abstract images (http://www.noigroup.com/en/Product/BTRON). This method of graded motor imagery involving a period of training in which the patient with CRPS is shown pictures of hands (or feet, if they have CRPS in a lower limb), and responds to each picture simply by recognizing it as a left hand or a right hand has been successfully used in the assessment and treatment of CRPS patients with consistently good results (Moseley et al. 2005; Bowering et al. 2013; Moseley 2006; Hudson et al. 2006; Moseley 2004). Validity and reliability data on the Noigroup product for laterality judgement task perception was not found, decreasing the reliability and generalization of results found using this test.

Two-Point Discrimination

According to the McGraw-Hill Concise Dictionary of Modern Medicine © 2002, two-point discrimination is defines as: “The ability to localize two points of pressure on the surface of the skin and to identify them as discrete sensations”. The test involves the use of a digital callipers on the patient’s skin, who is then asked to report whether one or two points is felt and the smallest distance between two points that still results in the perception of two distinct points is recorded as the patient's two-point threshold (Moseley 2008). In a study investigating graded sensorimotor retuning, it was Pleger et al found that “Patients with complex regional pain syndrome (CRPS) and intractable pain showed a shrinkage of cortical maps on primary (SI) and secondary somatosensory cortex (SII) contralateral to the affected limb” (Pleger et al. 2005). Using fMRI, this shrinkage of the cortical maps of the primary and secondary somatosensory cortices was paralleled by an impairment of the two-point discrimination thresholds (Pleger et al. 2005). This method of assessment is supported by a recent critical review of 16 studies testing altered tactile acuity in people with chronic pain (Catley et al. 2014).

Limb Perception

Body image or physical self-awareness depends on internal body maps that are controlled by somatic and proprioceptive input. This self-awareness is sometimes disruptive in patients suffering from pain disorders. Moseley et al found that when asking patients suffering from chronic lower back pain to draw an outline of their back, they struggled to complete the drawing at the site corresponding to their painful area on the body. A control group of healthy individuals had no such problem. The disrupted body image of the back coincided with disrupted tactile acuity in the same area and both corresponded to the patient's area of chronic back pain. This indicates a cortical representation that is markedly different from the control group (Moseley 2008). Similarly, altered limb perception is also theorised to be associated with cortical representation of the painful affected body part (Moseley 2008).

Summary of the Literature

Ankle sprains are one of the leading causes of injuries in professional football (Dvorak et al. 2007) which sometimes becomes a recurring injury due to a variety of factors. A chronic ankle sprain injury is a challenging and frustrating injury to manage for both the medical professional and the professional athlete who experiences it. Although there has been a large amount of research investigating the cause and management thereof, the highest predictor of a future ankle sprain injury is previously having had one (Beynnon et al. 2002). Research has shown that some therapeutic interventions are more beneficial than others (particularly balance and proprioception training) (Akbari et al. 2006; Steib et al. 2013), yet to date, no research has investigated the effect of a chronic ankle sprain injury on the ankles cortical representation in the brain. Most research focuses on the anatomical site of injury and its rehabilitation, without considering the possible changes to the structures involved in the control and perception of the injured limb.

The aim of this paper is to investigate whether any central nervous system changes are present in professional football players with chronic ankle injuries, using inferred results of the laterality judgement task, TPD and body image test, as this could lead to possible changes in the way that this condition is assessed and managed in the future.

Chapter 3 - Aims and Objectives

Aims

To determine whether there are changes in the primary and secondary somatosensory cortices of football players who have a history of recurrent ankle sprains

Objectives

The objectives of this study are:

In a group of football players with a history of recurrent ankle sprains and a matched non-injured group:

1. To determine whether there are any changes in the somatosensory representation of the affected areas of both groups using:
    a. Laterality judgement task testing (Dey et al. 2012)
    b. Limb perception drawing (Moseley 2008)
    c. Two-point discrimination testing (Moseley 2008)
2. Where differences exist, to determine whether differences are associated with:
    a. limb dominance; rehabilitation;
    b. number of occurrences of injury;
    c. age and
    d. BMI.

Chapter 4 - Methodology

A descriptive cross-sectional analytical study was conducted.

Participants

Study participants were all recruited from a professional first division football club in Cape Town. As a result of the investigator having worked closely with professional football players in Cape Town, a sample of convenience was used as it was thought to facilitate recruitment.

Sample Size

A total of 25 professional football players (age: 24.6y ± 4.49) were tested, with the group divided into the experimental group of 13 injured (previous ankle sprain injuries) and control group of 12 non-injured players (no history of ankle injuries).

Recognition time on the laterality judgement task test was selected to determine the required sample size, as this was the main outcome measure for this study, and may have the greatest degree of standard deviation of all the parameters to be measured in the study. Based on a previous study utilising a motor imagery task to evaluate laterality (Dey et al. 2012), required sample size was calculated using a smallest meaningful difference of 3015.4 ms, and a standard deviation of 1330 ms. With statistical significance accepted as $p < 0.05$, a group of 11 participants would provide 95% statistical power.

Inclusion and Exclusion Criteria

The experimental group consisted of healthy professional male football players between the ages of 18 and 35. They must have sustained at least two lateral ankle injuries within the last 12 months, with the last injury occurring a minimum of six weeks prior to testing. The severity of injuries must have been classified as at least "minor" according to the FIFA classification of injury severity i.e. a minimum of four days off training or match play (Woods et al. 2003). Bilateral ankle injuries were excluded.

The control group included healthy professional male football players, with no current lower limb injuries, between the ages of 18 and 35 with no history of ankle injury. Participants were excluded from the experimental and control groups if there was a history of lower limb surgery.

Recruitment Process

All participants were recruited from a professional football teams in Cape Town. They were contacted via their coaches and physiotherapist and were asked if they would be willing to participate. Each potential participant was given an informed consent form explaining the purpose of the study and the process it entails (Appendix 2). After agreeing to participate, all participants were asked to read and sign the informed consent form before continuing any further in the process

Questionnaire

A medical and injury history questionnaire was used to document participant demographics, injury and playing history (Appendix 3). Participants were requested to provide information on any specific ankle injury that may be relevant to this study, past and present.

Procedure

All testing occurred at Vasco Da Gama Football Club in Parow Cape Town before the onset of training sessions. All participants who completed the questionnaire and were deemed eligible for testing were tested that same day.

Anthropometry

Participant's body mass was assessed on a scale calibrated to the South African National Accreditation Standard (SANAS) standard with an auto zero tracking facility (Clover scale model: TCS); while height was assessed on a flat concrete floor using a tape measure attached to the wall. A sum of four skinfolds was taken (triceps, biceps, subscapular, and suprailiac). All data were collected by the same investigator who had been trained in and was familiar with the skinfold testing procedure.

Laterality Judgement Task

The NoiGroup Recognise ™ product was used for this test (http://www.noigroup.com/en/Product/BTRON) and was administered to the participant on an iPad utilizing all three available testing formats – vanilla, context and abstract. Forty images were randomly displayed for 5 seconds in different positions and rotated zero, 90, 180 and 270 degrees. Forty images from each level of complexity were completed as a group. Following a short break, the next levels of images are then evaluated. The time between the image appearing on screen and the participant reacting by pressing a button indicating left or right was timed and accuracy was recorded. Reaction time and correct answers were then compared between left and right images for each level of complexity.

Two-Point Discrimination

Two-point discrimination was tested in millimetres (mm) using a digital calliper which was recalibrated between participants by approximating the two measuring surfaces to each other to achieve a 0 mm reading before testing the next patient. The calliper was also cleaned between participants. The points tested were: 2cm proximal to the lateral malleolus; 2cm below the lateral malleolus and; 2cm anterior to the lateral malleolus. The test was administered bilaterally after a trial on the participant's lower arm to familiarize them with the procedure.

The test began by explaining the procedure to the participant, followed by a trial on the participant's forearm. The participant was instructed to close his eyes and concentrate on the sensation in his forearm. The digital calliper was applied to the forearm with the "teeth" of the calliper making contact with the skin with enough pressure to cause blanching. The participant was then asked to comment on the amount of points he felt making contact with the skin. The "teeth" of the calliper was then lifted off the skin and gradually widened at random intervals and reapplied to the participant's skin and comment for the amount of calliper points making contact with the skin was requested again. This process was repeated until the participant distinctively felt two points making contact with the skin and not one. Once the investigator felt that the participant was comfortable and adequately understood the test, the test was repeated on the ankle in the above mentioned anatomical areas around the lateral malleolus. Both ankles on all participants were tested.

Limb Perception

This test is similar to a study in chronic lower back pain (Moseley, 2008) and instructions given to participants were similar:

Concentrate on your foot and ankle. Add to this a drawing by following the outline of your own foot and ankle as you track it in your mind. Concentrate on where you feel your foot and ankle to be. Also draw in the bones that you can feel. Do this without touching your foot. Your drawing should relate to your own sense of your foot and ankle. Don't draw any part that you cannot sense. Do not draw what you think your foot looks like, draw what it feels like.

Participants were requested to complete a drawing of the lateral surface of their foot without looking at it or touching it using a pre-printed image of a partially drawn foot and ankle (Appendix 4). An example of a completed drawing is given in Appendix 6. The size of each drawing (cm^2) was determined by overlaying the original drawing with grid paper and differences compared.

This study used the previously mentioned tests, which were developed and used in the assessment of complex regional pain syndrome and other chronic pain conditions, to evaluate if similar cortical reorganization is present after a recurrent ankle sprain. The investigator conducted pilot tests on three participants prior to testing to ensure familiarity with testing procedures, to reduce any testing errors and to ensure intra-rater reliability.

Statistical Analyses

Data Analysis

A visual inspection of a graph of one of the main outcome measure (paired two tail t-test on accuracy on laterality judgement task recognise test) data was conducted and the data were seen to be normally distributed (Figure 1).

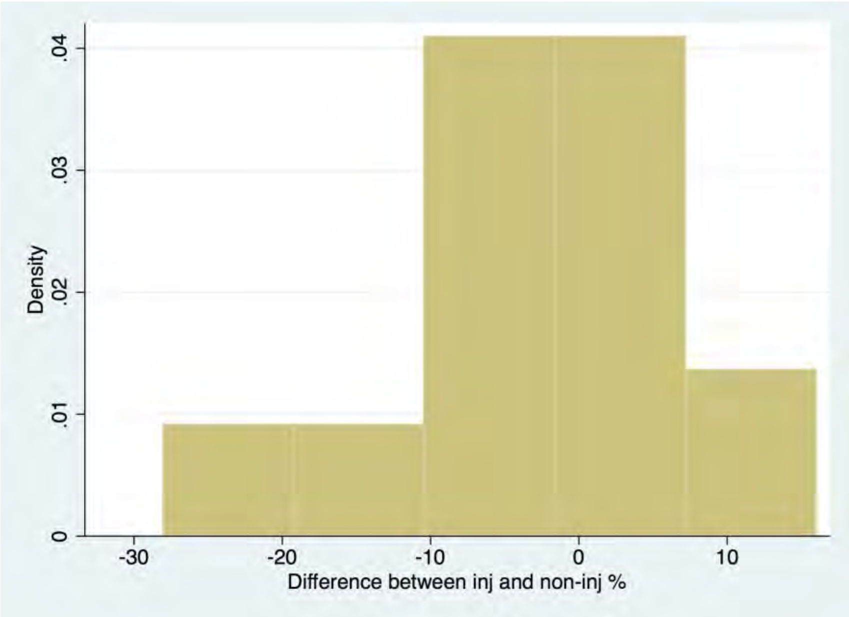


Figure 1: Graph of Laterality judgement task recognition accuracy differences within groups between limbs (%)

The data was further analysed in STATA (data analysis and statistical software) and results for a Shapiro-Wilk W test for normal data (p = 0.21668), Skewness/Kurtosis tests for Normality (p = 0.1393) and a Two-sample Kolmogorov-Smirnov test for equality of distribution functions (p = 0.480) were unremarkable and not significant indicating a normal distribution of data. As a result, all data collected were assumed to be normally distributed and parametric analysis (two-tailed t-tests) were conducted. Data is displayed in table format in the results section.

Ethical Considerations

The study proposal was presented to the UCT Division of Physiotherapy for internal review. Following corrections and suggestions, the study proposal was submitted to the Faculty of Health Sciences Human Research Ethics Committee, University of Cape Town and approved without further recommended changes to the study design or methodology (HREC: 415/ 2013) (Appendix 1). The study was conducted observing the principles outlined in the Declaration of Helsinki (WMA 2013).

An informed consent form (Appendix 2), which explains the purpose of the study, voluntary participation, the right to withdraw from the study at any time and confidentiality, was read by each participant, who then had an opportunity to request clarification on any part of the study they did not understand completing the questionnaire (Appendix 3). All data were kept confidential.

Risk to participants

There were minimal risks to participants during the testing procedure. Any discomfort caused by the callipers during skinfold testing was a sensation the football players were accustomed to, as skinfold testing is conducted several times during the professional football season to monitor the players' physical condition throughout the playing year.

Benefits to participants

Participants were provided with information on the pathophysiology of chronic ankle sprains and treatment advice was given to the medical staff based on the findings of this study. Anthropometric data was shared with the tested individuals, who requested it.

Chapter 5 - Results

Descriptive Characteristics

Demographics

As seen in Table 3, participants in both groups were evenly matched for age, height, weight, BMI, lean body mass and predicted percentage body fat.

Table 3: Physical characteristics of the participants (mean ±sd)

	Sample (N=25)	**Injured (n=13)**	**Non-injured (n=12)**	**Statistical test**
Age (y)	24.6 ± 4.5	25.1 ± 4.9	24.1 ± 3.9	t=0.54, p=0.60
Height (cm)	176 ± 7	176 ± 8	175 ± 6	t=0.27, p=0.79
Weight (kg)	73 ± 8	71 ± 8	75 ± 8	t=-1.11, p=0.28
BMI	23.65 ± 1.66	23.10 ± 1.42	24.24 ± 1.69	t=-1.74, p=0.10
Sum of skin folds (mm)	37 ± 11	37 ± 10	37 ± 12	t=0.03, p=0.98
Lean body mass (kg)	67 ± 7	66 ± 6	69 ± 7	t=-1.23, p=0.23

Football Playing History

Both injured and non-injured groups had a similar amount of training and playing time over their football playing careers and a similar amount of game time over the previous six months before testing (Table 4).

Table 4: Football playing history (mean ±sd)

	Sample (N=25)	**Injured (n=13)**	**Non-injured (n=12)**	**Statistical test**
Total years playing football	16.4 ± 4.68	17.62 ± 4.01	15.08 ± 4.99	t=1.33, p=0.20
Total years playing professional football	6.46 ± 4.96	5.85 ± 5.08	7.13 ± 4.74	t=-0.62, p=0.54
Game time played in last 6 months (min)	885.40 ± 524.46	802.69 ± 623.74	975.00 ± 368.95	t=-0.81, p=0.43

Injury History

There were a total of 29 lateral ankle injuries among the previously injured group (n=13) (Table 5). The participants' self-reported average time taken to recover (declared fit to play by the club's medical staff) from the first injury was 28.15 days (±22.77) days while subsequent injuries recovered faster with the second and third injuries taking 15.46 (±15.02) and 18.67 (±3.3) days respectively.

Table 5: Injury History (mean ±sd)

	1st injury	2nd injury	3rd injury
Total amount of left ankle injuries	4	4	1
Total amount of right ankle injuries	9	9	2
Months since ankle injury	43.50 ± 37.46	29.08 ± 39.84	9.67 ± 10.14
Time off play (days)	28.15 ± 22.77	15.46 ± 15.02	18.67 ± 3.30

Tests for Changes in Cortical Representation

Laterality Judgement Task

There were no significant differences in accuracy when identifying laterality judgement task of limbs in images within groups (Table 6). In other words, both the injured group and the non-injured group were equally accurate in recognising the laterality judgement task of a limb in images for both the left and right or the injured and non-injured limb.

Table 6: Laterality judgement task recognition accuracy differences within groups between limbs (%) (mean ±sd)

Images	Injured side % correct	Non-injured side % correct	Statistical test
Vanilla Injured group	91.54 ± 9.24	93.15 ± 5.05	t=-0.53, p=0.60
Context Injured group	88.00 ± 13.35	92.54 ± 9.55	t=-0.96, p=0.35
Abstract Injured group	84.62 ± 10.57	82.38 ± 9.69	t=0.53, p=0.59
	Left % correct	Right % correct	
Vanilla Non-injured group	87.75 ± 9.94	92.75 ± 5.95	t=-1.43, p=0.17
Context Non-injured group	95.42 ± 7.78	95.50 ± 6.02	t= -0.03, p=0.98
Abstract Non-injured group	91.92 ± 7.85	91.92 ± 8.18	t=0, p=1.00

There were no significant differences between injured and non-injured groups in time taken to identify laterality of the images in the laterality judgement task recognition test (Table 7).

Table 7: Laterality judgement task recognition accuracy differences between groups (%) (mean ± sd)

	Injured Group (n=13)	Non-injured group (n=12)	Statistical test
Vanilla group limb differences	8.08 ± 6.90	5.67 ± 7.92	t=0.78, p=0.45
Context group limb differences	12.23 ± 10.84	5.08 ± 6.36	t=1.95, p=0.07
Abstract group limb differences	9.15 ± 8.65	4.67 ± 4.09	t=1.61, p=0.12

There were no significant differences within groups in time taken to identify laterality of images (Table 8).

Table 8: Laterality judgement task recognition time differences within groups between limbs (ms) (mean ± sd)

	Injured side	Non-injured side	Statistical test
Vanilla Injured group	1.53 ± 0.41	1.65 ± 0.51	t=-0.61, p=0.55
Context Injured group	1.64 ± 0.45	1.68 ± 0.59	t=-0.18, p=0.86
Abstract Injured group	1.76 ± 0.47	1.67 ± 0.56	t=0.43, p=0.67
	Left	Right	
Vanilla Non-injured group	1.55 ± 0.25	1.53 ± 0.20	t=0.25, p=0.80
Context Non-injured group	1.47 ± 0.28	1.52 ± 0.26	t=-0.43, p=0.67
Abstract Non-injured group	1.69 ± 0.20	1.59 ± 0.28	t=0.96, p=0.35

There were no significant differences when testing for laterality judgement task recognition time differences between groups (Table9).

Table 9: Laterality judgement task recognition time differences between groups (ms) (mean ± sd)

	Injured Group (n=13)	Non-injured group (n=12)	Statistical test
Vanilla group limb differences	0.24 ± 0.22	0.16 ± 0.16	t=1.00, p=0.33
Context group limb differences	0.30 ± 0.19	0.18 ± 0.12	t=1.78, p=0.09
Abstract group limb differences	0.22 ± 0.17	0.22 ± 0.23	t=-0.02, p=0.99

Two-Point Discrimination

There were no significant differences when testing for two-point discrimination differences between limbs within groups (Table10).

Table 10: Two-point discrimination within groups between limbs (mm)(mean ± sd)

Injured Group	**Position**	**Injured**	**Non-injured**	**Statistical test**
	Proximal	22.40 ± 9.51	20.43 ± 9.73	t=0.50, p=0.62
	Anterior	16.46 ± 8.73	20.65 ± 9.24	t=-1.14, p=0.27
	Inferior	19.45 ± 10.77	17.06 ± 7.96	t=0.62, p=0.54
Non-injured Group		**Left**	**Right**	
	Proximal	15.63 ± 6.50	13.95 ± 6.38	t=0.61, p=0.55
	Anterior	13.79 ± 6.44	14.85 ± 6.03	t=-0.40, p=0.69
	Inferior	15.97 ± 6.56	14.84 ± 7.75	t=0.36, p=0.72

In the between group analysis of two point discrimination, there were significant differences between groups at the site proximal to the lateral malleolus and anteriorly to the lateral malleolus (Table 11). The injured group had a significantly larger distance between the two points than the non-injured group i.e. the injured group was less able to discriminate between two points than the non-injured group. At the site of the inferior malleolus, the difference between groups was nearing significance (p = 0.06) (Figure 1).

Table 11: Two-point discrimination differences between groups (mm)(mean ± sd)

	Injured Group (n=13)	Non-injured group (n=12)	Statistical test
Proximal malleolus differences	**7.91 ± 7.51**	**3.07 ± 2.50**	**t=2.1, p=0.05**
Anterior malleolus differences	**9.52 ± 6.81**	**3.84 ± 2.02**	**t=2.76, p=0.02**
Inferior malleolus differences	11.01 ± 9.16	5.17 ± 3.78	t=2.03, p=0.06

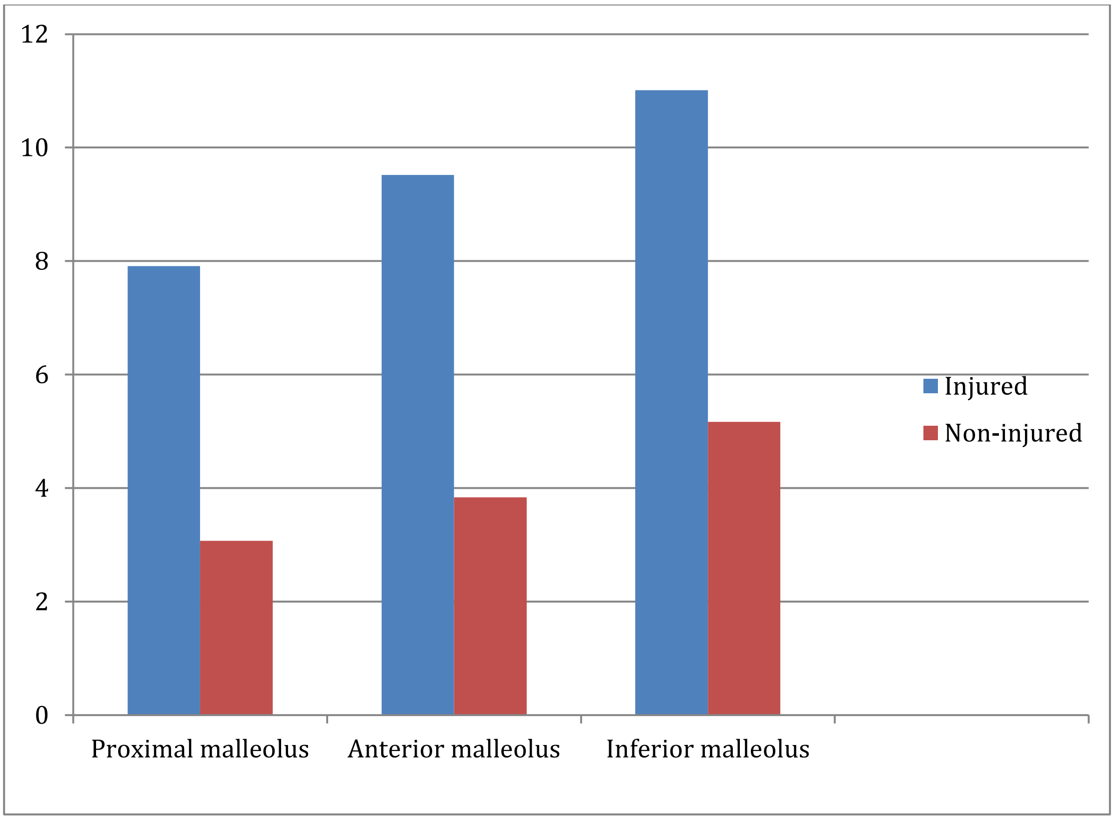


Figure 1 Comparison of mean differences of two-point discrimination test in three regions (proximal, anterior and inferior malleolus) between injured and non-injured athletes (mm)

Limb Perception

There were no significant differences in surface area of the limb drawings within groups (Table 12) or between groups (Table 13).

Table 12: Drawing surface area differences within groups between limbs (cm2) (mean ± sd)

	Injured side	Non-injured side	Statistical test
Surface area injured group	8.42 ± 1.17	8.94 ± 1.00	t=-1.17, p=0.25
Surface area non-injured group	11.75 ± 7.95	10.13 ± 6.44	t=0.52, p=0.60

Table 13: Drawing surface area differences between groups (mm2) (mean ± sd)

	Injured Group (n=13)	Non-injured group (n=12)	Statistical test
Surface area	1.13 ± 0.78	1.75 ± 1.87	t=-1.02, p=0.33

Summary of Results

Results of the laterality judgement task tests yielded no significant differences between the injured and non-injured groups, nor did it show any differences between injured and non-injured limbs in the injured population. However, the results for the context images (the most challenging laterality judgement task task) were approaching significance for both accuracy (p=0.07) and time (p=0.09), with the injured group appearing to be less accurate in recognising affected limbs and taking longer to recognise affected limbs.

In the two-point discrimination test, there were statistically significant differences between groups at the sites proximal (p=0.05) and anterior (p=0.02) to the lateral malleolus, with the injured group having less sensitivity to two-point discrimination compared to the non-injured group. No differences were found in the limb perception drawings between groups or within groups.

Chapter 6 - Discussion

Introduction

The primary aim of the study was to determine whether there are changes in the primary and secondary somatosensory cortices of professional football players who have a history of recurrent ankle sprains. To achieve this, this study adopted techniques used in the assessment of CRPS and other chronic pain conditions to assess for changes in the cortical representation of the previously injured ankle. The tests used were: laterality judgement task testing, two-point discrimination and limb perception drawing. There was a positive finding with the two-point discrimination testing, with statistically significant differences between groups at the sites proximal and anterior to the lateral malleolus.

Descriptive Characteristics

A sample of convenience of 25 male first division professional football players, all from the same football club, in Cape Town was used. With statistical significance accepted as $p < 0.05$, a group of 11 participants in a previous study of a similar nature (Dey et al. 2012) provided 95% statistical power, indicating that with an injured population of 13, this study sample size should have been be large enough to detect any meaningful differences.

The two groups were well matched for physical characteristics. The average age of the uninjured population was 24.08y (± 3.9y) and the injured population was 25.08y (± 4.92y). Both groups had a similar football playing history over their entire professional playing career and in the preceding six months to the testing. Both injured and uninjured groups were well matched physically for age, height, weight, BMI, predicted fat percentage and football playing history, enabling a fair comparison between the two groups.

Laterality Testing

There were no significant differences when testing for Laterality Judgement Task recognition differences between limbs for time or accuracy for all three different testing formats (vanilla, context and abstract. However, when looking at the differences between injured and non-injured groups, there were some values that were close to significant. The p-values of 0.07 and 0.09 were found in the context testing format between groups for accuracy and time respectively. Despite the study being adequately powered based on Dey et al's findings, these results may be a consequence of underpowering. Dey et al's population were different from those in the current study being children. It is possible that the testing was more sensitive in their population thus requiring a smaller sample than in a population of professional adult athletes. In addition, Dey et al tested laterality judgement task recognition of hands, given that the representation of the hand on the somatosensory homunculus is far larger than the representation of the feet, laterality judgement task testing of these limbs may be more sensitive than testing for feet. A larger sample size could provide more clarity on this as it may be able to pick up smaller significant differences between the groups.

Altered representation in the somatosensory cortex is associated with longer recognition time and a greater number of errors on the affected side (Moseley et al. 2005). These results hint at the possibility of somatosensory changes being present following an ankle injury, as the values found between the injured and uninjured groups are approaching significance between injured and uninjured limbs of the previously injured sample, with a small sample size perhaps limiting the likelihood of a significant finding. These results should be viewed as preliminary findings and need to be confirmed with further investigations and studies of this nature.

Two-point Discrimination Testing

Similar to the laterality judgement task testing, there were no differences between injured and non-injured limbs when testing for differences in the injured population during the two-point discrimination test. Recorded values were very similar with very small standard deviations once again hinting that any possible changes in cortical representation, which predisposes a football player to recurrent ankle sprain injuries, does not occur unilaterally, but in both hemispheres of the brain. This is a very similar finding to that of the laterality judgement task testing.

The two-point discrimination differences between injured and non-injured groups' results were very interesting. There were significant differences found at the sites proximal (p = 0.05) to the lateral malleolus and anterior to the lateral malleolus over the site of the anterior talofibular ligament (p = 0.02). The testing site inferior to the lateral malleolus had a near significant p-value (p = 0.06) and the values recorded for the inferior malleolus site of testing also had large standard deviations, which were similar to those found in the laterality judgement task testing between injured and non-injured groups.

Patients with complex regional pain syndrome (CRPS) and intractable pain show a shrinkage of cortical maps on the primary and secondary somatosensory cortex contralateral to the affected limb and this is paralleled by an impairment of the two-point discrimination thresholds (Pleger et al. 2005). As altered representation in the somatosensory cortex is associated with worse sensitivity on two point discrimination testing, we can speculate that there is possible correlation between the site of recurrent injury [the ATFL being the most commonly injured lateral ankle ligament (Renström & Lynch 1998) and representation of that site in the somatosensory cortices, similar to changes found in patients with CRPS.

Limb Perception Testing

The limb perception tests yielded no meaningful differences between the injured and non-injured limb in the previously injured population, nor did it reveal any meaningful differences between the injured and non-injured sample. This test has been theorised to be associated with cortical representation of the painful body part (Moseley 2008), so it may not be sensitive enough to yield results in the asymptomatic individual, as both previously injured and non-injured groups were asymptomatic and declared fit to play by their clubs medical staff at the time of testing.

Limitations of the Study

One of the limitations of the study, as mentioned above, was the small sample size. Despite appearing to be adequately powered using the data from Dey et al, the study may have been underpowered, limiting the possibility of finding any meaningful differences either within or between groups. The large variation in standard deviation could indicate under powering i.e. not enough numbers in the sample. Also, all of the injured players tested were available for selection to play, i.e. were considered fit to play by the clubs medical staff and were thus pain free. This differs to the studies where these assessment and treatment tools were used on symptomatic patients (Lotze & Moseley 2007; Moseley 2006; O'Sullivan 2005; Pleger et al. 2005; Moseley 2008; Reinersmann et al. 2010). It raises the possibility that the tests used are not sensitive enough to detect differences in asymptomatic, previously injured football players. A larger sample size may be required as the variability in results in the asymptomatic previously injured football player may be greater than those with a recent injury that is still causing pain. This could be addressed by testing injured players while they are still symptomatic, before being declared fit to play by the football club medical staff, and by increasing the sample size. Differences in the results of the tests may be primarily due to a difference in the sensitivity of each test (laterality judgement perception task, two-point discrimination and limb perception testing). However, the difference in results may also be a reflection of different cortical areas being activated in association with the somatosensory cortices.

Another limitation was that the study was restricted to one professional football club. While this helps control for different coaching philosophies, injury management, group physical condition and training history, it does limit the study as it does not give any indication of possible test result variations that may result from differences in training methods or injury management at different professional clubs. Further research could compensate for this by replicating this study at a few different professional football clubs in South Africa thereby increasing the generalizability of the results.

A further limitation was the gender of the sample. As the entire sample was of professional male football players, the results and conclusions should not be used to draw conclusions for a similar female population. This limitation can be overcome by repeating the research on professional female football players (with the previously mentioned changes), but this study would have to be conducted abroad where female professional football leagues exist, as women's football in South Africa is still largely an amateur sport.

Clinical Implications of the Study

More studies of this nature would have to be conducted before a direct correlation between chronic ankle sprain injury and altered somatosensory representation in professional football players can be assumed. Further research would have to include more participants from multiple professional teams, spread across different playing divisions and leagues, both local and international.

Despite the need for further studies, the preliminary results of this study do raise the possibility that a direct correlation between chronic ankle sprain injury and altered somatosensory representation in professional football players is indeed the case, especially when compared with the results of previous studies, which show that processing differences exist at the cortical level between chronic ankle instability sufferers and healthy controls (Anderson 2008). Given that balance and proprioception training have been shown to be more effective at reducing injury recurrence than all the other locally applied treatment modalities and strength training (Mcguine & Keene 2006; McKeon & Hertel 2008; Olmsted et al. 2002; Akbari et al. 2006; Verhagen et al. 2004; Steib et al. 2013; Verhagen & Bay

2010; Hiller, Kilbreath, et al. 2011) and that balance and proprioception training directly affect several central nervous system (CNS) circuits, including the somatosensory cortices (Akbari et al. 2006), this study adds credibility to the hypothesis that central nervous system changes are a possible cause of recurrent ankle sprain injuries and that these changes could occur after a single ankle injury.

Treatment techniques used in complex regional pain syndrome (such as graded motor imagery) target the changes recorded in the somatosensory cortices. These techniques could easily be applied in the clinical setting, without risk of adverse side effects, and should be considered for ankle sprain rehabilitation programs, along with dynamic balance control and proprioception training to minimize the risk of recurrent injury.

Chapter 7 - Summary and Conclusion

Chronic ankle pain is a leading cause of injury in amateur and professional athletes (Rosa & Fernandes 2014; Woods et al. 2003), and it is well-established that a previous ankle injury is one of the main risk factors for further injury (Arnason 2004). Research to date has investigated a large amount of different treatment and rehabilitation techniques, treatment modalities and exercise (Kim et al. 2014; Dubin et al. 2011; De Vries et al. 2011; Kemler et al. 2011; Kerkhoffs et al. 2012; van den Bekerom et al. 2013) without being able to find a definitive solution in reducing the recurrence of such a common injury, although some rehabilitation exercises focusing on balance and proprioception were found to be superior at reducing the risk of re-injury over other treatments (Akbari et al. 2006). A Cochrane review found that up to 20% of people will develop CAI after an ankle sprain (De Vries et al. 2011); and that the likelihood of developing impairment and active limitation is independent of the severity of the initial injury and is not confined to the injured limb(De Vries et al. 2011). Symptoms have also been reported in the contralateral ankle in 85% of people who develop CAI, after a unilateral sprain (Hiller, Nightingale, et al. 2011). This literature lends credibility to this study's hypothesis that recurrent ankle sprain injuries may lead to central nervous system changes by altering cortical perception and control of the injured limb.

This study set out to determine whether were changes in the primary and secondary somatosensory cortices of football players with a history of recurrent ankle sprains. The two-point discrimination test revealed significant differences between the uninjured sample and the football players with a history of recurrent ankle sprain injuries. The main finding of this study was that injured players had significantly worse two point stimulus acuity around the lateral malleolus, compared to uninjured players. This indicates a possible reorganization of cortical representation when compared to uninjured players.

The findings of this study suggest that there is a possibility that professional football players with a history of recurrent ankle sprain injuries could have similar central nervous system changes in the cortical representation areas, as experienced by sufferers of complex regional pain syndrome. There is the possibility that greater differences may have been observed if the previously injured players were symptomatic at the time of injury.

Further studies of this nature with an increased sample size and testing the injured group while symptomatic should further enlighten the role of cortical representation changes in professional football players with chronic lateral ankle sprain injuries. In addition, it is recommended that techniques utilized in the treatment of complex regional pain syndrome be considered in the treatment regime of all lateral ankle sprain injuries.

Chapter 8 - References

Akbari, M. et al., 2006. Balance problems after unilateral lateral ankle sprains. *The Journal of Rehabilitation Research and Development*, 43(7), p.819. Available at: http://www.rehab.research.va.gov/jour/06/43/7/pdf/akbari.pdf [Accessed October 9, 2013].

Anandacoomarasamy, A & Barnsley, L., 2005. Long term outcomes of inversion ankle injuries. *British Journal of Sports Medicine*, 39(3), p.e14; discussion e14. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1725165&tool=pmcentrez&rendertype=abstract [Accessed January 19, 2014].

Anderson, K., 2008. *Movement Control And Cortical Activation In Functional Ankle Instability*. The University of Minnesota.

Anon, 2006. Big Count - FIFA.com. Available at: http://www.fifa.com/worldfootball/bigcount/index.html [Accessed January 9, 2016].

Arnason, A., 2004. Risk Factors for Injuries in Football. *American Journal of Sports Medicine*, 32(90010), p.5S–16. Available at: http://journal.ajsm.org/cgi/doi/10.1177/0363546503258912 [Accessed September 30, 2013].

Ashton-Miller, J., 1996. What Best Protects the Inverted Weightbearing Ankle Against Further What Best Protects the Inverted Weightbearing Ankle Against Further Inversion ? Evertor Muscle Strength Compares Favorably with Shoe. *The*

American Journal of Sports Medicine, 24(6), pp.800–809.

Bank, P.J.M. et al., 2013. Motor dysfunction of complex regional pain syndrome is related to impaired central processing of proprioceptive information. *The Journal of Pain : Official Journal of the American Pain Society*, 14(11), pp.1460–74. Available at: http://www.ncbi.nlm.nih.gov/pubmed/24064035.

van den Bekerom, M.P.J. et al., 2013. Management of acute lateral ankle ligament injury in the athlete. *Knee Surgery, Sports Traumatology, Arthroscopy*, 21(6), pp.1390–1395. Available at: http://cat.inist.fr/?aModele=afficheN&cpsidt=27252915 [Accessed October 9, 2013].

Beynnon, B.D., Murphy, D.F. & Alosa, D.M., 2002. Predictive factors for lateral ankle sprains: a literature review. *J Athl Train*, 37(4), pp.376–380. Available at: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12937558.

Birklein, F., 2005. Complex regional pain syndrome. *Journal of Neurology*, 252(2), pp.131–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15729516 [Accessed May 25, 2014].

Bowering, K.J. et al., 2013. The effects of graded motor imagery and its components on chronic pain: a systematic review and meta-analysis. *The Journal of Pain : Official Journal of the American Pain Society*, 14(1), pp.3–13. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23158879 [Accessed July 8, 2015].

Broughton, G., Janis, J.E. & Attinger, C.E., 2006. The basic science of wound healing. *Plastic and Reconstructive Surgery*, 117(7 Suppl), p.12S–34S. Available at:

http://www.ncbi.nlm.nih.gov/pubmed/16799372 [Accessed May 2, 2015].

Bullock-Saxton, J.E., 1994. Local Sensation Changes and Altered Hip Muscle Function Following Severe Ankle Sprain. *Physical Therapy*, (74), pp.17–28.

Calligeris, T., Burgess, T. & Lambert, M., 2015. The incidence of injuries and exposure time of professional football club players in the Premier Soccer League during football season. *South African journal of Sports Medicine*, 27(1), pp.27–30.

Cass, J.R. & Harry Settles, 1994. Ankle Instability: In Vitro Kinematics in Response to Axial Load. *Foot and Ankle International*, 15(3), pp.134–140.

Catley, M.J. et al., 2014. Is Tactile Acuity Altered in People With Chronic Pain? A Systematic Review and Meta-analysis. *The Journal of Pain*, 15(10), pp.985–1000. Available at: http://dx.doi.org/10.1016/j.jpain.2014.06.009.

Dey, A. et al., 2012. Are children who play a sport or a musical instrument better at motor imagery than children who do not? *British Journal of Sports Medicine*, 46(13), pp.923–6. Available at: http://bjsm.bmj.com/cgi/content/long/bjsports-2011-090525v1 [Accessed January 24, 2014].

Diegelmann, R.F. & Evans, M.C., 2004. Wound healing: an overview of acute, fibrotic and delayed healing. *Frontiers in Bioscience : a Journal and Vrtual Library*, 9(4), pp.283–289.

Dubin, J.C. et al., 2011. Lateral and syndesmotic ankle sprain injuries: a narrative literature review. *Journal of Chiropractic Medicine*, 10(3), pp.204–19. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3259913&tool=pmcentrez&rendertype=abstract [Accessed September 23, 2013].

Dvorak, J. et al., 2007. Medical report from the 2006 FIFA World Cup Germany. *British Journal of Sports Medicine*, 41(9), pp.578–581; discussion 581.

Friston, K.J. et al., 1998. Event-Related fMRI: Characterizing Differential Responses. *NeuroImage*, 7(1), pp.30–40. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1053811997903062.

Galer, B.S. et al., 2000. Course of Symptoms and Quality of Life Measurement in Complex Regional Pain Syndrome. *Journal of Pain and Symptom Management*, 20(4), pp.286–292. Available at: http://www.sciencedirect.com/science/article/pii/S0885392400001834 [Accessed December 14, 2015].

Geha, P.Y. et al., 2009. The brain in chronic CRPS pain: Abnormal gray-white matter interactions in emotional and autonomic regions. , 60(4), pp.570–581.

Gribble, P.A. et al., 2004. The Effects of Fatigue and Chronic Ankle Instability on Dynamic Postural Control. *Journal of Athletic Training*, 39(4), pp.321–329. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=535524&tool=pmcentrez&rendertype=abstract.

Harden, R.N. et al., 2007. Proposed new diagnostic criteria for complex regional pain syndrome. *Pain Medicine (Malden, Mass.)*, 8(4), pp.326–31. Available at: http://www.ncbi.nlm.nih.gov/pubmed/17610454 [Accessed May 25, 2014].

Hertel, J., 2002. Functional Anatomy, Pathomechanics, and Pathophysiology of Lateral Ankle Instability. *Journal of Athletic Training*, 37(4), pp.364–375.

Hiller, C.E., Nightingale, E.J., et al., 2011. Characteristics of people with recurrent ankle sprains: a systematic review with meta-analysis. *British Journal of Sports Medicine*, 45(8), pp.660–72. Available at: http://www.ncbi.nlm.nih.gov/pubmed/21257670 [Accessed October 19, 2013].

Hiller, C.E., Kilbreath, S.L. & Refshauge, K.M., 2011. Chronic Ankle Instability: Evolution of the Model. , 46(2), pp.133–141.

Hudson, M.L. et al., 2006. Expectation of pain replicates the effect of pain in a hand laterality recognition task: bias in information processing toward the painful side? *European Journal of Pain (London, England)*, 10(3), pp.219–24. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16490729 [Accessed August 24, 2015].

Kemler, E. et al., 2011. A Systematic Review on the Treatment of Acute Ankle Sprain: Brace versus Other Functional Treatment Types. *Sports Medicine*, 41(3), pp.185–197. Available at: http://cat.inist.fr/?aModele=afficheN&cpsidt=23973383 [Accessed October 9, 2013].

Kerkhoffs, G. et al., 2010. Surgical versus conservative treatment for acute injuries of the lateral ligament complex of the ankle in adults (Review). , (2).

Kerkhoffs, G.M. et al., 2012. Diagnosis, treatment and prevention of ankle sprains: an evidence-based clinical guideline. *British Journal of Sports Medicine*, 46(12), pp.854–60. Available at: http://www.ncbi.nlm.nih.gov/pubmed/22522586 [Accessed September 23, 2013].

Kim, T.-H. et al., 2014. Acupuncture for treating acute ankle sprains in adults. *The Cochrane Database of Systematic Reviews*, 6, p.CD009065. Available at:

http://www.ncbi.nlm.nih.gov/pubmed/24953665 [Accessed June 24, 2015].

Kunz, M., 2007. 265 Million Playing Football. *FIFA magazine*, (July), pp.11–13.

Lotze, M. & Moseley, G.L., 2007. Role of distorted body image in pain. *Current Rheumatology Reports*, 9(6), pp.488–96. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18177603.

Maihofner, C. et al., 2004. Cortical reorganization during recovery from complex regional pain syndrome. *Neurology*, 63(4), pp.693–701. Available at: http://cat.inist.fr/?aModele=afficheN&cpsidt=16035516 [Accessed December 29, 2015].

Maihofner, C. et al., 2007. The motor system shows adaptive changes in complex regional pain syndrome. *Brain*, 130(10), pp.2671–2687. Available at: http://www.brain.oxfordjournals.org/cgi/doi/10.1093/brain/awm131.

Mandelbaum, B.R. et al., 2005. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *The American Journal of Sports Medicine*, 33(7), pp.1003–10. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15888716 [Accessed April 29, 2014].

Mcguine, T.A. & Keene, J.S., 2006. The Effect of a Balance Training Program on the Risk of Ankle Sprains in High School Athletes. *American Journal of Physical Medicine & Rehabilitation*, 34(7), pp.1103–1111.

McKeon, P.O. et al., 2008. Balance training improves function and postural control in those with chronic ankle instability. *Medicine and Science in Sports and Exercise*, 40(10), pp.1810–9. Available at:

http://www.ncbi.nlm.nih.gov/pubmed/18799992 [Accessed September 24, 2013].

McKeon, P.O. & Hertel, J., 2008. Systematic review of postural control and lateral ankle instability, part II: is balance training clinically effective? *Journal of Athletic Training*, 43(3), pp.305–15. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2386424&tool=pmcentrez&rendertype=abstract.

Merritt, W.H., 2005. The challenge to manage reflex sympathetic dystrophy/complex regional pain syndrome. *Clinics in Plastic Surgery*, 32(4), pp.575–604, vii–viii. Available at: http://www.sciencedirect.com/science/article/pii/S0094129805000817 [Accessed December 14, 2015].

Mos, M. et al., 2007. The incidence of complex regional pain syndrome: A population-based study. *Pain*, 129(1-2), pp.12–20. Available at: http://www.sciencedirect.com/science/article/B6T0K-4M936TF-1/2/bc921d05781c4886e6964383e474552c.

Moseley, G., 2005. Distorted body image in complex regional pain syndrome. *Neurology*, pp.773–778. Available at: http://www.neurology.org/content/65/5/773.short.

Moseley, G.L. et al., 2005. Experimental hand pain delays recognition of the contralateral hand--evidence that acute and chronic pain have opposite effects on information processing? *Brain Research. Cognitive Brain Research*, 25(1), pp.188–94. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15963702

[Accessed September 27, 2013].

Moseley, G.L., 2006. Graded motor imagery for pathologic pain A randomized controlled trial. *Neurology*, 67, pp.2129–2134.

Moseley, G.L., 2008. I can't find it! Distorted body image and tactile dysfunction in patients with chronic back pain. *Pain*, 140(1), pp.239–43. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18786763 [Accessed September 27, 2013].

Moseley, G.L., 2004. Why do people with complex regional pain syndrome take longer to recognize their affected hand? *Neurology*, 62(12), pp.2182–2186. Available at: http://www.neurology.org/cgi/doi/10.1212/01.WNL.0000130156.05828.43 [Accessed October 7, 2013].

Moseley, G.L., Gallace, A. & Spence, C., 2009. Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain*, 132(11), pp.3142–3151.

Norman, K.A. et al., 2006. Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends Cogn Sci*, 10(9), pp.424–430. Available at: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16899397.

O'Sullivan, P., 2005. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy*, 10(4), pp.242–55. Available at: http://www.ncbi.nlm.nih.gov/pubmed/16154380 [Accessed August 8, 2013].

Oerlemans, H.M. et al., 1999. Pain and reduced mobility in complex regional pain syndrome I: outcome of a prospective randomised controlled clinical trial of adjuvant physical therapy versus occupational therapy. *Pain*, 83(1), pp.77–83.

Olmsted, L.C. et al., 2002. Efficacy of the Star Excursion Balance Tests Chronic Ankle Instability. , 37(4), pp.501–506.

Pietro, F. Di et al., 2013. Primary Somatosensory Cortex Function in Complex Regional Pain Syndrome: A Systematic Review and Meta-Analysis. *The Journal of Pain*, pp.1–18. Available at: http://dx.doi.org/10.1016/j.jpain.2013.04.001.

Pleger, B. et al., 2005. Sensorimotor retuning [corrected] in complex regional pain syndrome parallels pain reduction. *Annals of Neurology*, 57(3), pp.425–9. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15732114 [Accessed June 3, 2015].

Raymond, J. et al., 2012. The effect of ankle taping or bracing on proprioception in functional ankle instability: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, 15(5), pp.386–392. Available at: http://www.researchgate.net/publication/224707927.

Reinersmann, A. et al., 2010. Left is where the L is right. Significantly delayed reaction time in limb laterality recognition in both CRPS and phantom limb pain patients. *Neuroscience Letters*, 486(3), pp.240–5. Available at: http://www.sciencedirect.com/science/article/pii/S0304394010012917 [Accessed June 24, 2015].

Renström, P.A.F.H. & Lynch, S.A., 1998. Ankle ligament injuries. *Rev Bras Med Esporte*, Vol. 4(3), pp.71–80.

Rosa, B.B. & Fernandes, T.L., 2014. Epidemiology of sports injuries on collegiate athletes at a single centre. *Acta Ortopedica Brasileira*, 22(6), pp.321–324.

Sinkjaer T, Toft E, Andreassen S, H.B.C., 1988. Muscle stiffness in human ankle dorsiflexors: intrinsic and reflex components. *Journal of Neurophysiology*, 60(3), pp.1110–1121.

Stadelmann, W.K., Digenis, A.G. & Tobin, G.R., 1998. Physiology and healing dynamics of chronic cutaneous wounds. *The American Journal of Surgery*, 176(2), p.26S–38S. Available at: http://www.americanjournalofsurgery.com/article/S0002961098001834/fulltext [Accessed November 19, 2015].

Steib, S. et al., 2013. Fatigue-induced alterations of static and dynamic postural control in athletes with a history of ankle sprain. *Journal of Athletic Training*, 48(2), pp.203–8. Available at: http://www.ncbi.nlm.nih.gov/pubmed/23672384 [Accessed October 9, 2013].

Velnar, T. V & Bailey, T.B., 2009. The Wound Healing Process : an Overview of the Cellular and Molecular Mechanisms. *The Journal of International Medical Research*, 37(5), pp.1528–1542.

Verhagen, E. et al., 2004. The effect of a proprioceptive balance board training program for the prevention of ankle sprains: a prospective controlled trial. *The American Journal of Sports Medicine*, 32(6), pp.1385–93. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15310562 [Accessed October 19, 2013].

Verhagen, E.A.L.M. & Bay, K., 2010. Optimising ankle sprain prevention: a critical review and practical appraisal of the literature. *British Journal of Sports*

Medicine, 44(15), pp.1082–8. Available at: http://bjsm.bmj.com/cgi/content/long/44/15/1082 [Accessed October 4, 2013].

De Vries, J. et al., 2011. Interventions for treating chronic ankle instability (Review). *The Cochrane Collaberation*, (8).

Wikstrom, E. A, Fournier, K. a & McKeon, P.O., 2010. Postural control differs between those with and without chronic ankle instability. *Gait & Posture*, 32(1), pp.82–6. Available at: http://www.ncbi.nlm.nih.gov/pubmed/20418101 [Accessed April 29, 2014].

WMA, 2013. Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects. *WMA - Ethical Principles for Medical Research Involving Human Subjects*, pp.1–8. Available at: http://www.wma.net/es/30publications/10policies/b3/.

Woods, C. et al., 2003. The Football Association Medical Research Programme : an audit of injuries in professional football: an analysis of ankle sprains. *British Journal of Sports Medicine*, 37(May 1999), pp.233–238.

Appendices

Appendix 1: Ethics Approval letter

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

09 September 2014

HREC REF: 673/2014

Dr R Parker
Physiotherapy
Health & Rehab
OMB

Dear Dr Parker

PROJECT TITLE: A CROSS SECTIONAL STUDY TO DETERMINE WHETHER THERE ARE CENTRAL NERVOUS SYSTEM CHANGES IN FOOTBALL PLAYERS WHO HAVE SUSTAINED RECURRENT LATERAL ANKLE INJURIES (MPHIL Candidate - R Jakoet) - Sub-study linked to 415/2013

Thank you for submitting your sub-study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th September 2015.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

We acknowledge that the student, Rashaad Jakoet will also be involved in this study.

Please quote the HREC reference no in all your correspondence.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN ETHICS
Federal Wide Assurance Number: FWA00001637.

HREC 673/2014

Appendix 2: Informed consent

Information Sheet and Consent Form

Study: A cross sectional study to determine whether there are central nervous system changes in football players who have sustained recurrent lateral ankle injuries

INTRODUCTION

I am an MPhil (Sports Physiotherapy) student completing my degree at the University of Cape Town and I'm currently researching the effects of chronic ankle sprains on possible changes in the central nervous system.

Ankle sprains are among the most common injuries sustained by football players, locally and internationally. Despite many advances in sports medicine in the treatment and management of this injury, you are still more likely to have an ankle injury in future if you have previously had one, despite receiving treatment that currently may be regarded as best practice. This study attempts to determine whether there are any changes in the central nervous system of football players who have experienced recurrent ankle sprains. Results of this study could lead to a better understanding of the injury and lead to more efficient management strategies.

Should you choose to participate in the study, you will be asked to undergo the testing described below. This will take approximately 1 hour.

PROCEDURE

On completion of reading the information sheet provided and signing the informed consent, an appointment will be arranged to complete the study. First, medical and injury questionnaires will be completed and should you meet the requirements of this study, you will then continue to the physical examination to be conducted. Anthropometric (body composition, e.g., weight height, skinfolds) data will be collected first, followed by a laterality judgement task test, two point discrimination, limb perception and pressure pain threshold tests which will tell us about the central nervous system. The tests are described below:

Laterality Judgement Task test

This evaluates the ability of a person to recognise whether an image projected on a computer screen is of the left or right foot. The time between the image appearing on screen and you, the participant, reacting by pressing a button indicating left or right is timed. The image is randomly displayed in different positions. This reaction time is then compared for all correct answers between left and right images.

Two point discrimination

Two-point discrimination is the ability to discern that two nearby objects touching the skin are truly two distinct points, not one. You will be asked to report whether one or two points is felt and the smallest distance between two points that still results in the perception of two distinct points is recorded as your two-point threshold.

Limb perception

You will be requested to complete a drawing of the lateral surface of your foot without looking at it or touching it. The instruction given to you will be:

Concentrate on your foot and ankle. Add to this a drawing by following the outline of your own foot and ankle as you track it in your mind. Concentrate on where you feel your foot and ankle to be. Also draw in the bones that you can feel. Do this without touching your foot. Your drawing should relate to your own sense of your foot and ankle. Don't draw any part that you cannot sense. Do not draw what you think your foot looks like, draw what it feels like.

POTENTIAL RISKS

There are no potential risks, but some mild transient pain/discomfort can be expected. You will be asked to inform the researcher as soon as you have any pain or discomfort and the test will stop at that point.

BENEFITS

You will receive information on the pathophysiology of your condition and treatment advice will be given. An estimate of the percentage body fat will be given to you, should you desire it. This research will add to the body of knowledge by increasing the understanding of the effect ankle sprains have on possible changes in the central nervous system and possibly decreasing the recurrence thereof.

I, ____ am aware that I will be free to withdraw from the study at any time and that I will not be subjected to any pressure whatsoever to remain in the trial. I understand the implications of my consent and that questions have been answered to my satisfaction.

"The University of Cape Town and its team of researchers, who are working under the mandate of the university, will be responsible for treating any

adverse or untoward events arising from participation in this research study."

Signed at...on this .... day

of .... 20........

Subject: ....

I understand the conditions of the contract as explained and interpreted to me and accept it voluntarily.

Researcher: ....

WITNESSES:

1…………………………………………………………..

2……………………………………………………..

Investigator contact details

Rashaad Jakoet

The Sport Science Physiotherapy Centre

Sport Science Institute of South Africa

Boundary Road

Newlands

Cape Town

7700

Tel: 021 659 5684

Fax: 021 659 5654

Email: rashaad@sspc.co.za

Supervisors:

Dr Romy Parker

Division of Physiotherapy

Department of Health and Rehabilitation Sciences

University of Cape Town

Groote Schuur Hospital

Anzio Road

Observatory

7725

021 406 6431

Romy.parker@uct.ac.za

Dr Theresa Burgess

Division of Physiotherapy

Department of Health and Rehabilitation Sciences

University of Cape Town

Groote Schuur Hospital

Anzio Road

Observatory

7725

021 406 6171

Theresa.burgess@uct.ac.za

Prof Marc Blockman (chair of the ethics committee)

021 406 6492

Appendix 3: Questionnaire

MEDICAL AND SPORTS HISTORY QUESTIONNAIRE

Thank you for taking the time to complete this questionnaire, which will take 10 minutes of your valuable time to complete. The completion of the questionnaire is voluntary and all the information will be kept confidential. The information collected will only be used for research purposes.

Instructions:

Please complete Sections A, B, C, D, E, F

Section A	Personal Details
Section B	Playing History
Section C	Training History
Section D	General medical history
Section E	Additional detailed medical history
Section F	Specific Injury History

<table>
<tr><th colspan="4">Section A: Personal Details</th></tr>
<tr><td>Surname</td><td colspan="3"></td></tr>
<tr><td>First Name</td><td colspan="3"></td></tr>
<tr><td>Language</td><td colspan="3"></td></tr>
<tr><td rowspan="2">Postal Address</td><td rowspan="2"></td><td colspan="2"></td></tr>
<tr><td>Postal/ Zip Code</td><td></td></tr>
<tr><td>E-mail address</td><td></td><td>Phone (day time)</td><td>code number</td></tr>
<tr><td>Date of birth</td><td>yyyy-mm-dd</td><td>Cell</td><td></td></tr>
<tr><td>Height</td><td>cm</td><td colspan="2"></td></tr>
<tr><td>Weight</td><td>kg</td><td>Age</td><td></td></tr>
<tr><td>Rugby Institution</td><td colspan="3"></td></tr>
<tr><td>Current Playing Position</td><td></td><td>Preferred Playing Position</td><td></td></tr>
</table>

Section B: Playing History	
Year First Playing Team Football	
Total Years Playing Team Football	
Teams Represented since 16 years of age	
Highest Team Represented	
First Year Playing Professional / Contracted Football	
Total Years Playing Professional / Contracted Football?	
Number of games played in last 6 months	
Total Minutes Played in Last 6 months	

Section C: Training History

Total number of Training hours per week			
Total number of Hours Pre / Rehab per week			
Total number of hours Gym Training per week			
Total number of additional hours Conditioning Training per week			
Total number hours Team Training per week			
Total number hours Specialized Training per week			
Average week training hours for previous 6 Months			
Total days Pre-season Training for current football season		Average Hours per day Pre-season Training	
Preseason training blocks completed over previous 3 years			

Section D: General medical history	
In this section, you are asked to read through 14 questions about your personal general medical history. If you answer "yes" to any of questions 1 to 12, please complete the additional questions at the end of the section (Section F).	
1.In the past **6 weeks** did you suffer from any **symptoms of flu** (fever, sore throat, blocked or runny nose, cough, wheeze, muscle aches and pains)? **If you answer "yes", please complete the additional questions in Section E.**	Yes ☐ No ☐
2.Have you **ever** in your football career suffered from **muscle cramping** during or immediately (within 6 hours) after exercise (in training or competition)?	Yes ☐ No ☐
3.Have you **ever** in your football career suffered from **a tendon or ligament injury** (pain, swelling, stiffness) in any tendon (including Achilles tendon, knee tendons, and shoulder tendons) or ligaments (partial or complete tear)?	Yes ☐ No ☐

4.Have you **ever** in your football career **used medicines to treat injuries** in the week **before or during a game** – including anti-inflammatory drugs, cortisone (pills, or injection), or pain killers? **If you answer "yes", please complete the additional questions in Section E.**	Yes ☐ No ☐
5.Do you **currently** suffer from any **symptoms of injury** in the muscles, tendons, bones, ligaments or joints? **If you answer "yes", please complete the additional questions in Section E.**	Yes ☐ No ☐

6.Please tick in which anatomical area you ever had **surgery** performed.	☐ Head ☐ Finger ☐ Neck ☐ Lower back ☐ Face ☐ Hip ☐ Front chest ☐ Thigh ☐ Back chest ☐ Knee ☐ Shoulder ☐ Lower leg ☐ Upper arm ☐ Achilles ☐ Elbow ☐ Ankle ☐ Forearm ☐ Foot ☐ Wrist ☐ Abdomen ☐Other(Specify: ____________________________)

THANK YOU FOR COMPLETING THE QUESTIONNAIRE

The following sections E, F and G relate to injury and medical history. Please answer section E. If indicated please continue to sections F and G. If section D does not indicate for you to answer section F, please continue to section G.

Section E: Additional detailed medical history ***(Please complete all the sections to which you answered "Yes" in the Personal general medical history). If you did not answer yes to any of the questions in section D, please continue to section F.***

1. Flu symptoms in the last 6 weeks If you answered **YES** to **question 1** in section E, please complete the following two questions related to flu symptoms in the last 6 weeks.	
(1a) Please tick which of these flu symptoms you suffered from <u>**in the last 6 weeks**</u>.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: ____________________________)

(1b) Please tick which of these flu symptoms you suffered from **<u>in the last 7 days</u>**.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: ___________________________)

2. Use of medicines to treat an injury before or during participation

If you answered **YES** to **question 4** in section D, please complete the following two questions related to medicine use for injuries before or during races.

(2a) Which of the following medicines have you used in the past to treat an injury **<u>in the week just before</u>** a game?	☐ Paracetamol (e.g. Panado, Tylenol) ☐ Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam) ☐ Cortisone (pills) ☐ Cortisone injection ☐ Codeine ☐ Anti-inflammatory gels/creams/patches ☐ Any other pain killers (Specify: ____________________________)

(2b) Which of the following medicines have you used in the past to treat an injury **<u>during a game</u>**?	☐ Paracetamol (e.g. Panado, Tylenol) ☐ Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam) ☐ Cortisone (pills) ☐ Cortisone injection ☐ Codeine ☐ Anti-inflammatory gels/creams/patches ☐ Any other pain killers (Specify: ____________________________)
3. Current use of Chronic Medication for Pain or Neuropsychiatric Conditions	
(3a) Are you currently taking any chronic medication for pain management?	☐ Yes ☐N0 ☐ Oral Cortisone ☐ Other (Please Specify: ______________ ____ ____ ________________________)

(3b) Are you currently taking any chronic medication for neuropsychological conditions?	☐ Yes ☐N0 (Please Specify: ________________________ ____ ____ __________________________)
4. Neurological Conditions	
(4a) Do you currently present with any neurological conditions?	☐ Yes ☐N0 (Please Specify: ________________________ ____ ____ __________________________)

5. History of any current injury that you suffer from If you answered **YES** to **question 5** in section D, please complete the following questions (3a. to 3f.) related to each of your current injury/injuries (Space is provided for two injuries)
Injury 1

(5a) What was the approximate date when you first became aware of the injury?	Month Year
(5b) Please indicate which side of your body is injured. (if applicable)	☐ Right ☐ Left
(5c) Please indicate which anatomical area is currently injured	☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: ____________________)
(5d) Please indicate the type of structure that was injured	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: ____________________)

(5e) Please indicate the severity of the injury. Please only tick one box.	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2 ☐ I experience symptoms during exercise that may interfere with my training/competition - Grade 3 ☐ I am so painful that I may not be able to train or compete - Grade 4
(5f) Please indicate how your injury was treated to date. You can tick more than one box.	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Other injection ☐ Surgery ☐ Orthotics ☐ Strengthening exercises ☐ Equipment change Other (Specify: ______________________)

Injury 2	

(5a) What was the approximate date when you first became aware of the injury?	Month Year
(5b) Please indicate which side of your body is injured. (if applicable)	☐ Right ☐ Left
(5c) Please indicate which anatomical area is currently injured.	☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: ______________________)

(5d) Please indicate the type of structure that was injured.	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: ______________________)
(5e) Please indicate the severity of the injury. Please only tick one box.	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2 ☐ I experience symptoms during exercise that may interfere with my training/ competition - Grade 3 ☐ I am so painful that I may not be able to train or compete - Grade 4

(3f) Please indicate how your injury was treated to date. You can tick more than one box.	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Other injection ☐ Surgery ☐ Orthotics ☐ Strengthening exercises ☐ Equipment change Other (Specify: ____________________)
Section F: Specific Injury history	
In this section, you are asked to read through 17 questions about your Specific Ankle Injury history.	

1. Date of first Ankle injury:	yyyy-mm-dd	Left: ☐ Right: ☐
2. Ankle structures injured?	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other Specify: ____________________	
3. Please indicate the	☐ Grade 1 - I only experience symptoms after	

severity of the injury (tick one box please)	exercise ☐ Grade 2 - I experience symptoms during exercise, but it does not interfere with training ☐ Grade 3 - I experience symptoms during exercise that may interfere with my training / playing ☐ Grade 4 - I am so painful that I may not be able to train or play
4. Please indicate how your injury was treated to date? (you can tick more than one)	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Other injection ☐ Surgery ☐ Orthotics ☐ Strengthening exercises ☐ Equipment change Other Specify: ______________________
5. Length of time from injury to return to full team training?	days - weeks - months

6. Date of second Ankle injury:	yyyy-mm-dd	Left: ☐ Right: ☐
7. Structures injured?	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other Specify: ______________	
8. Please indicate the severity of the injury (tick one box please)	☐ Grade 1 - I only experience symptoms after exercise ☐ Grade 2 - I experience symptoms during exercise, but it does not interfere with training ☐ Grade 3 - I experience symptoms during exercise that may interfere with my training / playing ☐ Grade 4 - I am so painful that I may not be able to train or play	
9. Please indicate how your injury was treated to date? (you can tick more	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Platelet Injection	

than one)	☐ Orthotics ☐ Other injection ☐ Surgery ☐ Equipment change ☐ Strengthening exercises Other Specify: ______________________	
10. Length of time from injury to return to full team training?	days - weeks - months	
11. Date of subsequent Ankle Injuries:	yyyy-mm-dd yyyy-mm-dd yyyy-mm-dd	Left: ☐ Right: ☐
12. Structures injured?	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other Specify: ______________________	
13. Please indicate the severity of the injury (tick one box please)	☐ Grade 1 - I only experience symptoms after exercise ☐ Grade 2 - I experience symptoms during exercise, but it does not interfere with training	

	☐ Grade 3 - I experience symptoms during exercise that may interfere with my training / playing ☐ Grade 4 - I am so painful that I may not be able to train or play
14. Please indicate how your injury was treated to date? (you can tick more than one)	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Platelet Injection ☐ Orthotics ☐ Other injection ☐ Surgery ☐ Equipment change ☐ Strengthening exercises Other Specify: ____________________
15. Length of time from injury to return to full team training?	days - weeks - months
16. Current Injuries:	Yes: ☐ No: ☐
17. Areas affected:	☐ Head ☐ Elbow ☐ Hamstring

	☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other Specify: ______________________

Appendix 4: Limb Perception Drawing

Left Foot

Right Foot

Appendix 5: Data Collection Form

Body Composition Measurements

Name	
Body Mass	**Kg**
Stature	**cm**
Body Mass Index	
Dominant Leg	

Skinfold measurements (mm)	
Triceps	
Biceps	
Sub-scapular	
Supra-iliac	
Thigh	
Calf	
Abdominal	

Sum of 7 skinfolds	
Lean body mass	
Predicted% body fat	

Left Foot

Right Foot

Name: ____ Date: ________________________________

	Left % correct	Right % correct	Left time	Right time
“Vanilla” feet				
“Context” feet				
“Abstract” feet				

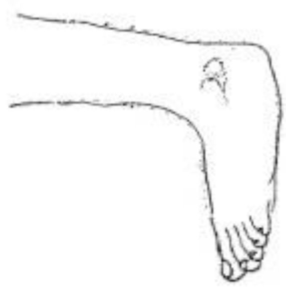
Name:______________________ Date:__________

Two-Point Discrimination

Point		Test 1	Test 2	Test 3	Average
1	Left				
	Right				
2	Left				
	Right				
3	Left				
	Right				

Appendix 6 – Completed limb perception drawing example

Left Foot



Right Foot