The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome

By

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I, Murray James McLaren, do declare that this dissertation is representative of my own work in both conception and execution (except where acknowledgements indicate to the contrary).

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DEDICATION

This dissertation is dedicated to my parents, Bruce and Lorian McLaren. Thank you for your encouragement and belief in me. Your continuous support and sacrifices throughout the process of this dissertation, as well as my entire academic career, have not gone unnoticed. I cannot put into words how much I appreciate what you have done for me.

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ABSTRACT

Background and Purpose: Ankle sprain injuries are prevalent in both the sporting and general population and can develop into chronic ankle instability syndrome (CAIS). When this occurs, there is a tendency for the ankle to re-sprain following an acute ankle sprain. Deficits in proprioception and neuromuscular control, specifically of the peroneal muscles, may lead to altered balance and postural stability in patients with CAIS. Recent research suggests that the ankle invertors and plantarflexors are also affected. Joint manipulation has been shown to result in reduced pain and improved foot and ankle functioning in individuals with CAIS, however, the exact mechanism(s) through which joint manipulation brings about these effects is not clear and the field of extremity joint manipulation on arthrogenic muscle inhibition (AMI) is under-investigated. This study aimed to determine the immediate effect of talocrural joint manipulation on postural stability and the muscle activity of the ankle invertors, evertors and plantarflexors by assessing surface electromyography (sEMG) of these muscles during static single-limb postural stability testing. Subjective outcomes of pain and disability were also measured through the use of the foot and ankle disability index (FADI).

Methods: This study used a randomized, single blinded placebo controlled pre-test, and a repeated post-test measures experimental design. A sample of 42 participants, with grade I or II CAIS, aged 18-45 years, were randomly allocated into two groups. One group received a long axis distraction talocrural joint manipulation and the other group, a sham manipulation. General pain and disability (FADI), postural stability (Biosway Portable Balance System) and muscle activity (Biopac wireless EMG system) measurements were taken before the intervention. Muscle activity and postural stability were assessed again immediately after the intervention and then again 20 minutes later. Postural stability and muscle activity were measured both with participants' eyes opened and eyes closed. FADI measurements were taken 24 hours after the intervention.

Results: The two groups were comparable at baseline for age, gender, body mass index, pain and disability, postural stability and muscle activity ($p > 0.050$). An inter-group analysis showed a significant improvement in FADI ($p= 0.005$) and general pain scores ($p= 0.039$) when compared to the placebo group post-manipulation. There were no significant changes in the manipulation group for muscle activity and postural stability when compared to the placebo group ($p > 0.050$). Intra-group analysis showed an overall improvement over time for eyes opened postural stability in the manipulation group ($p= 0.040$) and decreased fibularis longus muscle activity in the placebo group with eyes open balance testing ($p= 0.047$) and eyes closed balance testing ($p= 0.023$).

Conclusion: The results of this study showed that talocrural joint manipulation had a positive effect on pain and disability in individuals with CAIS. No significant differences were found between the intervention and placebo groups for limb muscle activity and postural stability. Intra-group analysis showed that the manipulation had a positive effect on eyes-open postural stability performance and that there may have been a trend of an effect of manipulation counteracting muscle fatigue experienced in the fibularis longus of the placebo group. Further investigation to further elucidate the effect of manipulation in CAIS is recommended.

Key words: chronic ankle instability syndrome, disability, manipulation, muscle activity, pain, postural stability.

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LIST OF ABBREVIATIONS

AAI : Activator adjustment instrument

AMI : Arthrogenic muscle inhibition

BBS : Berg balance scale

BESS : Balance Error Scoring System

BMI : Body mass index

CAIS : Chronic ankle instability syndrome

CDC : Chiropractic Day Clinic

CSP : Cortical Silent Period

DUT : Durban University of Technology

FAAM : Foot and ankle ability measure

FADI : Foot and ankle disability index

hrs : Hours

HVLA : High-velocity low amplitude

MEP : Motor-Evoked Potential

mV : Millivolt

MVC : Maximal voluntary contraction

N : Number of participants (total sample)

NRS : Numerical pain rating scale

p : Probability value of statistical significance

r : Pearson's correlation coefficient

RCT : Randomised clinical trial

RMS : Root mean squared

ROM : Range of motion

SEBT : Star excursion balance test

sEMG : Surface electromyography

TC : Talocrural

TCJM	**:**	Talocrural joint manipulation
TTB	**:**	Time-to-boundary
VAS	**:**	Visual analogue scale
WB	**:**	Weight bearing
>	**:**	Greater than
<	**:**	Less than
±SD	**:**	Standard deviation
%	**:**	Percentage

DEFINITIONS

Ankle joint: The articulation between the distal end of the tibia and fibula and the proximal part of the talus. Also referred to as the talocrural joint (Tortora and Derrickson, 2009; Moore *et al.,* 2010; McKinley and O'Loughlin, 2012).

Chronic ankle instability syndrome: The constant tendency of the ankle to re-sprain following an acute ankle sprain. It is associated with recurrent sprains, as well as the feeling of the ankle "giving way" (Gribble *et al.*, 2013).

Joint manipulation: A manual procedure that involves a directed high-velocity low-amplitude (HVLA) thrust to move a joint past normal physiological range of motion (ROM), into the paraphysiologic space, without exceeding the anatomical limit. It is commonly associated with an audible pop or cavitation (Haldeman, 2005; Bergmann and Peterson, 2011).

Mechanoreceptors: Mechanically sensitive neurons found within the joint's structure and surrounding tissues (Tortora and Derrickson, 2009; McKinley and O'Loughlin, 2012).

Muscle inhibition: The inability to fully activate a muscle due to on-going reflex inhibition (Taber's Cyclopedic Medical Dictionary, 2013).

Neuromuscular control: The subconscious activation of dynamic restraints occurring in preparation for, and in response to, joint motion and loading for the purpose of maintaining and restoring functional joint stability (Riemann and Lephart, 2002; De Ridder, 2014).

Placebo: A method used as an inactive control as a test of a treatment that is suspected of being useful in the treatment of a certain condition (Taber's Cyclopedic Medical Dictionary, 2013).

Postural control: The capacity of a person to keep their centre of mass over their base of support. The ability to do this is dependent on the integration of afferent visual, vestibular and somatosensory input, to generate an adequate efferent neuromuscular response (Winter, 1995; De Ridder, 2014).

Proprioception: The ability to integrate the sensory signals from various mechanoreceptors in order to determine body position and movements in space (Goble, 2010; Han *et al.,* 2015). It plays a crucial role in balance control (Speers *et al*., 2002; Bouisset and Do, 2008; Pasma *et al.,* 2012; R¨oijezon *et al.,* 2015; Clark *et al.,* 2015).

Surface electromyography: An electrical, non-invasive, accurate method of measuring muscle excitation and activation through the placement of electrodes over the muscle being assessed (Sousa and Tavares, 2012).

CHAPTER ONE INTRODUCTION

1.1 INTRODUCTION

The ankle is the most frequently injured joint of the lower extremity (Klykken *et al.,* 2011). Up to 75% of individuals who suffer from an acute ankle sprain encounter recurring episodes of injury and may develop chronic ankle instability syndrome (CAIS) (Hubbard and Wikstrom, 2010). This debilitating condition has a negative effect on the activities of daily living (Waterman *et al.,* 2010). Not only does CAIS limit an individual's physical activity but it may also lead to the articular degeneration of the talus and an increased risk of developing osteoarthritis (Hubbard and Wikstrom, 2010).

Insufficiencies associated with CAIS can be defined as being mechanical or functional in nature and may be present independently or in association with each other. Mechanical insufficiencies are related to anatomical abnormalities of a joint that occur either congenitally or as a result of trauma (Bonnel *et al.,* 2010). Mechanical insufficiencies consist of pathological laxity, degenerative and synovial changes and impaired arthrokinematics. Functional insufficiencies refer to postural, muscular and tendon abnormalities that contribute to the development of CAIS and include proprioceptive impairments, impaired neuromuscular firing, strength deficits and muscle imbalances and impaired postural stability (Bonnel *et al.,* 2010).

Notably, deficits in balance and postural stability have long been associated with CAIS (Linens *et al.,* 2014). Impaired postural control is believed to be the result of a combination of deficits in proprioception and neuromuscular control. Recently, altered muscle spindle activity has been noted as an important cause of deficits in proprioception in patients with CAIS (De Ridder, 2014). Neuromuscular deficits in CAIS have been related to arthrogenic muscle inhibition (AMI). Arthrogenic muscle inhibition is the continuous reflex inhibition of uninjured muscles that surround an injured joint, which has been purported to contribute to the joint dysfunction after the injury (Klykken *et al.,* 2011). Impairments in postural stability, due to neuromuscular abnormalities in CAIS, have been linked with weakness of the peroneal musculature (Hopkins *et al.,* 2009; Palmieri-Smith *et al.,* 2009). Conflicting evidence shows little to no deficits in the peroneal muscles in patients with CAIS (Delahunt, 2007; Klykken *et al.,* 2011). Some evidence suggests the presence of invertor, rather than evertor, strength deficits may play a significant role in the development of residual symptoms following lateral ankle sprains (Delahunt, 2007; De Ridder 2014). Lateral ankle sprains have also been shown to demonstrate long term effects on the joint's surrounding fascia. These changes include altered sensitivity and movability of the fascia in the calf and the foot as well as reduced

postural stability, therefore the role of fascia in chronic ankle instability should also be considered (Kalichmann *et al.,* 2016).

Interventions for CAIS include, but are not limited to, the use of non-steroidal anti-inflammatory drugs (NSAIDS), therapeutic ultrasound, laser and other electrotherapies and even surgery, all with varying levels of success or validity (Kerkhoffs *et al.,* 2012; Van den Bekerom *et al.,* 2012; Bruno *et al.*, 2014; Van den Bekerom *et al.,* 2014). Traditionally, CAIS has commonly been treated through rehabilitation, muscle strengthening and proprioceptive retraining (Denegar and Miller, 2002; Lee and Lin, 2008). However, evidence for the presence of joint fixations in the ankles of individuals with CAIS (Pellow and Brantingham, 2001, Vicenzino *et al.,* 2006; Joseph *et al.,* 2010) have shown that treatment using manipulation is beneficial in the treatment of this condition (Wikstrom and McKoen, 2010; Louden *et al.,* 2013).

Manipulation is thought to cause an increase in afferent activity and neuromuscular activation of the joint stabilising muscles and fascia, therefore enhancing postural control (Liebler *et al.,* 2001; Yerys *et al.,* 2002; Hoch and McKeon, 2010; Grindstaff *et al.,* 2011). Joint manipulation was found to have effects on pain, disability, balance and muscle activity. Botha (2013) reported that manipulation produced improvements in balance, dorsiflexion range of motion and self-reported pain and disability in participants with CAIS. Lopez-Rodrıguez *et al.* (2007) found that talocrural joint manipulation results in redistributed foot loading in participants with CAIS. Grindstaff *et al.* (2011) found an increase in soleus muscle activity following distal tibiofibular joint manipulation in participants with CAIS. Fisher *et al.* (2016) established that talocrural joint manipulation results in increased corticospinal input to the motor pool of the tibialis anterior, suggesting that the activity of this muscle may be altered by manipulation.

The findings of these separate studies indicate a possible association between joint manipulation and pain, disability, balance and muscle activity in CAIS, however, there is limited research examining the role of talocrural joint manipulation on muscle activity and balance in CAIS. Therefore, this study aimed to monitor the effect of talocrural joint manipulation on muscle activity of the invertors, evertors and plantar flexors of the ankle during single leg balance testing, as well as its effect on short term subjective pain and disability, in order to establish a more comprehensive understanding of the role, if any, that talocrural joint manipulation has in the management of CAIS.

1.2 STUDY AIMS, OBJECTIVES AND HYPOTHESES

1.2.1 Aim

The aim of this study was to determine the short term effect of talocrural joint manipulation, compared to a sham intervention on subjective (pain and disability) and objective (muscle activity of the invertors, evertors and plantarflexors of the ankle joint and balance) outcomes.

1.2.2 Study Objectives

1. To determine and compare subjective (pain and disability) and objective (muscle activity of the invertors, evertors and plantarflexors of the ankle joint and balance) measures between talocrural joint manipulation and sham manipulation groups at baseline.
2. To determine and compare the effect of talocrural joint and a sham manipulation on subjective (pain and disability) outcomes at 24 hours post intervention.
3. To determine and compare the effect of talocrural joint and a sham manipulation on objective (balance and muscle activity of the invertors, evertors and plantarflexors of the ankle) outcomes immediately post-intervention and at 20 minutes post intervention.

1.2.3 Hypothesis

1.2.3.1 Null Hypothesis

Ho: There will be no statistically significant ($p < 0.050$) effect on muscle activity, of the invertors, evertors and plantar flexors of the ankle, balance, pain and disability, when talocrural joint manipulation is compared to a sham intervention, immediately following the intervention and at 20 minutes post-intervention (muscle activity and balance) and 24 hours post-intervention (pain and disability) in participants with CAIS.

1.2.3.2 Alternate Hypothesis

HA: Talocrural joint manipulation when compared to a sham intervention will have a statistically significant ($p < 0.050$) effect on muscle activity of the invertors, evertors and plantar flexors of the ankle, balance, pain and disability, immediately following the intervention and at 20 minutes post-intervention (muscle activity and balance) and 24 hours post-intervention (pain and disability) in participants with CAIS.

1.3 DELIMITATIONS

The results of this study can only be generalized to the specific population identified for this study, which was limited to participants between the ages of 18 - 45 years, to allow for a

homogenous sample at lower risk for any potential degenerative disorders associated with advanced age.

This study focussed on the short term effects of manipulation on CAIS and measurements were only taken over one session, per participant. Therefore, the results of this study do not reflect the medium or long term effects of manipulation on CAIS.

Although different types of static and dynamic tests have been used to evaluate CAIS (Rosen *et al.,* 2017), a single limb static postural stability test was selected to measure participants' balance as it was felt that a dynamic balance test such as the limits of stability test, may be difficult to perform in individuals with chronically unstable ankles as balance testing was performed multiple times over one session in this study.

Only four muscles of the lower limb were chosen for examination in this study, as these muscles had been investigated previously in similar studies (Grindstaff *et al.,* 2011; Feger *et al.,* 2014; De Ridder *et al.,* 2015; Dicks, 2016; Kwon, 2018.)

1.4 SIGNIFICANCE OF THE STUDY

The high incidence of ankle sprains, and the subsequent development of CAIS, demonstrates the need for an adequate and effective treatment protocol (Anandacoomarasamy and Barnsley, 2005; Doherty *et al.,* 2013). Ankle joint manipulation has been shown to be clinically beneficial in the treatment of CAIS, as it has been suggested that manipulation improves neuromuscular activity, which enhances postural control (Liebler *et al.,* 2001; Yerys *et al.,* 2002; Hoch and McKeon, 2010; Grindstaff *et al.,* 2011). However, research regarding this theory is limited in the sense that previous studies have only investigated the effects of ankle joint manipulation on muscle activity and postural stability in CAIS in isolation (Lopez-Rodriguez *et al.,* 2007; Grindstaff *et al.,* 2011; Dicks, 2016).

This study is significant as it attempted to understand how ankle joint manipulation affected the major lower limb musculature and how these effects may have translated to postural instability. The results of this study may inform more effective and efficient treatment protocols thereby saving patients pain and disability. It will also add to the body of knowledge on this important aspect of care, not only for patients, but also those who participate in sports and incur ankle injuries. Indirectly, it may reduce health care costs by reducing rehabilitation and recovery time.

1.5 FLOW OF DISSERTATION

Chapter one provides the introduction for the study, as well as the aims, objectives, study hypotheses and delimitations and flow of the document.

Chapter two is a literature review and provides an overview of the anatomy of the ankle joint, the diagnosis and management of chronic ankle instability and critically discuss the literature related to the effect of manipulation on CAIS, balance, muscle activity, pain and disability.

Chapter three provides the research methodology used in this study, in order to accomplish the aims and objectives. The study design, methods, techniques and instruments are outlined and explained.

Chapter four displays and narrates the results of the study and the data analysed in this study. The characteristics of the sample, together with the muscle activity, balance, pain and disability data, will be presented in the form of figures and tables.

Chapter five provides the discussion of the results in relation to the current literature.

Chapter six will conclude the study, including conclusions, the study limitations and recommendations.

CHAPTER TWO LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a review of the ankle joint complex, followed by an overview of CAIS, including the epidemiology and management of CAIS. Joint manipulation will be discussed, and its effect on balance and muscle activity, relative to CAIS, will be explored.

The following sources were searched for information relevant to the study: Google Scholar, Summon, PubMed, ScienceDirect, eMedicine, ResearchGate and the Durban University of Technology Institutional Repository.

Key terms used in the study include: “chronic ankle instability syndrome”, “ankle sprain”, “incidence”, “prevalence”, “ankle joint manipulation”, “ lateral ankle sprains”, “joint manipulation”, “arthrogenic muscle inhibition”, “balance”,” postural stability”, “ankle joint manipulation and balance”, “foot and ankle pain and disability”, “muscle activity and surface electromyography in lower limb muscles”. Articles and sources were selected based on their relevance to the current study as well as their date of publication, with more recently published sources getting preference over older sources.

Ankle sprains are common injuries, with many people reporting persisting or lingering symptoms, such as pain and instability, following the initial sprain. Chronic ankle instability syndrome (CAIS) is one of the most common of these residual problems (Hiller *et al.,* 2011). Neuromuscular deficits, related to arthrogenic muscle inhibition (AMI) and functional instability, have been reported in patients suffering from CAIS, manifesting in the forms of reduced postural stability and muscle weakness (Klykken *et al.,* 2011). Some studies suggest functional instability (and the resultant postural instability) is due to weakness of the peroneal musculature, however, there is a body of research to suggest that the presence of invertor (rather than evertor) strength deficits may play a significant role in the development of residual symptoms following lateral ankle sprains (Delahunt, 2007). Others have suggested that strength deficits of the peroneals, invertors and plantarflexors are present in those with CAIS (De Ridder, 2014). Studies have also identified a decrease in ankle dorsiflexion range of motion in individuals with history of lateral ankle sprain (Deneger *et al.,* 2002; de Noronha *et al.,* 2006; Youdas *et al.,* 2009).

Manipulation has been considered a suitable intervention for CAIS, as it has been suggested that it causes an increase in afferent activity and neuromuscular functioning of the joint stabilising muscles, therefore enhancing postural control (Liebler *et al.,* 2001; Yerys *et al.,* 2002; Hoch and McKeon, 2010; Grindstaff *et al.,* 2011). Talocrural joint manipulation has also

been found to restore normal joint arthrokinematics and improve dorsiflexion range of motion and function, thus enhancing postural control (Beazell *et al.,* 2012). Therefore, a greater understanding of the effect that joint manipulation has on the neuromuscular control in CAIS, as well as its effect on the subjective outcomes of pain and disability, is necessary to provide an effective treatment strategy, so as to prevent long term disability.

2.2 OVERVIEW OF THE ANKLE COMPLEX

The ankle joint complex is the connection between the tibia, fibula and the foot. It is a unique joint as it forms a kinetic link between the lower limb and the ground, which is an important requirement for normal gait and the activities of daily living. Although the ankle joint is subjected to a significant amount of compressive and shear forces during the gait cycle, the ankle's bony and ligamentous anatomy allow it to function with a large degree of stability (Brockett and Chapman, 2016). The ankle consists of three articulations or joints, namely the talocrural joint, the subtalar joint and the tibiofibular syndesmosis (Hertel, 2002).

The talocrural joint is a modified hinge joint and is made up from the articulations of the talus, the lateral malleolus of the fibula and the medial malleolus of the tibia (Norkus and Floyd, 2001). It allows for plantarflexion and dorsiflexion. The subtalar joint is formed by the articulation between the talus and the calcaneus, and allows the movements of pronation and supination (Hertel, 2002). Unlike the talocrural and subtalar joints, which allow for mobility of the ankle, the role of the tibiofibular syndesmosis is to provide stability. The tiobiofibular syndesmosis consists of the distal tibia and fibula (forming the osseous part) and the distal anterior and posterior tibiofibular, the transverse and the interosseous ligaments (Hermans *et al.*, 2010).

There are medial (deltoid) and lateral ligaments that stabilise the ankle joint complex. The lateral ligaments are shown in Figure 2.1. The lateral collateral ligaments consist of the anterior talofibular ligament (ATFL), the posterior talofibular ligament (PTFL) and the calcaneofibular ligament (CFL).

During a lateral ankle sprain injury, the ATFL is most commonly injured (as it is the weaker of the three lateral collateral ligaments), followed by the CFL and then the PTFL (Hubbard, 2005). Rupture of the ATFL occurs alone in approximately 60% of all ruptures involving the lateral ankle ligaments, and in combination with the CFL, 20% of the time (Hubbard, 2005). Arthroscopic findings revealed that a rupture or elongation of the ATFL was noted in 86% of ankles with CAIS, the calcaneofibular ligament in 64%, and the deltoid ligament in 40%. Cartilage damage was noted in 66% of ankles with lateral ligament injuries, whereas 98% with

deltoid ligament injuries had cartilage damage (Hinterman *et al.,* 2002). It is estimated that injury to the subtalar joint, in combination with injury to the lateral ankle ligaments, occurs in approximately 75% to 80% of individuals with CAIS (Hertel *et al.*, 1999; Hubbard, 2005).

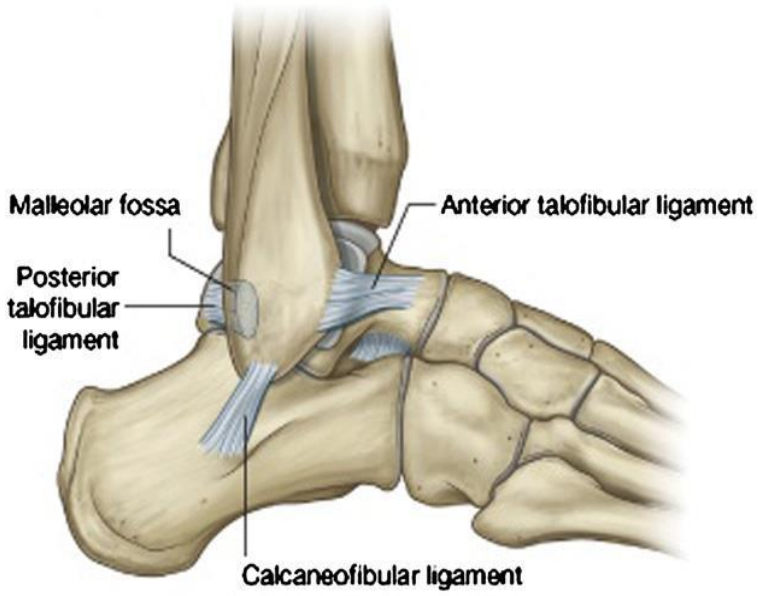


Figure 2.1: Lateral aspect of ankle joint, illustrating the lateral ankle ligaments (Delahunt, 2007)

The ankle joint is supported by several muscles, as seen in Table 2.1, which also aid in the movements of the foot and ankle complex. The primary movements are plantarflexion, dorsiflexion, inversion and eversion.

Table 2.1: The major muscles involved in inversion, eversion and plantarflexion (Moore *et al.*, 2010; Vizniak, 2010; McKinley and O'Loughlin, 2012)

Muscle	Origin	Insertion	Innervation	Action
Gastrocnemius	Lateral Head: Lateral aspect of femoral condyle. Medial Head: Popliteal Surface of the femur superior to medial femoral condyle.	Posterior calcaneus via the Achilles tendon.	Tibial nerve (S1, S2)	Plantarflexion in knee extension. During knee flexion, raises heel during walking.
Soleus	Posterior head of fibula and superior quarter of posterior fibula; soleal line and middle third of medial border of tibia; and tendinous arch between the bony attachments.	Posterior calcaneus via calcaneal tendon.	Tibial nerve (S1, S2)	Plantarflexion. Steadies the leg on Foot.
Peroneus longus	The head and superior two thirds of the lateral surface of fibula.	First metatarsal base and medial cuneiform.	Superficial Fibular Nerve (L5, S1, S2)	Eversion of the foot and plantarflexion of the ankle.
Tibialis anterior	Lateral condyle of the tibia.	Inferomedial aspect of medial cuneiform and base of the first metatarsal.	Deep peroneal nerve (L4, L5)	Dorsiflexion and inversion.

2.3 CHRONIC ANKLE INSTABILITY SYNDROME

As the ankle is the most frequently injured joint of the lower limb (Klykken *et al.*, 2011), there is a large number of patients, who suffer from acute lateral ankle sprain injuries, who encounter recurring episodes of injury (Hopkins *et al.*, 2009). Chronic ankle instability occurs when there is a tendency of the ankle to re-sprain following an acute ankle sprain, and it is associated with the feeling of the ankle "giving way" (Gribble *et al.,* 2013). The mechanism of injury most frequently associated with lateral ankle sprains occurs as result of forced plantarflexion and inversion of the ankle as the body's centre of gravity rolls over the ankle joint (Chan *et al.*, 2011).

2.3.1 Incidence and Prevalence of CAIS

It is estimated that, worldwide, there is approximately one acute ankle sprain per 10 000 people per day (Waterman *et al.,* 2010). In sporting populations, ankle sprains are the most prevalent musculoskeletal injury and make up around 30% of sports injuries (Waterman *et al.,* 2010; Strøm *et al.,* 2016).

In the Netherlands, approximately 600 000 people sustain an ankle sprain every year, and of these, general practitioners see about 125 000 patients (eight per 1000 patients) per year (Van Ochten *et al.,* 2014).

In the United States, there are an estimated 23 000 injuries of the ankle each day. In the UK, approximately 5000 ankle injuries occur every day (Van Ochten *et al.,* 2014).

Hopkins *et al.* (2009) reported that an estimated 80% of individuals who suffer an acute lateral ankle injury encounter recurring episodes of injury and/or develop CAIS.

In Australia, almost 20% of the population are affected by chronic musculoskeletal ankle disorders, with the majority being due to a previous ankle injury (Hiller *et al.,* 2010).

A study investigating the epidemiology of ankle sprains among Chinese athletes found that of the 563 sprained ankles investigated, 414 (74%) had been sprained at least twice. Symptoms of residual ankle pain, instability, and weakness were reported by 30%, 20%, and 17% of the study population respectively (Yeung *et al.,* 1994).

Hershkovic *et al.* (2015) reported that up to 40% of ankle sprains in young adults result in CAIS.

There is a paucity of prevalence rates for CAIS in the South African population.

2.3.2 Classification and Diagnosis

The classification of the grade of ankle sprains can be done according to three different systems, as outlined below in Table 2.2.

Table 2.2: The diagnostic grading systems of ankle sprains

Grade of ankle sprain	Grading system		
	Single ligament damage	**Number of ligaments involved**	**Clinical features**
Grade I	Microscopic and no macroscopic damage.	Stretching of the ATFL.	Mild sprain and ligament damage, no haemorrhage or bruising, minimal oedema, point tenderness and no gross instability.
Grade II	Ligament intact with macroscopic stretching/damage.	Tear of the ATFL, with or without a tear of the CFL.	Moderate sprain, partial tearing of the ligaments, minimal haemorrhage and bruising, localised oedema and minimal instability if at all.
Grade III	Complete tear of the ligament.	Tear of the ATFL, CFL and PTFL.	Severe sprain, complete rupture of the ligaments, early haemorrhage and bruising, diffuse oedema on both sides of the Achilles tendon, tenderness laterally and possibly medially, and gross instability
References	Caulfield (2000); Pellow and Brantigham (2001); Lynch (2002).	Chan *et al*. (2011).	Lynch (2002); Ajis and Maffulli (2006); Chan *et al*. (2011).

When making a diagnosis of CAIS, it is important to rule out conditions that may mimic symptoms of an ankle sprain/CAIS. The differential diagnoses of CAIS and ankle injuries include the following (Vertullo, 2002; Chan *et al.,* 2011; Pesquer *et al.,* 2014; Al-Mohrej and Al-Kenani, 2016):

- Fractures of the ankle or foot.
- Osteochondral fractures or lesions of the anterolateral talus, the posteromedial talus or the distal tibia.
- Peroneal tenosynovitis.
- Sinus tarsi syndrome
- Ankle impingement syndrome (anterior, posterior or calcaneal peroneal impingement).
- Hind-foot and/or mid-foot sprains.
- Tendon injuries of the peroneal tendons or retinaculum, medial ankle tendons, the flexor digitorum longus or the flexor hallucis longus.
- Achilles tendon injury/ tendonitis.

- Peroneal tendon subluxation.
- Injuries to the superficial peroneal nerve.
- Tarsal coalition.

While a number of individuals return to pre-injury levels of function in a short time following an ankle sprain, studies have shown that as many as 74% of people who have suffered an ankle sprain report some type of chronic symptom, with up to 47% reporting symptoms of functional ankle instability, and with approximately 6% of this population having occupational limitations (Braun, 1999; Arnold *et al.,* 2011).

Although there may be increased inversion associated with CAIS during gait, decreased dorsiflexion range of motion has also been demonstrated in individuals with CAIS during every day activities such as walking and jogging (Hoch and McKeon, 2010; Son *et al.,* 2019). The deficits in dorsiflexion are likely due to a talar positional fault in the form of anterior talar displacement and restricted posterior talar glide. Arthrokinematics associated with normal ankle dorsiflexion requires the talus to roll and glide posteriorly. Therefore, dorsiflexion may be reduced in cases where posterior talar glide is inhibited from restrictions in the non-contractile tissues surrounding the ankle (Hoch and McKeon, 2010; Kosik *et al.,* 2019).

2.3.3 Aetiology of CAIS

Hertel (2002) described the aetiology of CAIS as being mechanical, functional or a combination of both. Figure 2.2 illustrates the main categories of insufficiencies that can lead to CAIS.

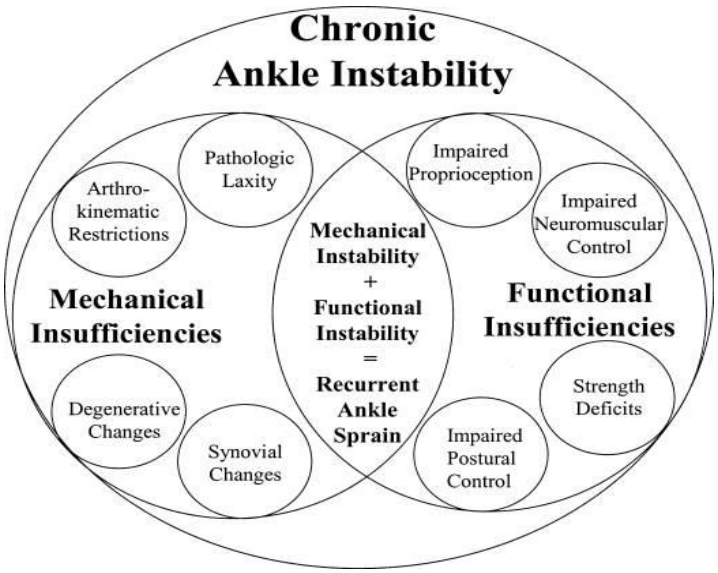


Figure 2.2: A diagrammatic representation of a paradigm demonstrating the mechanical and functional insufficiencies that contribute to CAIS (Hertel, 2002)

2.3.3.1 Mechanical Insufficiencies

Mechanical insufficiencies are related to the anatomical abnormalities of a joint that either occur congenitally or as a result of trauma (Bonnel *et al.,* 2010) and include the following:

1) Pathological laxity: This occurs when there is insufficient healing of the supportive ligaments of a joint following an ankle sprain resulting in joint instability. Often detected when the ankle is placed in vulnerable positions such as inversion, plantarflexion and supination (Hertel, 2002; Bonnel *et al.,* 2010).
2) Degenerative and synovial changes: Repetitive ankle sprains have been associated with degenerative changes in the ankle complex, such as synovial hypertrophy or the development of degenerative joint lesions (Hertel, 2002). Anterior osteophytosis or synovial hypertrophy have been considered aggravating factors for instability (Bonnel *et al.,* 2010).
3) Impaired arthrokinematics: This happens when there is disruption of the normal arthrokinematics, due to joint dysfunction or bony changes, of the joints of the ankle joint complex resulting in mechanical instability. Hypomobility of the joint, in particular decreased dorsiflexion of the talocrural joint, has been shown to contribute towards CAIS (Denegar *et al.,* 2002; Hertel, 2002; Bonnel *et al.,* 2010).

2.3.3.2 Functional Insufficiencies

Functional insufficiencies refer to postural, muscular and tendon abnormalities that contribute to the development of CAIS (Bonnel *et al.,* 2010) and include:

1) Proprioceptive impairments: There is evidence to support that individuals who suffer from repetitive ankle sprains display signs of impaired proprioceptive sensation, due to the disruption of the mechanoreceptors found within the joints structures (Konradsen *et al.,* 2002; Riemann and Lephart, 2002). Current research suggests altered muscle spindle activity is an important afferent source, explaining deficits in proprioception in subjects with CAIS (De Ridder, 2014).
2) Impaired neuromuscular firing, strength deficits and muscle imbalances: Authors have found altered activity in the muscles surrounding the ankle joint in individuals with CAIS (Willems *et al.,* 2002; McVey *et al*., 2005; Delahunt, 2007; Palmieri-Smith *et al*., 2009; Kwon, 2018). There are differing opinions as to which muscles are inhibited and contribute the most to the development of CAIS. Reduced output and inhibition have been demonstrated in the peroneal and soleus muscles of people with CAIS (McVey *et al.,* 2005; Palmieri-Smith *et al.,* 2009), however, other studies (Delahunt, 2007) have shown little to no deficits in peroneal muscles in patients with CAIS. A body of research suggests that the presence of invertor (rather than evertor) strength deficits may play

a significant role in the development of residual symptoms following lateral ankle sprains, contributing to CAIS (Delahunt, 2007; De Ridder, 2014).

3) Impaired postural stability: Postural instability has been found in patients with CAIS (Delahunt *et al.,* 2006; Bonnel *et al.,* 2010). Postural control impairments may be attributed to deficits in proprioception and neuromuscular control (Hertel, 2002).

It is believed that the symptoms of functional instability do not occur by themselves but rather that they are likely to occur as components of a complex pathoetiologic model. Joint injury results in proprioceptive deficiencies, which also contributes to impairments of neuromuscular control. These changes reduce the dynamic defence system of the ankle and predispose the ankle to recurring episodes of instability (Hertel, 2002; Hiller *et al*., 2011).

The interactions between, and within, the mechanical and functional insufficiencies associated with CAIS have not yet been fully understood and further research is required to explore these relationships and the effects of common treatment strategies on both types of insufficiency (Hertel, 2002; Hiller *et al.,* 2011).

2.3.4 Risk Factors for CAIS

Risk factors for lateral ankle injuries are traditionally categorised as intrinsic (internal) and extrinsic (external).

Intrinsic risk factors include:

- Previous sprains: The literature regarding the effect of previous sprains on the risk of future sprains or the development of CAIS is divisive (Beynonn *et al.*, 2002). Several studies have shown an increased risk of lateral ankle ligament injuries in people that have suffered previous lateral ankle sprains (Ekstrand and Gillcrest, 1983; Ekstrand and Tropp, 1990; Milgrom *et al.*, 1991; Surve *et al.*, 1994; McKay *et al.*, 2001). However, several studies have found no correlation between lateral ankle ligament injuries in athletes with previous ankle sprains (Barrett *et al.*, 1993; Sitler *et al.,* 1994; Baumhauer *et al.,* 1995). The contrast in findings may be explained by the varying severities of any previous ankle injuries and ligamentous damage, treatment and the rehabilitation of those previous ankle injuries and patients compliance of rehabilitation post-injury (Beynonn *et al.*, 2002).
- Height and weight: When in the ‘at-risk’ position for an inversion ankle sprain, a greater height and or weight proportionally increases the amount of inversion torque that must be countered by the ligaments and muscles of the ankle joint complex and, therefore, the greater the height or weight, the greater the risk of lateral ankle injury (Beynonn *et al.,* 2002; Hershkovich *et al.,* 2015).

- Gender: The relationship between gender and ankle injuries remains controversial. One study suggested that ankle ligament injuries are three times more common in males than females (Lindenfeld *et al.,* 1994). However, another study found a greater occurrence of grade I inversion ankle sprains in females and then an equal incidence of grade II and III amongst both genders (Murphy *et al.,* 2003). A more recent study revealed a greater prevalence of CAIS in males than in females, in a general healthy young adult population (Hershkovich *et al.,* 2015).

The extrinsic risk factors are:

- Type of sport and level of competition: According to Murphy *et al.* (2003), the sports with the highest incidence of ankle sprain injuries are the sports involving jumping and side stepping motions such as soccer and basketball, with a greater rate of injury occurring during competition, than at practice.
- Type of shoes: There is speculation as to whether or not shoe type has any effect on ankle-sprain incidence (Verhagen and Bay, 2010). Barrett *et al.* (1993) and Curtis *et al.* (2008) investigated the effects of shoe design on the incidence of ankle sprains. Neither study found any difference in the risk of injury between different shoe designs and suggested that shoe height does not play a significant role in injury prevention, but the efficacy of shoes lies more in the newness of the footwear.
- Strapping or bracing of the ankle: Strapping or bracing of the ankle provides stability to the joint and improves proprioception and, therefore, decreases the risk of ankle sprains (Schapiro *et al.,* 1994; Murphy *et al.,* 2003). The effect of strapping compared to bracing remains inconclusive. Mickel *et al.* (2006) found no differences in their effects, however, Rovere *et al.* (1988) found braces to be more effective. A study by Verhagen and Bay (2010) found the use of bracing to only be effective for the prevention of ankle sprain recurrence.

2.3.5 Balance in CAIS

Postural control is defined as the ability of a person to maintain his or her centre of mass over his or her base of support. Postural control deficits have been documented among individuals with CAIS (De Ridder, 2014). Although deficits in static balance have previously been reported using centre of pressure and time to boundary measures, the underlying mechanism behind these deficits warrants further investigation, as the underlying mechanism that mediates impaired postural control remains unclear (Pope *et al.,* 2011; Kim *et al.,* 2012).

The ankle joint complex contains numerous proprioceptors (mechanoreceptors) that are found in the joint capsules, ligaments, muscles, fascia and the surrounding skin (Schleip, 2003; Delahunt, 2007). These mechanoreceptors are responsible for detecting mechanical stimuli,

such as the deformation and stretching of cells, as well as providing the sensations of touch, pressure, vibration, proprioception, hearing and equilibrium (Tortora and Derrickson, 2009). Freeman *et al.* (1965) were amongst the first researchers to suggest that balance impairments, following lateral ankle sprains, are due to damage to the articular mechanoreceptors, in the lateral ankle ligaments, which leads to deficits in proprioception. These deficits would then contribute to the development of functional instability.

Despite the popularity of the theory developed by Freeman *et al.* (1965), factors other than mechanoreceptor disruptions, such as strength, mechanical stability and range of motion, often become altered in patients with CAIS and are considered contributing factors for the associated balance impairments. Impaired postural control is believed to be the result of a combination of deficits in proprioception and neuromuscular control and, currently, there is more focus on the altered muscle spindle activity as an important afferent source of the deficits in proprioception in subjects with CAIS (De Ridder, 2014).

Proprioception plays an important role in postural stability, and is defined as the ability to combine sensory information from mechanoreceptors to determine body position and movements in space. In order to control balance, the central nervous system incorporates visual, vestibular and proprioceptive information to create motor commands that organise the activation patterns of muscles (Han *et al.*, 2015). Ankle joint proprioception is an important component of balance control because the foot and ankle complex are the only components of the body to have contact the ground (Han *et al.*, 2015).

The subtalar joint is responsible for the adaptive movements of the foot on the ankle and any loss of mobility of the talus, as a result of an ankle sprain, may have an effect on the adaption of the foot to the ground during walking. Therefore, abnormal mobility of the talocrural and subtalar joint may have an effect on the static and dynamic functions of the body (Lopez-Rodriguez *et al.*, 2007). Talocrural joint restrictions are highly prevalent in individuals with CAIS (Deneger *et al.,* 2002).

2.3.6 Muscle Activity Changes in CAIS

The dynamic stability of the ankle joint is provided by the muscles surrounding the joint. The tibialis anterior and peroneal muscles protect the ankle against unexpected destabilisation and the soleus muscle is responsible for maintaining postural control and normal foot and ankle biomechanics (McVey *et al*., 2005). Neuromuscular deficits have been found in the peroneus longus, tibialis anterior and soleus muscles of individuals with CAIS (McVey *et al*., 2005; De Ridder, 2014). According to Strøm *et al.* (2016), the peroneal muscles are important in the protection of ankle sprains, as they are the primary evertors of the foot and ankle complex, and therefore are able to resist ankle inversion, associated with inversion ankle sprains. Thus,

in the case of CAIS in which neuromuscular deficits are present, the peroneal muscles may not have the sufficient strength required to counter the inversion moment associated with the ankle sprain mechanism (Munn *et al.,* 2003; De Ridder, 2014).

Functional deficits reported in peroneal muscles, following ankle sprains, include reduced muscle activation (electromyographic amplitude) during gait and jumping tasks and reduced evertor muscle strength (Santilli *et al.,* 2005; Delahunt *et al.,* 2006; Arnold *et al.,* 2009; Suda *et al.,* 2009). It has been found that diminished concentric and/or eccentric strength deficits are not only found in the ankle evertors but also in the invertor muscles in individuals with CAIS (De Ridder, 2014). It is hypothesised that this is due to an inhibitory reflex mechanism to the invertors in order to avoid increasing tensile stress on the damaged ligaments (Hiller *et al.,* 2011). Studies have also demonstrated decreased plantarflexion strength in subjects with CAIS (Hubbard *et al.,* 2007; Gribble and Robinson, 2009; Fousekis *et al.,* 2012).

This change in muscle activity may occur as a result of arthrogenic muscle inhibition (AMI) (McVey, 2005). An arthrogenic muscle response is the continuous reflex reaction of the muscles surrounding a joint following structural damage to the joint (Hopkins and Ingersoll, 2000). This response may either manifest as inhibition or an increased potential for muscle activation (facilitation) (McVey *et al.,* 2005).

AMI occurs after a joint injury, such as an ankle sprain, as joint distension occurs as a result of damage or oedema, altering normal neurophysiological functioning of the joints mechanoreceptors. This leads to afferent neurons sending inhibitory information from disrupted mechanoreceptors to the spinal cord with the information then synapsing on the inhibitory interneurons, leading to reduced activation within the motor neuron pool of the involved muscles surrounding the damaged joint. This results in decreased recruitment of motor units and therefore decreased contraction force of the involved muscles (Hopkins and Ingersoll, 2000; Rice *et al.,* 2014).

AMI is considered to be a contributing factor in CAIS as the inhibition of the muscles surrounding the ankle joint results in their inability to properly exert force and sufficiently stabilise the ankle, therefore increasing the likelihood of re-injury (McVey *et al.,* 2005; Sefton *et al.,* 2008; Palmieri-Smith *et al.,* 2009; Klykken *et al.,* 2011).

Klykken *et al.* (2011) assessed motor neuron pool excitability of the tibialis anterior, soleus and peroneal muscles in individuals with acute ankle sprains, compared to their uninjured side. They found arthrogenic muscle responses in the lower limb muscles on the side with the sprained ankle.

It was found that patients suffering from ankle instability, when compared to healthy controls, had decreased spinal reflexive excitability of the fibularis longus and soleus muscles,

supporting the long-held belief that ankle instability, following ankle sprains, is due to weakness of the ankle evertor muscles (McVey *et al.,* 2005; Hopkins *et al.,* 2009; Palmieri-Smith *et al.,* 2009). However, the exact muscles involved, and those responsible for CAIS, remains a debated subject.

Kim *et al.* (2016) explored the relationship between self-reported ankle function and the modulation of Hoffmann reflex in patients with chronic ankle instability. They found that there is a relationship between self-reported ankle function and H-reflex modulation during changes in body positions in patients with CAIS. Fundamentally, the patients' ankle disability scores correlated with modulation of H-reflex measures.

A study by Kim *et al.* (2012) found the H-reflex modulation was much lower in the soleus and fibularis longus in the injured limbs of individuals with CAIS, when compared to their contralateral, uninjured limb, as well as both limbs of a healthy control group. In contrast to those findings, conflicting studies have shown little to no deficits in peroneal muscles in patients with CAIS (Delahunt, 2007). The findings by Lentell *et al.* (1995) and Kaminski *et al.* (1999) were not in agreement with the presence of evertor muscle weakness in CAIS, initially described by Tropp (1986).

According to Liebler (2001), there is evidence to support that muscle strength and function may become altered due to motion restrictions in the spine. Talocrural joint restrictions are often present in individuals with CAIS, and therefore it is possible that these restrictions may have the same effect on the musculature of the lower limb. Restricted ankle dorsiflexion range of motion found in CAIS may contribute to impaired sensorimotor system function by disrupting the normal transmission of afferent information attributable to alterations in ankle rotation and tracking of the articular surfaces (Hertel, 2002). It is evident that, from the conflicting studies and results, further investigations into which muscles are affected in CAIS are recommended. However, there is evidence to state that the muscle activity of ankle evertors, invertors and plantarflexors may all be affected by CAIS.

2.3.7 Management of CAIS

The high incidence of ankle injuries highlights a need for effective and adequate treatment protocols (Kerkhoffs *et al.,* 2012). The aims of ankle sprain treatment are to achieve static and dynamic stability, normal ankle range of motion, and achieve optimal strength of the peroneal, dorsiflexors, plantarflexors, and inverter muscles of the ankle (Pellow and Brantingham, 2001). There are a several types of modalities that may be implemented in the management of CAIS. These are described below, with the effects of joint manipulation discussed in the next section.

- Bracing and strapping: This may be used as a prophylactic measure. Strapping or bracing of the ankle joint provides stability to the joint and has been shown to improve

proprioception and, therefore, decreases the risk of ankle sprains (Schapiro *et al.,* 1994; Murphy *et al.,* 2003). It is important to note that this intervention will not improve muscle strength or proprioception and may result in weakening of the muscles if worn for prolonged periods (Elis *et al.,* 2002; Papadopoulos *et al.,* 2005).

- Non-steroidal anti-inflammatory drugs (NSAIDs): A brief period of use of NSAIDs may facilitate a rapid decrease in pain and swelling and may also be effective in the acute phase of injury. A study by Van den Bekerom *et al.* (2014) supported the use of NSAIDs for the initial treatment for acute ankle sprains. However, adverse effects related to the use of NSAIDs may affect the gastrointestinal tract, the cardiovascular system, the renal system and the liver. Adverse effects related to the use of NSAIDs are associated with frequent and prolonged use and prescriptions, therefore, should be kept to the minimal dosage for the shortest period of time (Ong *et al.,* 2007; Bruno *et al.*, 2014).
- Cryotherapy: The application of ice following an ankle sprain is an accepted clinical practice, however, the strength of evidence supporting the use of cryotherapy in the management of an acute soft tissue injury is generally poor (Bleakley *et al.,* 2004; Bleakley *et al.,* 2006). A study by Bleakley *et al.* (2006), nevertheless, revealed that the intermittent application of cryotherapy protocol, following a mild to moderate ankle sprain, significantly reduced the level of subjective pain on activity, one week after the injury, when compared with a standard protocol.
- Therapeutic ultrasound: Ultrasound is used in the treatment of a wide variety of musculoskeletal disorders, including ankle sprains but, the use of ultrasound therapy for the treatment of musculoskeletal conditions is a controversial topic. A review by Van den Bekerom *et al.* (2012) showed that there is little evidence demonstrating the beneficial effects of ultrasound therapy on acute ankle sprains.
- Laser and other electrotherapies: A review by Kerkhoffs *et al.* (2012) found no effect with the use of laser and electrotherapy in the treatment of acute ankle injuries, and therefore concluded that they added no value and were not recommended.
- Surgery: Functional and conservative treatment is preferred over surgical therapy, however, sprains with complete tendon tears require surgical intervention (Wolfe, 2001; Cao *et al.,* 2018; Brown *et al.,* 2018).
- Rehabilitation: This involves muscle strengthening, proprioception and balance training, as well as regaining neuromuscular control (Caufield, 2000; Ajis and Maffulli, 2006; McBride and Ramamurthy, 2006; Lee and Lin, 2008). Exercise therapy has been found to prevent the recurrence of injury in those with lateral ankle injuries and it is recommended in the treatment of lateral ankle injuries (Kerkhoffs *et al.,* 2012). Although 80% to 85% of acute ankle sprains are successfully treated with a functional

ankle-rehabilitation programme, the remaining 15% to 20% are likely to experience recurrent ankle instability and may require surgical intervention (Baumhauer and O'Brian, 2002).

- Trigger point dry needling: A study by Salom-Moreno *et al.* (2015) compared the effect of a combination of trigger point dry needling and proprioceptive and strength training to only proprioceptive/strength training on pain and function in individuals with CAIS. Their study found that the inclusion of dry needling of the peroneal muscles into a proprioceptive/strengthening exercise programme results in better outcomes in pain and function.

2.4 JOINT MANIPULATION

Manual therapy may refer to either joint manipulation or joint mobilisation. Joint mobilisation involves passive rhythmic and repetitive movements within a range of motion or against a restrictive barrier. It is an extension of passive motion testing and can be applied to a single articulation or a group of spinal segments. It is a gentle technique where the force and amplitude can be controlled depending on the response of the tissue (Fryer *et al.,* 2004). Joint manipulation may be defined as a manual therapy technique in which a high velocity, low amplitude (HVLA) thrust is applied to a joint, at the end of the joint's physiological range of motion, without exceeding its anatomical limits (Herzog, 2010; Bergmann and Peterson, 2011). A 'cracking' or 'popping' sound may occur along with the manipulation (although it is not necessary for the manipulation to be successful), as the gapping of the joint creates fluid cavitation (Kaur *et al.,* 2014; Cardinale *et al.,* 2015). Although manipulation is most frequently applied to the spine, it can also be used on any synovial joint of the extremities (Pickar, 2002; Bergmann and Peterson, 2011). Joint manipulation was used as the intervention in this study.

2.4.1 Theoretical Models Explaining Joint Manipulation

It has been theorized that joint manipulation reduces joint restrictions, resulting in improved proprioception and muscle functioning and decreased reported levels of pain (Lindsey-Renton, 2005; Whitman *et al.,* 2009; Grindstaff *et al.,* 2011; Loudon *et al.,* 2013; Lubbe *et al.,* 2015).

It is understood that the manipulation of a joint stimulates the mechanoreceptors of the structures found in and around that joint, resulting in an alteration of the afferent information associated with the stimulation of the joints mechanoreceptors. This causes a change in motor neuron excitability, as the information is relayed along type I and type II afferent fibres to the dorsal horn of the spinal cord. The afferent neuron synapses with the interneuron that relays

an excitatory or inhibitory effect to the motor neuron; this information is then relayed to the appropriate muscles resulting in an increase or decrease of motor neuron pool excitability (Suter and McMorland, 2002; Dunning and Rushton, 2009; Haavik and Murphy, 2012; Pickar and Bolton, 2012; Cardinale *et al.,* 2015).

2.4.2 Clinical Research Investigating the Effects of Joint Manipulation

The neurophysiological mechanisms supporting the clinical benefits of joint manipulation are in need of further investigation, especially in extremity joints (Evans, 2002; Pickar, 2002; Maigne and Vautravers, 2003; Brantingham *et al.,* 2009). Several studies (Lalanne *et al.,* 2009; Haavik and Murphy, 2012; Fryer and Pearce, 2012; Niazi *et al.,* 2015; Haavik *et al.,* 2016) have investigated the neurophysiological effects of spinal manipulation, with varied results, as some studies have found the effects of manipulation on surrounding muscles to be excitatory, while others have found the effects to be inhibitory. The stimulation of the mechanoreceptors within the extremity joints, and their surrounding tissues, following joint manipulation, should have similar neurophysiological reactions to those seen in the spine (Haavik and Murphy, 2012; Pickar and Bolton, 2012).

2.4.3 Clinical Research Investigating the Effects of Joint Manipulation in CAIS

Hopkins and Ingersoll (2000) and McVey *et al.* (2005) determined that the disruption of afferent input to the nervous systems that is found in CAIS needs to be corrected in order for the muscles surrounding the ankle joint to function at an optimal level. It is theorised that the rapid influx of afferent information, as a result of joint manipulation, may correct this, and result in increased motor neuron pool excitability of the surrounding muscles (Maduro de Camargo *et al.,* 2010; Grindstaff *et al.,* 2011; Niazi *et al.,* 2015). Several studies have investigated the clinical effects of joint manipulation/ mobilization on CAIS, and these are summarised in Table 2.3.

Table 2.3: Clinical studies investigating the effect of joint manipulation/mobilization on CAIS and ankle sprains

Author	Sample Size	Study Design	Intervention	Outcome Measures	Results
Chae *et al.* (2017)	N= 15	RCT	1. Proximal and distal tibiofibular joint manipulation. 2. Control (opposite, non-injured ankle).	Ankle dorsiflexion (weight-bearing lunge test) and static and dynamic balance.	Manipulation resulted in significant improvements in ankle dorsiflexion and dynamic balance. There was no significant change in static balance.
Kamali *et al.* (2017)	N=40	Double-blind RCT.	1. TCJM. 2. Sham intervention.	Single leg hop, speed and Y balance tests pre and post intervention.	Functional tests showed significant improvement for TCJM.
Dicks (2016)	N=42	RCT	1. TCJM. 2. Sham intervention. 3. Control.	sEMG (H/M ratio) of the soleus and peroneus longus.	No effect was shown for TCJM on H/M ratios of the soleus and peroneal muscles.
Fisher *et al.* (2016)	N= 27	RCT	1. TCJM. 2. TC mobilisation. 3. Control.	MEP and CSP of the tibialis anterior and gastrocnemius using transcranial magnetic stimulation.	The manipulation group showed an increase in corticospinal excitability and MEP amplitude of the tibialis anterior and the mobilisation group showed decreased corticospinal excitability.
Lubbe *et al.* (2015)	N=33	RCT	1. TCJM with rehabilitation. 2. Rehabilitation.	VAS, FADI, WB dorsiflexion test, algometer, motion palpation, BBS.	Significant improvements in VAS, algometer, motion palpation and BBS scores.
Botha (2013)	N=40	RCT	1. TCJM. 2. AAI.	NRS, FADI, Algometer, weight-bearing ankle dorsiflexion test, BBS, motion palpation.	Both groups showed improvement in the Algometer, BBS, dorsiflexion ROM, NRS and FADI.
Beazell *et al.* (2012)	N=43	RCT	1. Proximal tibiofibular manipulation. 2. Distal tibiofibular joint manipulation. 3. Control (no intervention).	Dorsiflexion ROM, BESS, step-down test, FAAM sport subscale.	No significant change between manipulation groups and control for dorsiflexion, BESS, step-down test, and FAAI sport subscale scores.
Grindstaff *et al.* (2011)	N=43	RCT	1. Proximal tibiofibular manipulation. 2. Distal tibiofibular manipulation. 3. Placebo.	sEMG (H-reflex) of soleus and peroneus longus.	Group 1 had an acute increase in soleus muscle activity, with no significant change found in peroneus longus muscle activity.
Hoch and McKeon (2010)	N=20	Randomised cross-over design	1. Joint mobilization. 2. Control.	Dorsiflexion ROM, SEBT and TTB measures of postural control.	Mobilization resulted in significant improvements in dorsiflexion ROM and TTB in anterior-posterior direction with eyes open.
Joseph *et al.* (2010)	N=40	RCT	1. TCJM. 2. TC mobilization.	One leg standing test, NRS.	Significant improvements in balance, ROM, function and pain in both groups.
Khone *et al.* (2007)	N=30	RCT	1. Single TCJM. 2. Six TCLM.s	Proprioception, ROM and point tenderness.	Significant improvement in proprioception and dorsiflexion ROM in group two.
López-Rodríguez *et al.* (2007)	N=52	Repeated-measure RCT	1. TCJM. 2. Posterior glide manipulation of talus. 3. Placebo.	Stabilometry and Baropodometry using a Foot Work force platform.	Talocrural joint manipulation redistributed foot load.

RCT = Randomised clinical trial, ROM = range of motion, TCJM = talocrural joint manipulation, TC = talocrural, VAS = visual analogue scale, FADI = foot and ankle disability index, WB = weight bearing, BBS = berg balance scale, ROM = range of motion, NRS = numerical pain rating scale AAI = activator adjustment instrument, BESS = Balance Error Scoring System, FAAM = Foot and Ankle Ability Measure, MEP = Motor-Evoked Potential, CSP = Cortical Silent Period, SEBT = star excursion balance test, TTB = time-to-boundary

2.4.3.1 Effect of Manipulation on Pain, Disability and ROM

A systematic review by Louden *et al.* (2013) and Wikstrom and McKoen (2010) showed that joint manipulation in CAIS is associated with an increase in dorsiflexion range of motion, reduced pain and improved foot and ankle functioning (proprioception and muscle function) indicating that manipulation is effective, although the exact mechanisms through which joint manipulation brings about these effects is not clear.

Both distal tibiofibular and talocrural joint restrictions have been found in patients with CAIS, however, talocrural joint restrictions have been found to be more prominent than those in the distal tibiofibular joint (Deneger *et al.,* 2002).

Decreased dorsiflexion of the talocrural joint has also been shown to contribute towards CAIS (Denegar *et al.,* 2002; Hertel, 2002; Bonnel *et al.,* 2010).

Pellow and Brantingham (2001) compared the effects of talocrural joint manipulation versus a placebo treatment (n=30) with subacute and chronic grade I and II inversion ankle sprains. Their study revealed a significant improvement in subjective pain, range of motion and ankle functioning following manipulation, when compared to the placebo group.

A systematic review by Wikstrom and McKoen (2010) revealed that several HVLA thrusts, delivered over multiple treatment sessions, showed a statistical improvement in self-reported levels of pain.

2.4.3.2 Effect of Manipulation on Balance and Postural Stability

Studies assessing the effect of joint manipulation on postural control and weight distribution in CAIS participants are scarce and the results of studies have differed in their findings. Lopez-Rodriguez *et al.* (2007) found that talocrural joint manipulation resulted in notable redistribution of foot loading, as measured by stabiometry and baropodometry in participants with CAIS (n=52). The results of their study support that the manipulation of the ankle has immediate proprioceptive effects.

According to Lopez-Rodriguez *et al.* (2007), few studies have evaluated postural equilibrium and orientation following talocrural joint manipulation. They recommended that further research assessing balance changes associated with manipulation are required.

The effect of joint mobilisation on eyes-open, single leg postural control was investigated by Hoch and Mckeon (2010), and a single treatment session of Maitland Grade III anterior to posterior joint mobilisations was found to improve eyes open single-limb stance postural control.

In these studies, the improvements in postural stability were obtained through testing postural stability with the participants' eyes open. In order to maintain postural stability, the sensorimotor system receives input from three afferent systems (vestibular, somatosensory, and visual). When one of these systems (somatosensory) is impaired, the other two intact systems attempt to compensate for the impaired one. However, when an individual closes their eyes, only one intact afferent system remains for balance control (Akbari *et al.,* 2006). Therefore, if stability were to be tested with eyes closed, only proprioception would be in play, and so more studies examining the effects of ankle joint manipulation on balance with eyes closed may provide further insight into the relationship between manipulation and proprioception.

Unlike Lopez-Rodriguez *et al.* (2007) and Hoch and Mckeon (2010), Beazell *et al.* (2012) did not find that joint manipulation has a significant effect on balance. Their study explored the effects of proximal and distal tibiofibular joint manipulation on functional outcomes in individuals with CAIS (of which, balance was investigated). The study sample (n=43) was divided into three groups: a proximal tibiofibular joint manipulation group (n=15), a distal tibiofibular joint manipulation group (n=15) and a control group (n=13). Measurements were taken over a three week period, on days one, seven, fourteen and twenty-one, and it was found that the use of a proximal or distal tibiofibular joint manipulation in isolation did not enhance balance outcomes beyond those of the control group.

Chae *et al.* (2017) aimed to evaluate the changes in dorsiflexion and balance, following proximal and distal tibiofibular joint manipulation, in individuals with a history of lateral ankle sprain. They found that manipulation did not result in a significant change in overall static balance. However, their study did find that ankle dorsiflexion and dynamic balance were improved following the manipulation, compared to those prior to the manipulation.

Proximal and distal tiobiofibular joint manipulation was implemented in the studies by Beazell *et al.,* (2012) and Chae *et al.,* (2017), however, manipulation directed at the talocrural joint may be more beneficial as the talocrural joint restrictions are highly prevalent in individuals with CAIS (Deneger *et al.,* 2002) and this joint, along with the subtalar joint, has an effect on the static and dynamic functions of the body (Lopez-Rodriguez *et al.*, 2007).

Based on the conflicting findings between studies, further research investigating the effects of joint manipulation on balance and postural control in individuals with CAIS is recommended.

2.4.3.3 Effect of Manipulation on Muscle Activity

The distal tibiofibular joint manipulation of individuals with CAIS demonstrates an acute increase in soleus muscle activity, with no significant change found in peroneus longus muscle activity (Grindstaff *et al.,* 2011). However, a limitation of that study was that measurements

were taken in a supine position, while the subject remained in a quiet, still, relaxed state, and, therefore, it is not known how the increase in soleus activation, due to distal tibiofibular joint manipulation, would translate to standing or other functional activities. It was suggested that future studies should investigate how changes in muscle activation may affect self-reported function and symptoms associated with CAIS.

Dicks (2016) assessed the immediate effect of talocrural joint manipulation on peroneal and soleus muscle activity in CAIS and found no significant treatment effect. Dicks (2016) and Grindstaff *et al*. (2011) limited their investigations to the peroneal and soleus muscles. Yet research has suggested that the tibialis anterior and gastrocnemius muscles may also have a role in CAIS.

Fisher *et al.* (2016) compared the effects of low-velocity mobilization compared to high-velocity thrust manipulation of the talocrural joint on the corticospinal excitability of the tibialis anterior and gastrocnemius muscles at rest and during submaximal active contraction. Participants were assigned to control, joint mobilization, or thrust manipulation groups. The motor-evoked potential (MEP) and cortical silent period (CSP) of the tibialis anterior and gastrocnemius were obtained with transcranial magnetic stimulation at rest and during active contraction. Their study found that talocrural joint manipulation increased corticospinal motor excitability of the tibialis anterior approximately 30 minutes after the manipulation. The input/output-curve slopes for the tibialis anterior rest and tibialis anterior active conditions increased following thrust manipulation, representing heightened excitability of involved corticospinal neurons. The maximal MEP amplitude also increased post manipulation for the tibialis anterior rest condition, indicating an excitatory corticospinal motor modulation following this intervention. The findings of their study suggested that the sEMG data acquired during functional testing or movements may have detected changes in muscle activity of the tibialis anterior following manipulation, therefore the use of sEMG to record muscle activity of the tibialis anterior should be investigated to further validate the findings of that study.

2.5 CONCLUSION

It is evident from the literature that the findings related to the effects of joint manipulation on CAIS are varied, and although some studies have found that a relationship exists between manipulation and the outcomes of pain and disability, balance and muscle activity in individuals with CAIS, it would appear that more research into this field is required.. It is also not clear how these mechanisms may effect or influence each other with respect to each outcome. Therefore, the holistic nature of this study aims to gain further insight into whether or not talocrural joint manipulation has an effect on the individual outcomes of pain and

disability, balance and muscle activity, as well as to identify any potential relationships these outcomes may have with each other, based on changes, if any, in this study.

CHAPTER THREE METHODOLOGY

3.1 INTRODUCTION

This chapter describes the methodology utilised to achieve the aims and objectives of this study, along with the ethical considerations that were respected to ensure the participants' safety and well-being.

3.2 STUDY DESIGN

This study made use of a quantitative paradigm and a randomized single blinded placebo controlled pre-test, repeated post-test measures experimental design. This type of design allowed the allocation of participants into two groups randomly, where each group was tested prior to the intervention, immediately after the intervention, and then again 20 minutes after the intervention. Both groups were re-tested in order to determine the effect of the independent variable (Crano *et al.,* 2015).

3.3 PERMISSION TO CONDUCT THE STUDY AND STUDY LOCATION

Permission to conduct the study was obtained from the Institutional Research Ethics Committee (IREC) (Appendix A) and the study was registered on the South African Clinical Trials register (DOH-27-0618-6048, Appendix B). The study took place at the institutions Day Clinic following approval from the Clinic Director of the Chiropractic Day Clinic, as well as the IREC (Appendix C and D).

3.4 STUDY POPULATION

The population being investigated in this study were people who were suffering with chronic ankle instability syndrome (CAIS), who resided in the area of eThekwini Municipality. The participants were diagnosed by a case history that met the diagnostic criteria of CAIS, which included symptoms of ankle instability, more than one sprain or recurrent sprains, or 'giving way' that persisted for over six months, following an ankle sprain, as well as a physical and foot and ankle regional examination.

3.5 PARTICIPANT RECRUITMENT

Participants were recruited through advertisements (Appendix E) which were placed, following permission from appropriate authorities, at the institution's notice boards, local sports' clubs and gyms around Durban. In addition, prospective participants were recruited through word of mouth.

Potential participants were screened using the following questions:

1. Are you willing to answer a few questions?
2. Have you suffered an ankle sprain?
3. Have you sprained your ankle any time within the last 3 months?
4. Have you experienced symptoms of ankle instability, recurrent sprains or 'giving way' of your ankle since the ankle sprain?
5. Are you currently undergoing treatment for your ankle problem/pain?
6. Have you had any surgery to your lower limb?

A participant needed to answer "yes" to questions 1, 2 and 4, and answer "no" to questions 3, 5 and 6 to be included in the population. When a participant met the qualifying criteria, an appointment was made at the Chiropractic Day Clinic (CDC) for an assessment and sampling.

Participants were required to meet the study inclusion and exclusion criteria to be enrolled in the project.

3.5.1 Inclusion Criteria

1. Participants were required to be between the ages of 18-45 years old to allow homogeneity within the population, as it eliminated inclusion of participants that had not yet achieved full musculoskeletal maturity, as well as participants that may have been experiencing degenerative joint changes (Chowdry *et al.,* 2006; Lubbe, 2011).
2. Participants were required to meet the diagnostic criteria of CAIS, which includes symptoms of ankle instability, more than one sprain or recurrent sprains or 'giving way', that persisted for over six months following an ankle sprain (Karlsson *et al.,* 1996; de Vries *et al.,* 2011; Van Ochten *et al.,* 2014).
3. Participants demonstrating CAIS must have experienced at least one grade one or grade two ankle sprain, three or more months prior to the consult, to be included in the study. The grading method according to the associated clinical features of ankle sprains was used in the diagnosis (Pellow and Brantingham, 2001; Ajis and Maffulli, 2006; Chan *et al.,* 2011):

- Grade 1: Mild sprain, mild ligament damage, no haemorrhage or bruising, minimal oedema, point tenderness and no gross instability.
- Grade 2: Moderate sprain, partial tearing of the ligaments, minimal haemorrhage and bruising, localised oedema and minimal instability if at all.

4. Participants had to sign an informed consent form (Appendix F)

3.5.2 Exclusion Criteria

1. Participants who had experienced acute injury/re-injury less than three months prior to the initial consultation were excluded from the study (Gribbel *et al.,* 2013).
2. Participants who presented with diffuse swelling on both sides of the Achilles tendon, early haemorrhage and bruising, tenderness occurring medially and laterally, and gross instability were excluded as this was indicative of a grade three ankle sprain (Pellow and Brantingham, 2001).
3. Participants with contraindications to manipulation or diagnosed ankle osteoarthritis, current pregnancy, or neuromuscular disease were excluded (Pellow and Brantinham, 2001; Köhne, 2005; Grindstaff *et al.,* 2011).
4. Participants who made use of anti-inflammatory medication or muscle relaxants were excluded, unless they were willing to undergo a three day 'washout' period before taking part in the study (Poul *et al.,* 1993; Dryer *et al.,* 2012).

3.6 SAMPLE SIZE AND ALLOCATION

A power analysis was calculated using G-Power version 3.1.9.2 (Franz Faul Universität Kiel Germany G*Power 3.1.9.2). The sample size was calculated at 80% power, with a medium effect size of 0.25 and an alpha of 0.05, using repeated measures ANOVA with in-between interactions. This resulted in a sample of 42 participants being required to participate in the study, with 21 per group. The recruited participants were randomly allocated into two groups, using a randomisation table (Cottrell and McKenzie, 2005) (Appendix G). The numbers 1 – 42 were listed on the randomisation table, with either the letter 'A' or 'B' randomly allocated to each number. When the participants were recruited into the study, they were allocated to a group, depending on which number they represented. Those with letter 'A' fell into group one and received the intervention (manual long-axis distraction manipulation), while those with the letter 'B' were allocated to group two, the placebo group.

3.7 MEASUREMENT TOOLS

The measurement tools were used to determine the effect of the independent variable on the dependant variables in this study. Independent variables are stable and unaffected by the other variables that are measured, therefore the independent variable in this study was the talocrural joint manipulation. Dependant variables are expected to change as a result of an experimental manipulation of the independent variable or variables, thus the dependant variables in this study were balance, muscle activity (using sEMG) and pain and disability (Salkind, 2010).

3.7.1 Subjective Measurements

3.7.1.1 Foot and Ankle Disability Index (FADI)

This index (Appendix H) was used to measure disability and pain relative to CAIS. It was designed by Martin *et al.* (1999) and is a self-administered questionnaire in which participants are asked to answer every question with the response that most closely describes their condition. Participants rated the difficulty in performing the respective activities of daily living listed in terms of the following scores:

- No difficulty at all - 4 points.
- Slight difficulty - 3 points.
- Moderate difficulty - 2 points.
- Extreme difficulty -1 point.
- Unable to do - 0 points.

For pain measurements, the activities listed were rated by the participants as follows:

- No pain - 4 points.
- Mild pain - 3 points.
- Moderate pain - 2 points.
- Severe pain - 1 point.
- Unbearable pain - 0 points.

The FADI score was recorded as a percentage of 104 points, with 100% representing no dysfunction. Therefore, an increase in the FADI score post intervention from the pre intervention FADI score would demonstrate a decrease in pain and disability, and a decrease in the FADI score would demonstrate an increase in pain and disability. This study did not make use of the minimally clinical important difference (MCID) to measure changes in the FADI. The MCID is used to indicate the smallest difference that the patient perceives as beneficial. According to a systemic review by Eechuate *et al.* (2007) on the clinimetric qualities

of patient-assessed instruments for measuring chronic ankle instability, only the foot and ankle ability measure (FAAM) presented an MCID.

This study also made use of the FADI general pain score, which was also converted to a percentage in order to monitor any changes in overall pain following the intervention. FADI scores were recorded prior to the intervention and then participants were contacted 24 hours after the consultation to rate their pain and disability again.

The FADI has been deemed reliable in detecting functional limitations in patients with chronic ankle instability (Hale and Hertel, 2005). The systematic review by Eechuate *et al.* (2007) found the FADI to be one of the most appropriate patient-assessed tools to quantify functional disabilities in patients with CAIS. The FADI has had good to excellent intersession reliability, with interclass coefficients of 0.85 to 0.95 (Cosby *et al.,* 2011).

3.7.2 Objective Measurements

3.7.2.1 Balance

The Biosway Portable Balance System was selected for use in this study as it has been shown to provide valid, reliable, and repeatable objective measurements of a participant's neuromuscular control and balance ability (Akhbari *et al.,* 2015; Biosway, 2016). A force platform (like the one used by the Biosway Portable Balance System) collects pressure readings from four pressure sensors, located at each corner of the force platform.

A postural stability test was used to measure changes in balance, as this test emphasized the participant's ability to maintain their centre of balance. The participant's score on this test assessed deviations from the centre; the lower the score, the more postural control the individual exhibited. The participant stood at the centre of the platform to ensure optimal results (Biosway Portable Balance System: Operation Manual, 2016).
The procedure for testing postural stability through the Biosway Balance scale, according to Biosway Portable Balance System: Operation Manual (2016), was performed as follows:

- From the on-screen menu, postural stability testing was selected.
- The participant's age and height were entered where appropriate on screen.
- The participant was asked to stand on the balance scale.
- The "Start" button was pressed to activate a cursor on screen and the participant was positioned so that the on-screen cursor was moved onto the centre point of the grid. The test protocol was then explained to the participant.
- The "Record" option was selected, bringing up the "Position Patient Entry" screen and suggested standardized foot positions were provided. If the participant could

not be positioned as suggested, they were re-centred and a new foot position was entered.

- The “Start” button on the display screen was then pressed to activate the cursor and the participant was again told to move the cursor to the centre point on the grid. Participants were told to try and keep the cursor on the centre point of the grid during the testing procedure. The “Record” option was selected to bring up the “Position Patient Entry screen”. The keypads were used to enter the participant’s left foot, left heel or right foot and right heel positions using the midline of the foot and the platform grid as reference points.
- When the participant was ready to begin the test, the “Collect Data” option was selected. The screen provided a three-second countdown before beginning the first of three test trials.
- After completing the test, a “Test Complete” message was displayed on screen.
- The “Results” button was selected after a test was complete and the participant’s balance test scores were taken down manually from the monitor.
- This study made use of the participant’s overall balance scores. As mentioned previously, the participant’s score reflected how much they deviated from the centre, as when the participant deviated from the centre, their score increased, therefore a lower score was more desirable than a higher score, as it reflected greater postural stability.

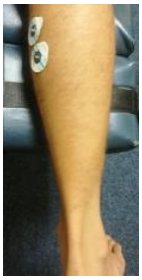
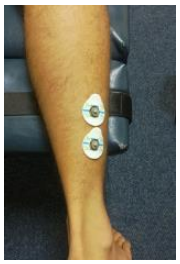
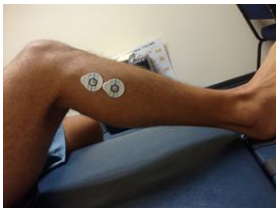
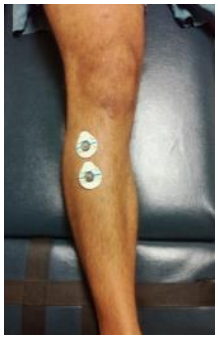
3.7.2.2 Muscle Activity

Muscle activity monitored through sEMG is considered an established evaluation tool for applied research and allows the measurement of muscular performance as well as documentation of treatment regimes, amongst many other uses (Konrad, 2006). Surface electromyography has also been used in studies that have assessed the muscle activity of individuals suffering from ankle instability during single-leg balance tests (Feger *et al.,* 2014; Kwon, 2018).

The Biopac – Bionomadix complete wireless research system was used in this study to measure muscle activity in millivolts (mV) during static single-legged balance tests, before and after intervention. The system consisted of the MP150 Data Acquisition System, Acqknowledge software and the Bionomadix Dual-channel Wireless EMG Transmitter and Receiver Pair (Biopac Systems Inc, 2015). The sEMG readings were taken from the tibialis anterior, soleus, medial gastrocnemius and peroneus longus muscles of the injured limb using disposable, round, 35mm, pre-gelled Ag/AgCl conductor electrodes. A new set of electrodes were used for each new participant.

The areas where the sEMG electrodes were placed were shaved using an electric hair trimmer and cleaned with an alcohol swab and the hair trimmer was disinfected before use on every participant to avoid the possibility of infection (Grindstaff *et al.,* 2011). The electrodes were attached to a Transmitter and Receiver pair, which connected wirelessly to the Biopac – Bionomadix wireless research system to record the muscle signals. The electrode placement protocol for each muscle is described and shown in Table 3.1.

Table 3.1: The electrode placement protocols of the relevant test muscles (Palmieri *et al.,* 2004; Criswell, 2011)

Muscle	Electrode placement	Example
Medial gastrocnemius	Two electrodes running parallel to the muscle fibres, just distal from the knee and 2 cm medial to midline (Criswell, 2011).	
Soleus	Two electrodes placed parallel to the muscle fibres on the inferior and lateral aspects of the leg, below the belly of gastrocnemius (Criswell, 2011).	
Peroneus longus	Two electrodes placed 2cm distal to the fibular head (Palmieri *et al.,* 2004).	
Tibialis anterior	Two electrodes were placed parallel and just lateral to the medial shaft of the tibia approximately one-third of the distance between the knee and the ankle. On palpation of the area while the patient dorsiflexed their foot, the electrode was placed over the largest muscle mass (Criswell, 2011).	

Surface EMG amplitude is highly sensitive to many factors, including, but not limited to, electrode placement and application, temperature, muscle fatigue, contraction velocity, muscle length, cross talk from surrounding muscles, external noise and electronic devices,

subcutaneous fat thickness and slight variation in task execution. It is very difficult to control all of these influential factors of sEMG amplitude in a clinical setting, therefore, in order to compare amplitude variables between measurements, normalisation is required (Sousa and Tavares, 2012).

This study made use of the maximal voluntary contraction (MVC) method to identify the belly of the muscle for electrode placement and as a standard to normalise individual responses to the intervention. This is one of the most common methods of normalising sEMG signal (Halaki and Ginn, 2012). This method consists of sEMG signals being expressed as a percentage of the maximum neural drive acquired, while a participant performed a maximal voluntary contraction (MVC) of the desired muscle (Sousa and Tavares, 2012; Halaki and Ginn, 2012). Maximal sEMG values of the tibialis anterior, medial gastrocnemius, soleus and peroneus longus were measured by asking the participant to perform MVCs of the mentioned muscles against manual resistance for five seconds in inversion, plantarflexion and eversion, according to the techniques, as described by Kendall (2006), for each muscle. A rest of 30 seconds between each contraction was implemented.

Two trials of maximal voluntary contraction were required from each muscle. Participants were instructed by the researcher to contract as forcefully as possible with a gradual increase in force. The MVCs were used for normalisation of muscle activity obtained during balance testing (Harput *et al.,* 2013; Feger *et al.,* 2014; De Ridder *et al.,* 2015; Strøm *et al.,* 2016). In order to further regulate the sEMG signal, the same consultation room was used for the duration of the study with the door closed during each research session, in order to reduce outside noise and interference. Electronic devices were also kept away from the acquisition system to prevent noise interference.

Measurements of muscle activity were taken during the three 20 second trials of each respective balance test. Root mean squared (RMS) sEMG was analysed over the time intervals of the balance tests measured pre-intervention, immediately post-intervention, and 20 minutes post-intervention (Feger *et al.,* 2014; Muehlbauer *et al.*, 2014).

Root Mean Squared reflects the mean power of the sEMG signal and is the recommended method for sEMG signal smoothing (Konrad, 2006). The mean RMS sEMG value was determined for every 20 second balance test and, subsequently, the mean of the three trials for each balance test was calculated. For every muscle, these mean values were then normalised as a percentage of the highest MVC value obtained from the respective muscle (De Ridder *et al.,* 2015).

3.8 DATA COLLECTION PROCEDURE

At the consultation, the participants were given a verbal explanation of the study, as well as a letter of information explaining the study procedure (Appendix I) and an informed consent form to complete. Participants were given an opportunity to ask any questions regarding the study and were informed that they were free to withdraw from the study at any time. Participants then underwent a case history (Appendix J), physical examination (Appendix K) and a foot and ankle orthopaedic assessment (Appendix L).

Once it was determined that they were eligible to participate in the study, the participants were allocated into either the intervention or control groups, by means of the randomisation table. The participants were then asked to fill out the FADI and on completion the participants were prepared as necessary for the placement of the sEMG electrodes on to the muscles of the involved limb, as described in Table 3.1.

Maximal sEMG values of the tibialis anterior, soleus and peroneus longus and medial gastrocnemius were measured by asking the participant to perform MVC of the mentioned muscles against manual resistance for five seconds in inversion, plantarflexion and eversion according to the techniques as described by Kendall (2006).

The balance testing procedure was then explained to the participants and they underwent a short test trial to familiarise them with the procedure. Surface EMG recorded muscle activity during the postural stability test as soon as the test had begun. The recording of muscle activity was stopped as soon as each postural stability test was finished. Each postural stability test consisted of three 20 second trials that contributed to an overall balance score. The postural stability test was performed with eyes open and eyes closed, with a 30-second break between trials to avoid muscle-fatigue (Strøm *et al.,* 2016).

Participants then received an intervention:

- **Group one (experimental group)** received a high-velocity, low-amplitude caudal thrust directed at the talocrural joint by the researcher. Each participant was in a supine position and the researcher wrapped his hands around the participant's foot, with his fingers at the level of the neck of the talus. Caudal traction was applied, with an increase of dorsiflexion at the talocrural joint (Paes *et al.*, 2013). Manipulation is often associated with a popping or a cracking, which is referred to as a cavitation, however, the cavitation is not necessary for manipulation to be deemed successful, and thus the presence or absence of cavitation was not used to determine if the manipulation was successful in this study (Pickar, 2002; Maigne

and Vautravers, 2003; Kaur *et al*, 2014; Cardinale *et al*, 2015). The set up for the talocrural joint manipulation is demonstrated below in Figure 3.2.

- **Group two (control group)** received a placebo manipulation. The placebo intervention consisted of the researcher's hands being placed around a participant's foot with his fingers at the level of the neck of the talus. No therapeutic traction or joint manipulation occurred and the participant's foot was simply held for 20 seconds and then repositioned on the table according to the technique used by Paes *et al.* (2013). The contact between the researcher and the participant was emphasised to ensure any change in muscle activity was due to the talocrural joint manipulation and not due to simple physical contact with the skin surrounding the ankle joint (Grindstaff *et al.*, 2011). The set up for the talocrural joint manipulation and placebo is demonstrated in Figure 3.1.

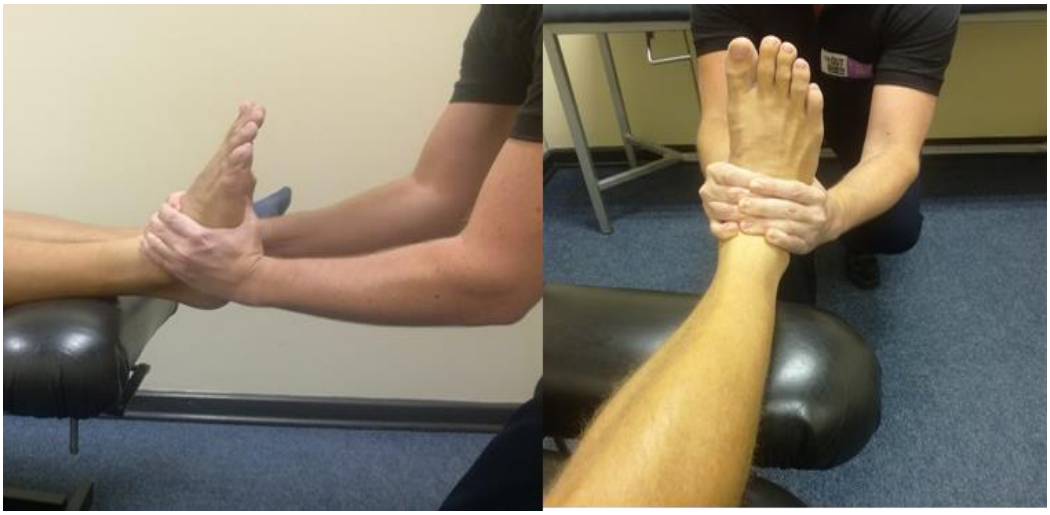


Figure 3.1: Set up for talocrural joint manipulation

The participant's balance and muscle activity were then measured again immediately following the intervention, implementing the same protocol described previously. Once these measurements were taken, the participants were given a 20 minute rest period, during which they were required to remain seated in a chair provided in the consultation room for the duration of the 20 minutes until balance and muscle activity were recorded once again, following the same procedure described previously. This procedure is illustrated in Figure 3.2 below.

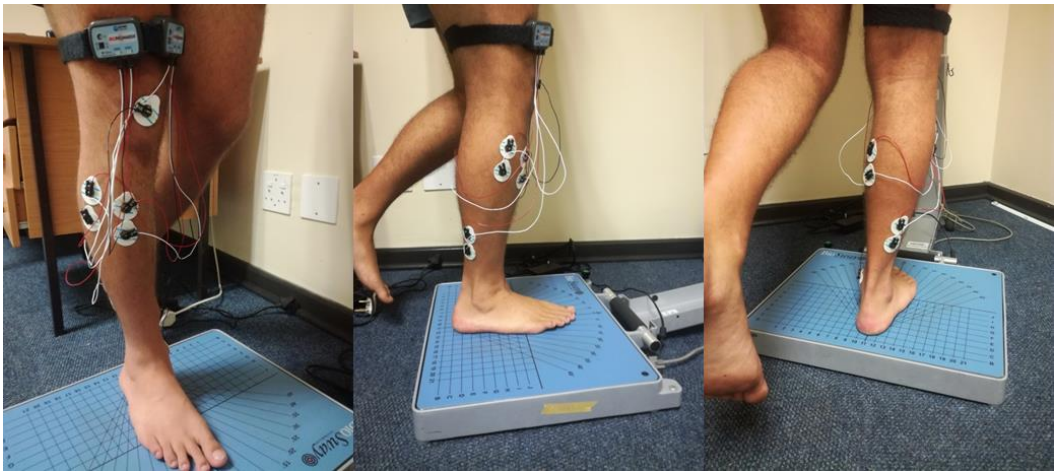


Figure 3.2: Photograph showing muscle activity and postural stability being recorded

Twenty-four hours after the consultation, the participants were contacted telephonically by the researcher to rate their pain and disability using the FADI. The FADI was read out to the participants telephonically, with the participants being required to answer every question with the response that most closely described their condition (as done on the initial consult). Once the measurements had been taken and the study was complete, each participant was thanked for their participation and was offered a free treatment session.

A voucher (Appendix M) was given to each participant, with the date/time it was issued. It was valid for six months, and allowed the participants to attend a complimentary visit to the chiropractic clinic. Any participants requiring further treatment (from either group one or two) were referred to an appropriate practitioner, or to the CDC, as an outpatient for treatment.

3.9 DATA REDUCTION AND ANALYSIS

3.9.1 Data Reduction

The FADI has a total value of 104 points and was scored as a percentage, with 100% representing no dysfunction (Cosby *et al.,* 2011). One of the subscales within the FADI is a general pain score with a value of four points. This score was also analysed as a percentage (out of four) to determine any changes in overall pain.

As mentioned previously, one of the most common methods of normalising sEMG signals from a given muscle is to make use of the sEMG recorded from the same muscle during a MVC as a reference value (Halaki and Ginn, 2012). The mean root mean square (RMS) sEMG value was determined for every 20 second balance test and, subsequently, the mean of the three trials for each balance test was calculated for each of the four muscles. For every muscle, these mean values were then normalised as a percentage of the highest MVC value obtained

from the respective muscles (Halaki and Ginn, 2012; De Ridder *et al.,* 2015). Postural stability was analysed as an overall score for each time point for eyes open and eyes closed. These scores were taken directly from the Biosway Portable Balance System monitor directly after each postural stability test and scores were compared between, and within, the groups for changes in postural stability.

3.9.2 Data Analysis

The normalised sEMG data, the two FADI scores and the three postural stability test scores, were captured using Microsoft Excel and transferred into IBM Statistical Package for Social Sciences (SPSS) version 25 for data analysis (Esterhuizen, 2018). A p value <0.05 was considered as statistically significant. Baseline means were compared between groups using independent samples t-tests for continuous normally distributed variables. Categorical variables were compared between groups using Pearson's chi square tests.

Kolmogorov-Smirnov tests were used to test outcome measurements for normality and were found to be reasonably and normally distributed. Initially, paired t-tests were used for intra-group comparisons for the outcomes that had only two time points (FADI and general pain scores) and repeated measures analysis of variance (ANOVA) testing was used in all other outcomes, where there were three time points per group (muscle activity and balance) to assess changes over time for each outcome. For inter-group comparisons, repeated measures ANOVA testing was used for within, and between, group effects of time (three levels) and treatment group (two levels). A statistically significant time by group interaction effect indicated a significant treatment effect.

Repeated contrasts were used to assess the effects at time 1 vs time 2 and time 2 vs time 3. Partial eta squared was calculated for each effect assessed in order to determine the size of the effect. Changes over time between each pair of outcome variables were correlated using Pearson's correlation analysis in order to determine which outcomes measures were improving together over time and which were not (Esterhuizen, 2018).

3.10 ETHICAL ISSUES

The ethical issues that applied to the study were as follows:

- Non-maleficence was adhered to in the study as the well-being of participants was protected by only making use of equipment and procedures that have been validated and proven to be safe. Each participant was given a letter of information and consent that was required to be signed prior to being enrolled in the study. No coercion was

used to recruit participants. In addition, the participants' confidentiality was ensured by using the allocation of codes to the participants, ensuring that no names appeared in the dissertation or publication stemming from the project, allowing for the participants' autonomy.

- All participants were offered one free treatment session at the end of the study
- Participants requiring further treatment were referred to an appropriate practitioner after completion of the study.
- Permission to conduct the study was obtained from the IREC. This committee ensured that the rights of participants were protected and maintained.
- Beneficence was accounted for as the results of this study will contribute to the body of knowledge regarding CAIS and peripheral joint manipulation.

CHAPTER FOUR RESULTS

4.1 INTRODUCTION

This chapter presents the results of the study in the form of tables and figures, supported by concise narratives. To place the study in perspective in terms of the final response rate, a CONSORT flow diagram is included.

4.2 CONSORT FLOW DIAGRAM

Figure 4.1 shows the flow of the participants through the research study, which resulted in a final participation of 42 participants, with 21 participants per group.

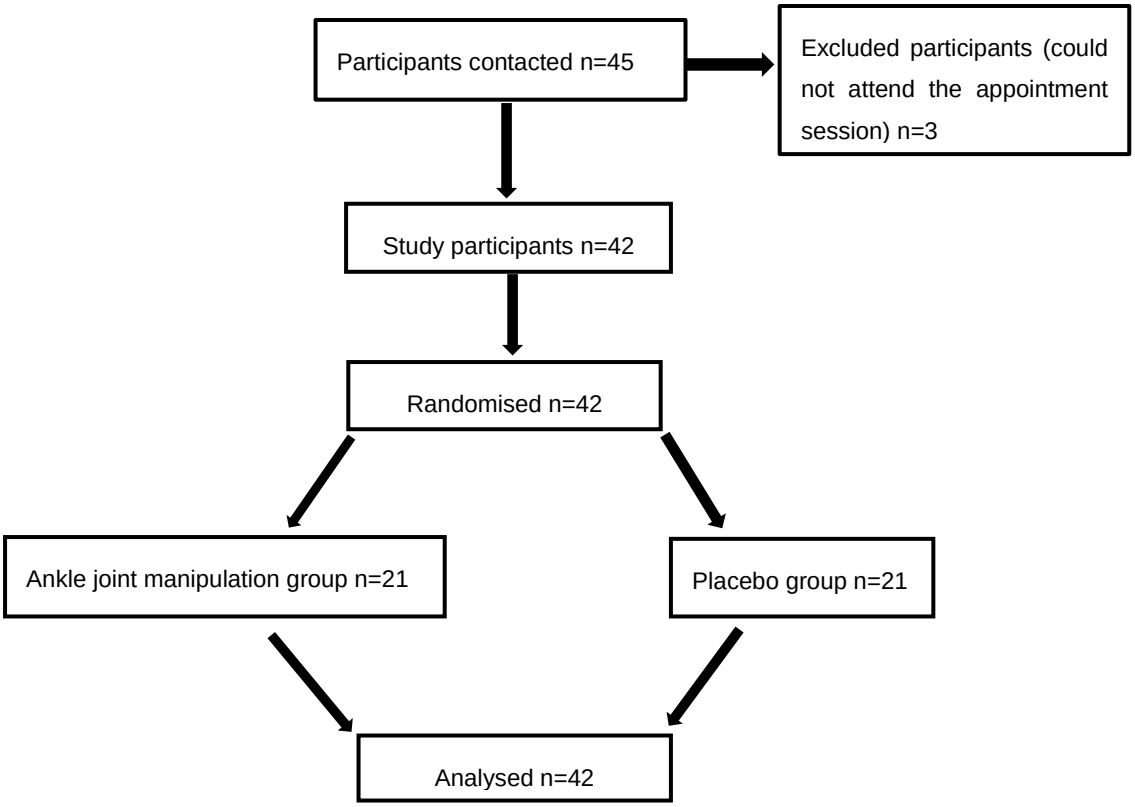


Figure 4.1: CONSORT flow diagram outlining the study

4.3 DEMOGRAPHIC AND ANTHROPOMETRIC CHARACTERISTICS OF THE PARTICIPANTS

Table 4.1 shows the gender, race, age and BMI of the participants per group and standard deviation (±SD). The participants were predominantly male and from the white race group.

There were no significant differences found between the two groups for genders, age or BMI using Pearson's Chi-square tests. The mean age for this study population was 26.2 years (± SD 6.9 years) old and the mean BMI was 25.1 (±SD 4.3).

Table 4.1: Demographic and anthropometric characteristics of the participants

Characteristic		Total		Intervention		Placebo		*p* value
		N	%	N	%	N	%	
Gender	Female	18	42.9	9	42.9	9	42.9	1.000
	Total	42	100	21	100	21	100	
Race	Black	4	9.5	3	14.3	1	4.8	0.479
	Indian	5	11.9	3	14.3	2	9.5	
	White	33	78.6	15	71.4	18	85.7	
		Mean	SD	Mean	SD	Mean	SD	
Age		26.2	6.9	26.0	7.4	26.4	6.6	0.878
BMI		25.1	4.3	25.8	4.6	24.4	3.9	0.296

M=mean; SD=standard deviation

4.4 FOOT AND ANKLE DISABILITY INDEX (FADI) AND GENERAL PAIN

At baseline, using independent t-tests, there was no significant difference (*p*=0.932) found between the intervention and control groups for FADI scores. This indicates that the groups were similar in their reporting of pain and disability at baseline.

Figure 4.2 shows that in the intervention group there was an improvement in the FADI score over time (*p*=0.006), while in the placebo group there was no significant change (*p*=0.329). When the two groups were compared, using repeated measures ANOVA test, the intervention group showed a statistically significant treatment effect, compared to the placebo group (*p*=0.005), with a large effect size (partial eta squared=0.179).

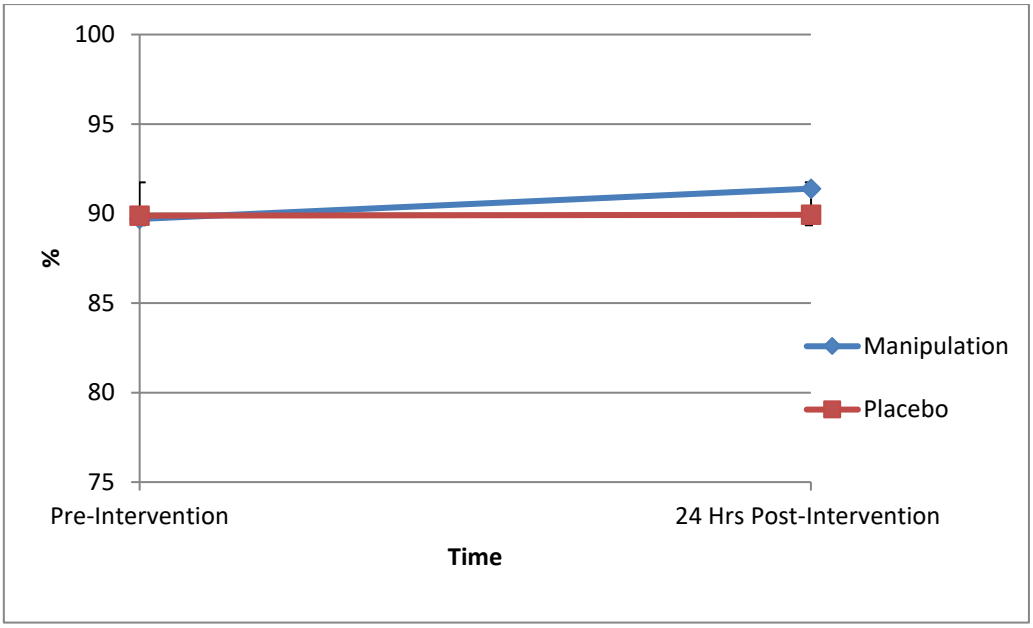


Figure 4.2: FADI scores as percentages (%) per group pre and 24 hrs post-intervention

For the general pain scores, the two groups were comparable as there was no statistically significant difference between the two groups at baseline (p=0.257). Intra-group analysis revealed that there was a significant change over time (p=0.010) in the manipulation group for general pain rating, while there was no significant change for the placebo group (p=0.329).

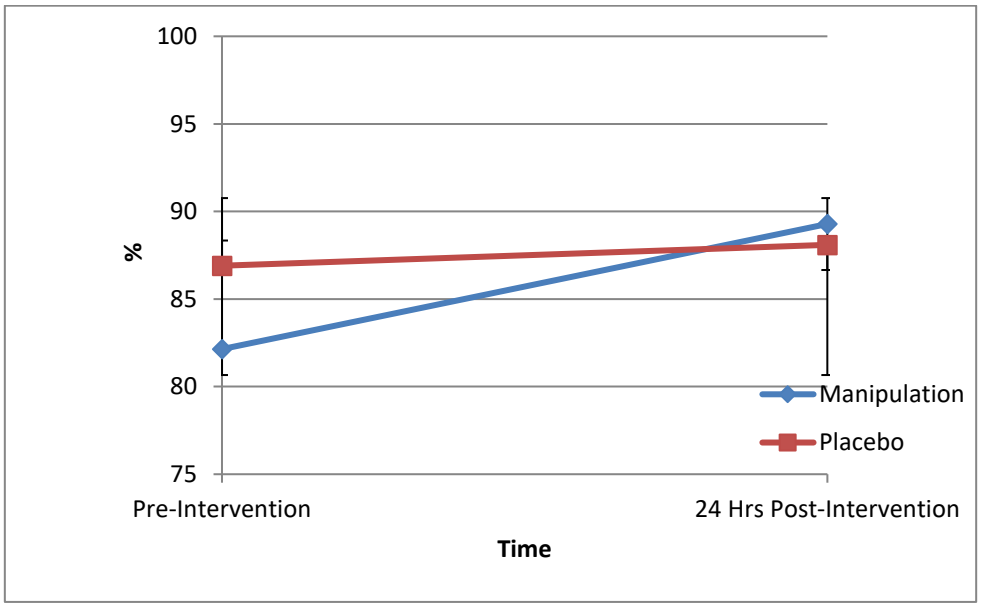


Figure 4.3: General pain scores as percentages (%) per group pre-intervention and 24 hrs post-intervention

When the two groups were compared, using repeated measures ANOVA test, the intervention group showed a statistically significant treatment effect compared to the placebo group for general pain scores (p=0.039, with a medium effect size, partial eta squared=0.102).

4.5 BALANCE

4.5.1 Postural Stability (Eyes Open)

At pre-test levels, there was no significant difference in postural stability between the manipulation and placebo groups for eyes open testing (p=0.515), allowing the groups to be compared.

Using repeated measures ANOVA testing, an intra-group analysis revealed that there was a significant overall (p=0.040) decrease (improvement) in the manipulation group's balance test scores over time for eyes open testing. The placebo group did not demonstrate a significant change over time (p=0.075), as seen in Figure 4.4.

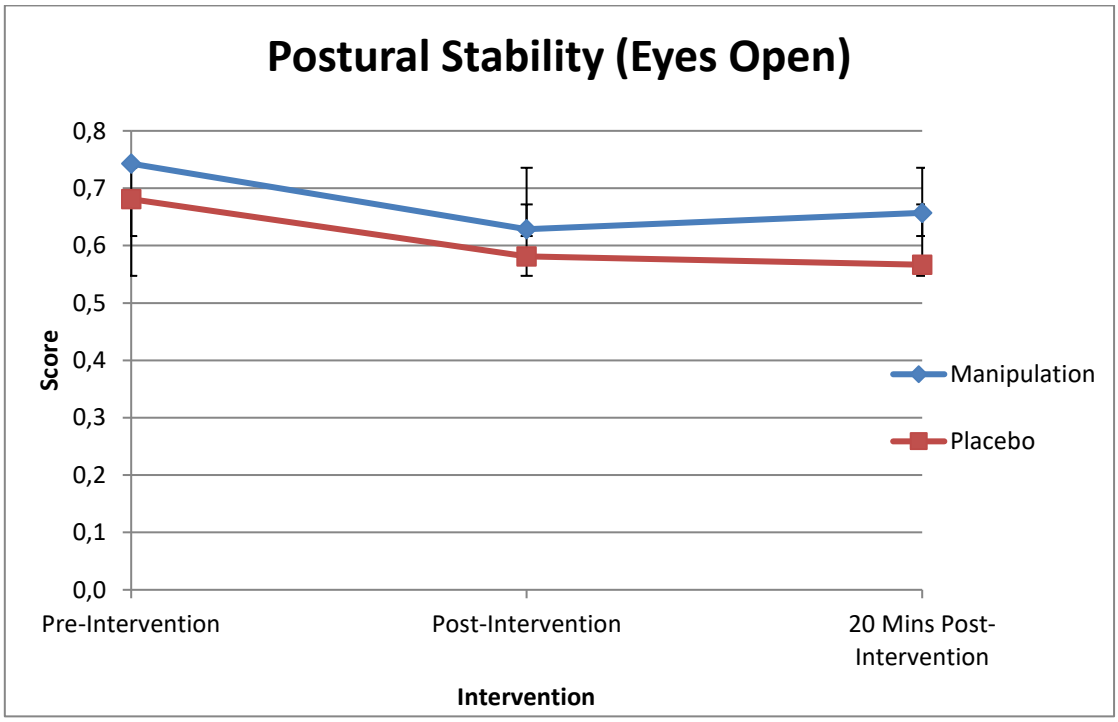


Figure 4.4: Postural stability for both groups over time for (eyes open)

There were no significant differences between the two groups immediately post-intervention (p=0.803) or 20 minutes post-intervention (p=0.207), both with a small effect size (partial eta squared=0.002 and 0.040 respectively). There was no significant overall difference between the two groups over time (p=0.451) and a small effect size (partial eta squared=0.040).

4.5.2 Postural Stability (Eyes Closed)

Baseline postural stability of the control group was not different from the experimental group (p=0.675). An intra-group analysis demonstrated a statistically significant change in postural stability for the intervention group (p=0.046) and no significant change in the placebo group (p=0.648). The changes in postural stability for each group are seen in Figure 4.5.

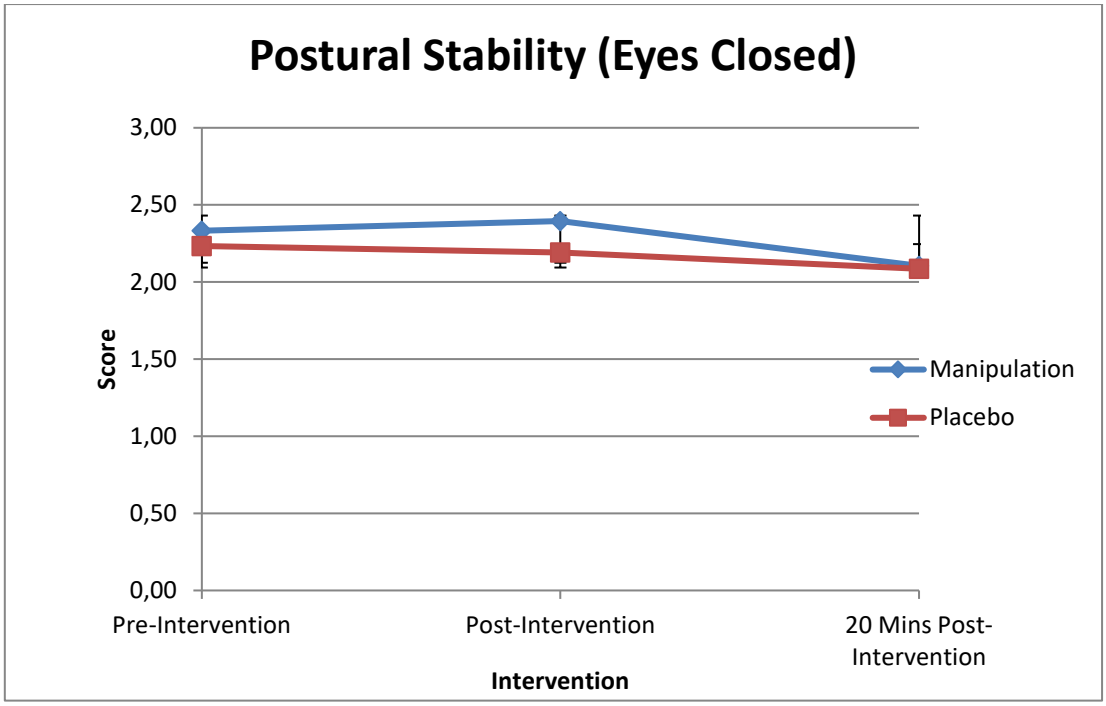


Figure 4.5: Postural stability for both groups over time (eyes closed).

There were no significant differences between the two groups immediately post-intervention (p=0.604) or 20 minutes post-intervention (p=0.271), and both showed a small effect size (partial eta squared=0.007 and 0.030 respectively). Overall postural stability with the eyes closed was not different between the two groups over time (p=0.543) and there was a small effect size (partial eta squared=0.031).

4.6 MUSCLE ACTIVITY

4.6.1 Muscle Activity during Postural Stability Test with Eyes Open

Table 4.2 shows the mean normalised muscle activity per group for each of the muscles assessed in this study during the postural stability test with eyes open. At baseline, no statistically significant differences were found between the groups. When the groups were compared at the different time points, there were no statistically significant differences (p> 0.05). Similarly, when the time by group interaction was assessed, no statistically significant differences, as well as small effect sizes, were observed for the tibialis anterior (p=0.618) (partial eta squared=0.024), medial gastrocnemius (p=0.407) (partial eta squared=0.045) and soleus muscles (p=0.600) (partial eta squared=0.026). Although no statistically significant difference was found for the fibularis longus (p=0.107), a medium effect size was observed for this muscle (partial eta squared=0.108).

Table 4.2: Mean normalised activity for muscles of the lower limb for both groups, at the three time points, during eyes open postural stability testing

Muscle	Group	Baseline		Post intervention		20 minutes		*p* value (intra-group)
		M	SD	M	SD	M	SD	
Tibialis anterior	1	28.35	12.94	26.94	9.78	27.47	11.26	0.752
	2	33.34	14.79	29.73	12.56	32.26	13.98	0.125
***p* value (EE)**		0.251*(N/A)		0.382** (0.019)		0.454** (0.014)		
Medial gastroc	1	30.54	11.50	28.70	12.35	30.65	12.00	0.554
	2	36.65	20.26	34.51	19.21	33.41	17.69	0.219
***p* value (EE)**		0.237*(N/A)		0.929**(0.00)		0.249**(0.033)		
Soleus	1	33.03	14.44	31.80	12.33	32.29	13.08	0.856
	2	30.14	14.11	31.48	15.22	30.31	13.23	0.656
***p* value (EE)**		0.516*(N/A)		0.330**(0.024)		0.491**(0.012)		
Fibularis longus	1	30.02	15.49	30.37	13.66	30.26	14.25	0.981
	2	31.19	14.47	27.98	10.18	26.53	12.77	0.047
***p* value (EE)**		0.802*(N/A)		0.165**(0.048)		0.550**(0.009)		

M = mean; SD = standard deviation; * = student paired t-test; ** = ANOVA; EE = Effect size

The intra group comparisons for the muscle activity of the tibialis anterior, medial gastrocnemius and soleus revealed no significant differences between the groups (repeated measures ANOVA). An intra-group analysis of the placebo group for the fibularis longus revealed that there was a significant change (decrease) in muscle activity in eyes open testing (p=0.047). This change is demonstrated in Figure 4.6. There was no significant change found in the manipulation group (p=0.981).

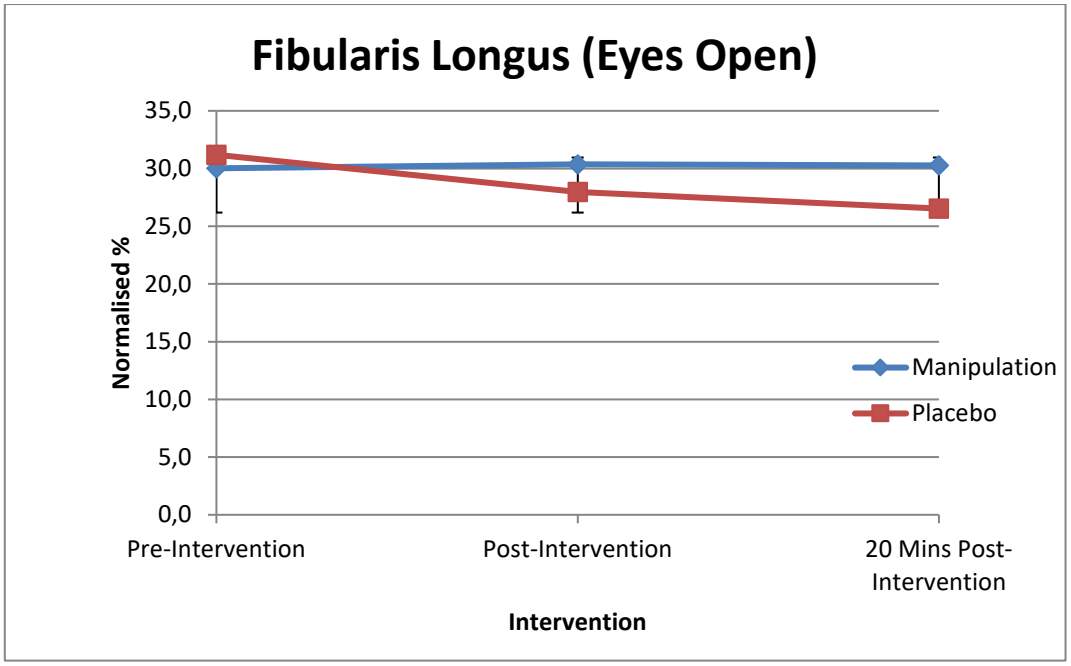


Figure 4.6: Mean muscle activity of fibularis longus as a percentage of MVC for both groups over time during eyes open postural stability testing

An inter-group analysis found no significant difference between the two groups for the tibialis anterior, medial gastrocnemius or soleus. Although the fibularis longus muscle activity of the placebo group revealed a sharp rate of decrease over time compared to the manipulation group, the difference between the two groups was not statistically significant (p=0.107).

Muscle activity during eyes open postural stability testing was correlated for change over time using Pearson's correlation analysis. In the manipulation group, the gastrocnemius muscle activity was negatively correlated with change FADI scores (r=-0.487) and change in pain scores (r=-0.473). In the placebo group, the fibularis longus muscle activity was positively correlated with the change in FADI (r=0.449) and pain scores (r=0.449). There were no significant correlations between muscle activity and postural stability during eyes open testing.

4.6.2 Muscle Activity during Postural Stability Test with Eyes Closed

The mean normalised muscle activity per group, for each of the muscles assessed in this study, during eyes closed testing, is shown in Table 4.3. At baseline, using independent student t-tests, no statistically significant differences were found between the groups for muscle activity for all muscles (p>0.05). No significant differences were found between the two groups over time, and small effect sizes were found for the tibialis anterior (p=0.796; partial eta squared=0.012), medial gastrocnemius (p=0.601; partial eta squared=0.026), soleus (p=0.934; partial eta squared=0.003) and fibularis longus (p=0.514; partial eta squared=0.034).

Table 4.3: Mean normalised muscle activity measured at the three time points for the investigated lower limb muscles during eyes closed testing

Muscle	Group	Baseline		Post intervention		20 minutes		*p* value (intra-group)
		M	SD	M	SD	M	SD	
Tibialis anterior	1	40.34	11.08	37.36	12.24	38.54	13.61	0.097
	2	47.11	17.45	43.37	13.32	43.43	15.95	0.226
***p* value (EE)**		0.141*(N/A)		0.781**(0.002)		0.605**(0.007)		
Medial gastroc	1	33.32	12.78	34.29	15.81	34.32	15.49	0.924
	2	38.94	21.51	38.28	21.56	37.06	20.92	0.511
***p* value (EE)**		0.310*(N/A)		0.572**(0.008)		0.531**(0.010)		
Soleus	1	39.10	14.60	35.19	13.80	36.67	13.58	0.102
	2	40.89	17.97	37.38	15.52	37.98	16.82	0.078
***p* value (EE)**		0.724*(N/A)		0.862**(0.001)		0.723**(0.003)		
Fibularis longus	1	37.10	15.20	34.78	13.53	34.61	12.49	0.296
	2	38.23	14.06	33.57	10.99	32.98	11.52	0.023
***p* value (EE)**		0.804*(N/A)		0.307**(0.026)		0.845**(0.001)		

M = mean; SD = standard deviation * = student paired t-test; ** = ANOVA; EE = Effect size

An intra-group analysis of the muscle activity of the tibialis anterior, medial gastrocnemius and soleus revealed no significant differences between the groups (repeated measures ANOVA) during eyes closed testing. The placebo group demonstrated a significant change in fibularis longus muscle activity (p=0.023). This change is demonstrated in Figure 4.7. The fibularis longus of the manipulation group did not demonstrate a significant change (p=0.296).

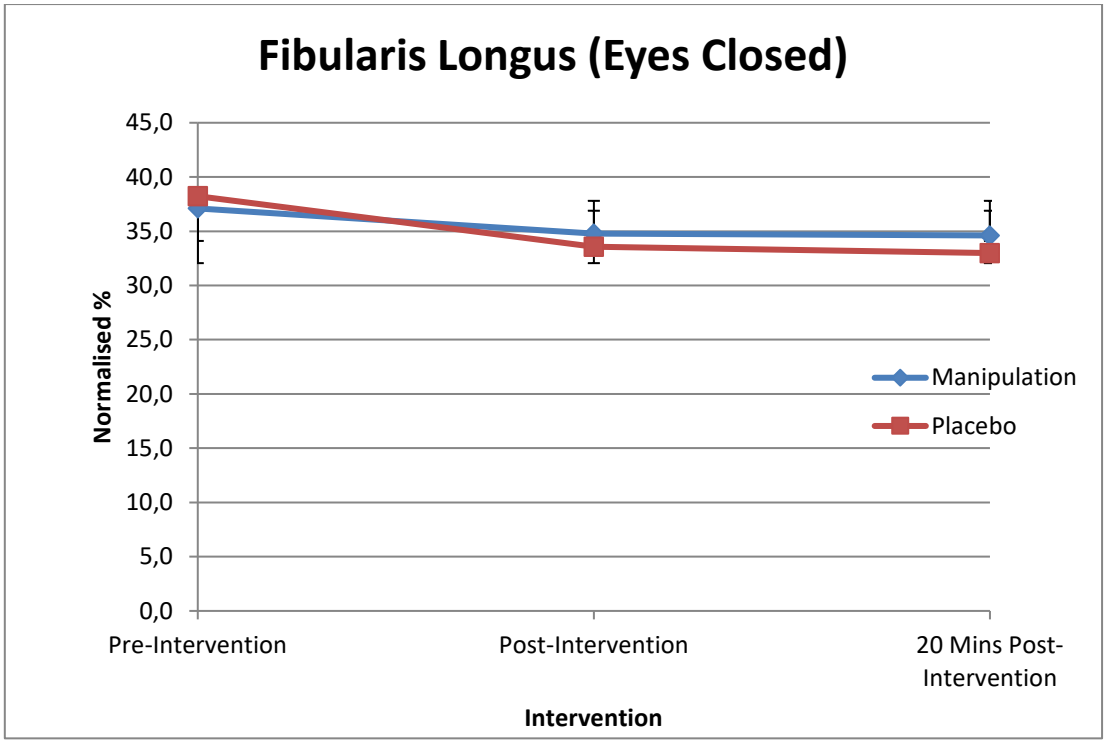


Figure 4.7: Mean muscle activity as a percentage of MVC for both groups over time during eyes closed balance testing

As with the eyes open tests, an inter-group analysis revealed no significant difference between the two groups for the tibialis anterior, medial gastrocnemius or soleus (repeated measures ANOVA). Although the intra-group analysis revealed that there was a significant change in the placebo group's fibularis longus muscle activity, an inter-group analysis demonstrated that there was no intervention effect (p=0.514) for eyes closed testing for the fibularis longus between the two groups.

Pearson's correlation analysis of muscle activity during eyes closed postural stability testing showed that, in the placebo group, there was a positive correlation between changes in the FADI and general pain scores, when assessed against changes in soleus (r=0.525 for both the FADI and general pain scores) and fibularis longus (r=0.531 for both the FADI and general pain scores) muscle activity. There was also a positive correlation between the change in muscle activity of the soleus and the fibularis longus (r=0.682). There were no significant correlations observed between muscle activity and postural stability during eyes closed testing.

4.7 CONCLUSION

Only the FADI and general pain scores were significantly influenced by manipulation in this study. Therefore, this study does not provide sufficient statistical evidence that muscle activity

and postural stability measurements were affected differently in the manipulation and placebo groups. An intra-group analysis revealed that the manipulation group showed improvements in postural stability (eyes open) and that there was an overall decrease in muscle activity over time for the fibularis longus in the placebo group for eyes open and eyes closed testing. However, the effect sizes in this study were small and a larger study sample may be necessary to observe significant changes between groups for these outcomes.

CHAPTER FIVE DISCUSSION

5.1 INTRODUCTION

In this chapter the results of the study are discussed in relation to the aims and objectives of the study and the relevant literature.

5.2 DISCUSSION OF DEMOGRAPHIC AND ANTHROPOMETRIC DATA

Demographic and anthropometric characteristics have the ability to influence the outcome of a study and thus require measures of control to limit their effect. A relationship between age, muscle activity and postural control has been reported: with increasing age there is deterioration of the sensory systems which can alter the pattern of muscle activation. This in turn affects balance, which is especially noticeable in elderly individuals, compared to young adults (Gomes *et al.,* 2013). In this study, the age of the participants was limited to 18-45 years of age to minimise the confounding effects of aging on muscle recruitment patterns and sEMG readings. There was no statistically significant (p=0.878) difference between the two groups in terms of age, indicating that the groups were comparable, and that age would not have influenced the results. The mean age of the participants in this study (26.2 years) is similar to that reported in previous studies conducted on CAIS (Hoch and Mckeon, 2010; Grindstaff *et al.,* 2011; Beazell *et al.,* 2012; Dicks, 2016).

The effect of gender on muscle activity or balance has not been reported in literature. The gender distribution of the participants in the control and intervention groups was not significantly different (p=1.000).

The muscle mass and subcutaneous fat of an individual may affect sEMG readings (Criswell, 2011). A thicker layer of subcutaneous fat acts as an insulator between the muscle and electrodes resulting in a smaller signal picked up by the sEMG electrodes. According to Criswell (2010) and Bartuzi *et al*. (2010), a negative relationship exists between skinfold thickness/ subcutaneous fat and sEMG amplitude. They also reported that certain muscles have thicker layers of subcutaneous fat than others, therefore it is dependent on the muscles being tested. It is suggested that sEMG data is normalised in order to reduce variability in data as a result of individual differences in subcutaneous fat thickness (Nordander *et al.,* 2003).

The mean BMI of this study population narrowly fell into the overweight category (25.1) as a BMI of 18.5 - 24.9 is considered normal and a BMI of 25 - 29.9 is considered overweight. Yet, there was no significant difference between the two groups for BMI, indicating that BMI could not have affected the outcomes seen in this study. A higher BMI has been reported to negatively affect stability where obese people performed significantly poorer than those who were classified as underweight, normal weight and overweight (Ku *et al.,* 2012). The current study did not use BMI as an inclusion criteria and the BMI of this study population was similar or only slightly greater than those of similar studies (Hoch and McKeon, 2010; Grindstaff *et al.,* 2011; Beazell *et al.,* 2012; Dicks, 2016).

5.3 SUBJECTIVE OUTCOMES: DISABILITY AND GENERAL ANKLE PAIN

It has been shown that joint mobilization and manipulation decreases pain and improves patient function, however, the processes underlying these changes are not well understood (Fisher *et al.,* 2016). The results of this study demonstrate that ankle joint manipulation has a significant positive effect on the FADI (p=0.005) and general pain scores (p=0.039) when compared to the placebo group, indicating that long axis talocrural joint manipulation results in reduced levels of perceived pain and disability. There was no statistically significant difference between the two groups at baseline for FADI (p=0.932) and general pain scores (p=0.257). Large and medium effect sizes were found for the changes in FADI and general pain rating scores respectively. The relationships between the changes in FADI and general ankle pain scores and changes in muscle activity were found with Pearson's correlation analysis.

In the eyes open testing, the gastrocnemius muscle activity in the manipulation group was negatively correlated with change FADI scores and general pain scores, whereas in the placebo group, the fibularis longus muscle activity was positively correlated with the change in FADI and general pain scores. In the eyes closed testing conditions, there was a positive correlation between changes in the FADI and general pain scores when assessed against changes in soleus and fibularis longus muscle activity.

It is has been reported that manipulation brings about its effect through a combination of psychological, biomechanical or neurophysiological factors (Bialosky *et al.,* 2009).

The International Association for the Study of Pain states that the sensation of pain is subjective and that it is learned individually through experiences related to injuries sustained in early life, and, therefore, it is difficult to question or objectify an individual's perception of

pain (Merskey, 1994). Because pain is an individual, unique experience, only the individual can determine whether or not they are in pain, as well as the amount of pain they are suffering (Bishop *et al.,* 2015).

There is a relationship between pain and an individual's level of disability as disability is associated with the perception of pain, and pain limits an individual's ability to complete activities or tasks of daily living (Yeomans, 2000; Botha, 2013). Therefore, the improved FADI scores found in this study could be the result of diminished levels of general pain, as the ability to perform functional activities would not be limited by pain. It is also possible that the improved FADI and general pain scores found in this study may be a result of the Hawthorne effect.

The Hawthorne effect is the result of participants' awareness of being studied and the consequential influence on their behaviour based on this awareness as it may provoke beliefs about the researcher's expectations', therefore causing a participant to give responses that they believe will help the researcher (McCambridge *et al.,* 2014). This applies to the intervention group, more than to the placebo group, as the nature of the placebo may have been too obvious, as no traction or thrust was applied. Developing credible placebos for studies investigating manipulative therapy is potentially difficult (Koes, 2004) and this placebo had been used previously in similar studies (Paes *et al.,* 2013; Dicks 2016; Kamili *et al.,* 2017).

This study only examined the subjective effects of a single joint manipulation compared to a placebo, over a 24-hour period and therefore, the test retest had a very short time between tests and memory may have played a role in the outcomes.

One of the possible reasons for the disability found in CAIS is the resultant loss of ankle dorsiflexion, with the talar dome not being able to fully lock into the ankle mortise, resulting in a loss of bony stability during locomotion (Pellow and Brantingham, 2001). A decreased dorsiflexion range of motion has been demonstrated in individuals with CAIS during activities such as walking and jogging (Hoch and McKeon, 2010) and this may lead to disability. Manipulation is believed to break these intra-articular lesions and restore normal movement (Pellow and Brantingham, 2001; Vicenzino *et al.,* 2006; Glasgow *et al.,* 2010), thus improving function. Participants who received manipulation of the ankle in sub-acute and chronic ankle inversion sprains, compared to a placebo, reported significant improvement in the ankle's range of motion, function and pain (Pellow and Brantingham 2001). Similar results were reported by Louden *et al.* (2013).

Although literature seems to demonstrate a potential relationship between ankle range of motion and ankle function and pain rating, the current study did not investigate changes in ankle range of motion post-manipulation. Therefore, the results of this study cannot be unequivocally attributed to those factors but it does provide a possible explanation for the

results obtained. It would therefore be recommended that further studies investigating the effects of manipulation on pain and disability in CAIS also examine changes in ankle range of motion.

It has also been suggested that manipulation may affect pain processing at the spinal cord level through the phenomenon, first described by Melzack and Wall (1965), known as the "gate control theory". This theory suggests that large diameter myelinated neurons, from mechanoreceptors, modulate and inhibit incoming nociceptive information and that manipulation would activate these mechanoreceptors, therefore providing pain relief by activating this spinal gate control mechanism (Fryer *et al.,* 2004).

A descending inhibition of pain from higher centres in the CNS may also play a role in hypoalgesia, resulting from manipulation, as manipulation may be mediated by descending pain inhibition pathways from the midbrain via the release of serotonin and noradrenalin (Skyba *et al.,* 2003).

5.4 OBJECTIVE OUTCOMES: BALANCE AND MUSCLE ACTIVITY

Although the results of this study found no significant difference between the manipulation and placebo groups for changes in postural stability, with eyes open or eyes closed, or for muscle activity, in eyes open or closed testing conditions, an intra-group analysis revealed a significant overall decrease (improvement) in the manipulation group's balance test scores over time for eyes open testing (p=0.040) and eyes closed testing (p=0.046), although, with eyes closed testing, the postural stability worsened immediately after the manipulation and then improved beyond pre-manipulation levels when measured 20 minutes later.

At baseline, there were no statistically significant differences between the two groups for balance testing with eyes open (p=0.515) and eyes closed (p=0.675) or for muscle activity with eyes open and eyes closed (p> 0.05). Small effect sizes were observed for eyes open and eyes closed postural stability test scores, as well as for the muscle activity for all muscles investigated, in this study, for eyes open and eyes closed testing, except for the fibularis longus, which displayed a medium effect size for eyes open postural stability testing.

An intra-group analysis of the placebo group for the fibularis longus revealed that there was a significant change (decrease) in muscle activity in eyes open (p=0.047) and eyes closed stability testing (p=0.023) over time, with no significant change in this muscle in the manipulation group over time.

Manipulation has been considered appropriate for individuals with CAIS as they exhibit AMI and altered spinal reflex modulation patterns (McVey *et al.,* 2005; Hootman *et al.,* 2007). It is

believed that manipulation stimulates the mechanoreceptors of the structures found in and around that joint, resulting in an alteration of the afferent information and a change in motor neuron excitability, as the information is relayed along type I and type II afferent fibres to the dorsal horn of the spinal cord. The afferent neuron synapses with the interneuron that relays an excitatory or inhibitory effect to the motor neuron, which is then relayed to the appropriate muscles, resulting in an increase or decrease of motor neuron pool excitability (Suter and McMorland, 2002; Dunning and Rushton, 2009; Haavik and Murphy, 2012; Pickar and Bolton, 2012; Cardinale *et al.,* 2015). Consequently, the increase in afferent activity and neuromuscular functioning of the joint stabilising muscles would result in enhanced postural control (Liebler *et al.,* 2001; Yerys *et al.,* 2002; Hoch and McKeon, 2010; Grindstaff *et al.,* 2011). Based on this theory, it is possible that the excitatory effect of the manipulation may have limited the effect of fatigue in the fibularis longus of the manipulation group, thus allowing a sustainable level of muscle activity, which in turn, may have allowed for better postural stability scores over time, in comparison to the placebo group, who demonstrated a decrease in muscle activity in the fibularis longus and no significant change in balance performance. Nevertheless, this theory does not account for the initial worsening of balance performance during eyes closed testing in the manipulation group, where there were no significant correlations found between changes in postural stability and changes in fibularis longus muscle activity using Pearson's correlation analysis.

It is also important to remember that the objective of the current study was not to assess the effects of extremity joint manipulation on muscle fatigue but to assess the effects of ankle joint manipulation on muscle activity and balance performance. The findings of diminished fibularis longus muscle activity in the placebo group support the theories suggesting that the peroneal muscles are primarily affected by AMI in CAIS (McVey *et al.,* 2005; Hopkins *et al.,* 2009; Palmieri-Smith *et al.,* 2009), as the fibularis longus was the only muscle to demonstrate a significant decrease in activity over time in the placebo group. A larger sample size would be recommended to examine this trend further.

Although the intra-group analysis revealed significant changes in postural control in the manipulation group and reduced fibularis longus muscle activity in the control group over time, there were no significant differences between the two groups for these outcomes, indicating that talocrural joint manipulation did not have a significant effect when compared to a placebo intervention in this study.

The findings of postural stability in this study are in contrast to those of Lopez-Rodriguez *et al.* (2007) and Hoch and McKeon (2010). Lopez-Rodriguez *et al*., (2007) found that talocrural joint manipulation, when compared with a placebo manipulation, in patients with grade II ankle

sprains, resulted in the favourable redistribution of foot loading, supporting the hypothesis that manipulation of the ankle exerts proprioceptive effects.

Hoch and McKeon (2010) found that a single treatment of Maitland Grade III anterior to posterior joint mobilisations improved eyes open single-limb stance postural control. Unlike the use of only long axis talocrural joint manipulation in this study, the intervention group of Lopez-Rodriguez *et al*. (2007) was subjected to two techniques of manipulative treatment: long axis talocrural joint manipulation and posterior gliding manipulation over the talus.

Hoch and McKeon (2010) made use of Maitland Grade III anterior to posterior joint mobilisations, which consisted of large amplitude, rhythmic oscillations from the joint's mid to end-range, with translation taken to tissue resistance, which was done over two, two-minute sets with a one minute rest in between.

In these studies, the number of manipulations/mobilisations as well as the duration for which they were applied were greater and may account for the lack of findings in the current study.

Regarding muscle activity, the findings of this study support those of Dicks (2016), who failed to show that talocrural joint manipulation affected the soleus and fibularis longus muscles in terms of sEMG measurements in participants with CAIS. However, this is in contrast to the findings of Grindstaff *et al.* (2011), who indicated that manipulation of the distal tibiofibular joint acutely increased soleus muscle activity in individuals with CAIS.

In the studies by Grindstaff *et al.* (2011) and Dicks (2016), measurements were taken with the participants in a quiet, still, relaxed state, in a supine position, whereas in the current study, fatigue may have had a larger influence, as measurements were taken while the muscles were active and supporting the participant’s body weight, as the participants were balancing on the injured limb.

The findings of this study also did not support those of Fisher *et al.* (2016), who implied that talcocrural joint manipulation would affect the muscle activity of the tibialis anterior in individuals with CAIS, as no significant changes were demonstrated in those muscles in the current study.

All muscles investigated in this study displayed small effect sizes during eyes open and eyes closed testing, except for the fibularis longus, which showed a medium effect size for eyes open postural stability testing, and a positive correlation was found between changes in fibularis longus and soleus muscle activity during eyes closed testing. A larger study sample would be recommended to further explore the relationship between talocrural joint manipulation and lower limb muscle activity.

In this study, postural stability was measured during eyes open, and eyes closed, testing conditions, and it was evident that participants achieved better postural stability scores with eyes open, when compared to eyes closed. In order to maintain balance, the sensorimotor system obtains inputs from three afferent systems, namely the vestibular, somatosensory, and visual systems. When one of those systems (somatosensory) is impaired, the two intact systems compensate for the impaired one to some extent. However, when an individual closes their eyes, only one intact afferent system remains for balance control (Akbari *et al.,* 2006). Therefore, with eyes closed, only proprioception was in play, and, with eyes open, both vision and proprioception were in play, which may explain why there was better balance performance during eyes opened testing than eyes closed. Future studies should investigate the effects of ankle joint manipulation on balance with eyes closed and eyes open in order to gain further insight into the relationship between manipulation and proprioception.

The muscles investigated in this study provide different roles in the stabilization of the ankle joint. While the fibularis longus and tibialis anterior protect the ankle against unexpected destabilisation, the soleus muscle is responsible for the maintenance of postural control (McVey *et al.,* 2005). Although research has indicated that all of these muscles are affected by CAIS (Delahunt, 2007; Palmieri-Smith *et al.,* 2009; De Ridder 2014), due to the nature of this study, it may have been expected that talocrural joint manipulation would have affected the gastrocnemius and soleus muscle activity during postural stability tasks, yet the results of this study did not provide evidence of this.

Although measures were taken to limit fatigue, its influence should not be overlooked in this study, as its detrimental effect on static postural control is established (Gribble *et al.,* 2004). Fatigue may impair the proprioceptive and kinesthetic properties of joints and increase the threshold of muscle spindle discharge, which disrupts afferent feedback, subsequently altering joint awareness (Rozzi *et al.,* 2000). Therefore the results of this study may have been limited by fatigue, as it seems that neuromuscular control, quantified through measures of static postural control, is affected by CAIS and fatigue, individually, and future studies should implement further strategies to eliminate its influence.

5.5 CONCLUSION

The results of this study did not support the theory that talcocrural joint manipulation has a positive effect on the objective outcomes of postural stability and muscle activity when compared to a placebo manipulation, still a positive effect was found for the subjective outcomes of pain and disability.

A positive trend was found within the manipulation group for eyes open postural stability, suggesting that talocrural joint manipulation resulted in better balance performance, with eyes open, in this group.

Essentially, the current study differed from the other studies as it explored the effects of manipulation on three aspects associated with CAIS (pain and disability, balance and muscle activity) that, according to the researcher's knowledge, had not been done before in a single study, therefore, further research into this field would be recommended.

Considering that this was a pre-post study, future studies with long-term follow-ups may provide more reliable results about the long-term effectiveness of this type of treatment, taking into account that CAIS is a chronic condition.

CHAPTER SIX

6.1 CONCLUSION

The purpose of this study was to determine the effects of ankle joint manipulation on pain and disability, postural stability and the muscle activity of the lower extremity in CAIS. Analysis of the results revealed that ankle joint manipulation had no statistically significant effect on postural stability or muscle activity of the lower limb, in comparison to the placebo, but there was a significant effect on FADI scores for pain and disability, indicating that ankle joint manipulation had a positive effect on pain and disability in CAIS.

Resulting from this investigation, the researcher was unable to reject the null hypothesis that there would be no statistically significant effects on muscle activity, of the invertors, evertors and plantar flexors of the ankle and balance, when talocrural joint manipulation is compared to a placebo, immediately following the intervention, and at 20 minutes post-intervention, in participants with CAIS. However, the researcher was able to reject the null hypothesis for pain and disability, as there was a significant positive change in these outcomes when measured 24 hours post-intervention.

Importantly, an intra-group analysis revealed that the manipulation group displayed significant improvements in postural stability during eyes opened balance testing, suggesting that talocrural joint manipulation may have a positive effect on postural stability in CAIS.

The intra-group analysis also showed that the placebo group displayed diminishing levels of fibularis longus muscle activity over time, possibly as a result of fatigue, and therefore it is possible that talocrural joint reduced the effect of fatigue in this muscle in the manipulation group.

This study may have been under-powered and thus it is recommended that a larger sample is used in future studies, as further research is needed to determine the effects of extremity joint manipulation on muscle activity and balance.

6.2 LIMITATIONS

There were a number of limitations in the current study, therefore there is potential for future studies based on these limitations. The following limitations were identified during the course of this study:

1. This study only investigated the immediate effect of talocrural joint manipulation on the outcomes of pain/disability, balance and muscle activity, and therefore only investigated these outcomes over one session. As CAIS is a chronic condition, it is plausible that more than one treatment session may be required to detect changes in these outcomes.
2. Due to the differing thickness of subcutaneous fat of participants, as well as between different muscles within each participant, the sEMG readings may have been affected as subcutaneous fat acts as an insulator between the muscle and electrodes.
3. Due to the repetitive nature of procedures in the study, it is possible that improvements in postural stability were achieved through increased participant confidence and better understanding of the testing procedure.
4. The placebo intervention in this study consisted only of the researcher's hands being placed around the participant's foot with the fingers at the level of the neck of the talus, with no therapeutic traction or joint manipulation being applied. The nature of this placebo may have been too obvious for the subjective outcomes of pain and disability, as participants in this group may have recognized that no true intervention was being performed. Developing credible placebos for studies investigating manipulative therapy is potentially difficult. In addition, the act of placing one's hands on the skin will activate skin afferent neurons and this may have affected the outcomes of this study.
5. This study required participants to perform multiple postural stability tests over a short period of time, hence it is likely that fatigue influenced the results of this study.
6. The mobility of the ankle joint was not included as a variable in this study, however, in a clinical setting, manipulation is used on participants demonstrating hypomobility of this joint. A clinical prediction rule by Whitman *et al*. (2009), to determine who will demonstrate the greatest improvements following manual therapy applied to a sprained ankle, found that hypomobility was one of the criteria that predicted a successful outcome. Therefore, it can be assumed that individuals who present with CAIS, associated with hypomobility of the ankle joint, may have demonstrated a more significant change in the outcomes presented in this study.
7. The same researcher assessed participants, provided the interventions and conducted the data collection procedure, leading to a potential bias.
8. It is possible that the sample size for the study was not large enough to detect a statistically significant difference in balance and muscle activity between groups.

6.3 RECOMMENDATIONS

Recommendations for future studies include the following:

1. Future studies with long-term follow-ups may provide more reliable results about the long-term effectiveness of this type of treatment of CAIS as a chronic condition.
2. Skinfold thickness over the muscle being tested should be measured and used in the inclusion criteria.
3. Future studies should incorporate ankle dorsiflexion hypomobility and inversion hypermobility as well as a history of several ankle sprains an inclusion criterion and include changes in the range of motion as a study outcome.
4. It is recommended that future studies make use of a research assistant to deliver the intervention, or conduct the data collection procedure, so to remove any potential researcher bias.
5. Further measures should be incorporated in future studies to limit the effect of fatigue.
6. A larger sample size would be recommended as there was a positive trend detected in the manipulation group for eyes open postural stability, in this study, and it is possible that a larger sample would have provided more information with regards to this outcome.

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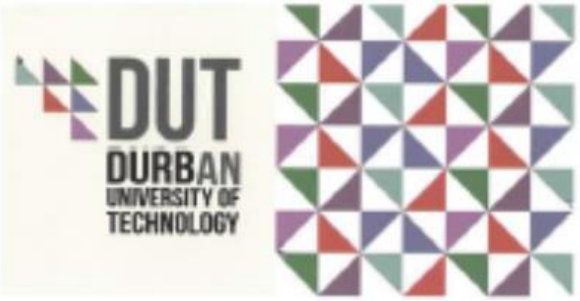
APPENDICES

Appendix A: IREC Approval



Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

28 May 2018

IREC Reference Number: **REC 149/17**

Mr M J McLaren
36 Vernin Road
Musgrave
Durban

Dear Mr McLaren

The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome

The Institutional Research Ethics Committee acknowledges receipt of your gatekeeper permission letters.

Please note that FULL APPROVAL is granted to your research proposal. You may proceed with data collection.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC Standard Operating Procedures (SOP's).

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely,

[redacted]

Professor J K Adam
Chairperson: IREC

Appendix B: Trial Application and Registration

NHREC

South African Human Research Electronic Application System

TRIAL APPLICATION

Application ID:	5048	DOH Number	DOH-27-0618-8048	Page:	1/2

Applicant Details

Organisation :	Durban University of Technology
Applicant Type :	Academic Investigator
Contact Name :	Laura O'Connor
Address :	Chiropractic Programme Durban University of Technology PO Box 1334 Durban 4000
Telephone :	0313732923
Fax :	0865324209
E-mail :	lauraw@dut.ac.za
Responsible Contact person (for public)	L. O'Connor
Telephone :	03137372923
Research contact person	L. O'Connor
Telephone :	0313732094

Trial Application Details

Issue Date :	2018/06/08
Sponsors :	Durban University of Technology
Primary Sponsor :	Durban University of Technology
FundingType :	Not Funded
Research Site Names :	Durban University of Technology chiropractic clinic
Primary Research Site Name :	
Total National Budget for Trial :	R R 8500.00
Protocol / Grant Reference Number	REC 149/17

Study Descriptive Information

Brief Title of Study :	The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome.
Full Title of Study :	The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome.
Anticipated Start Date :	2018/06/20
Anticipated End Date :	2018/09/20
Target Sample Size :	42
Study Phase :	Other
Study Scope :	Single Site
Study Type :	Interventional
Disease Type Heading :	Muscle, Bone and Cartilage Diseases
Disease Type Condition :	Musculoskeletal Diseases
Intervention Name (Generic) :	Manipulation
Intervention Duration :	No. Type 2 Minutes

NHREC

South African Human Research Electronic Application System

TRIAL APPLICATION

Application ID:	5048	DOH Number	DOH-27-0618-8048	Page:	2/2

Interventional

Intervention Type :	Procedure
Purpose :	Treatment
Allocation :	Randomised
Masking :	Open
Control :	Placebo
Assignment :	Parallel
Endpoints :	Efficacy

Study Descriptive Information

Recruitment Status as at Date:	2018/06/08
Recruitment Status :	Not Yet Recruiting
Gender :	Both
Ethnicity :	All
Age :	From 18 Years To 45 Years
Qualifying Disease Condition for Inclusion :	Chronic ankle instability syndrome
Major Exclusion Criteria :	1. Participants that have experienced acute injury/ re-injury within the three months prior to the initial consultation will be excluded from the study (Gribbel et al, 2013). 2. Participants demonstrating grade three CAIS will be excluded from the study. Grade three CAIS included diffuse swelling on both sides of Achilles tendon, early haemorrhage, tenderness occurring medially and laterally, positive anterior drawer sign, positive varus laxity (Pellow and Brantingham, 2001). 3. Participants demonstrating contraindications to manipulation based on findings from the case history and physical examination will be removed from the study (Khone, 2005). 4. Participants that make use of anti-inflammatory medication or muscle relaxants will be excluded unless they are willing to undergo a three day washout period before taking part in the study.
Key Primary Outcome :	Muscle activity, pain and disability
Key Secondary Outcomes :	

Committees

Ethics Committee :	Approval Status	Ethics Number	Ethics Date
Durban University of Technology Institutional Research Ethics Committee	Approved	REC149/17	2018/06/08

Appendix C: Permission to Conduct Research at the DUT Chiropractic Day Clinic

MEMORANDUM

To : Prof Adam
Chair : IREC

From : Prof A Ross
Deputy Dean : Faculty of Health Sciences

Dr Charmaine Korporaal
Clinic Director : Chiropractic Day Clinic : Chiropractic and Somatology

Date : 06.05.2018

Re : Request for permission to use the Chiropractic Day Clinic for research purposes

---

Permission is hereby granted to :

Mr Murray James McLaren (Student Number: 21323459)

Research title : "The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome".

Mr McLaren, is requested to submit a copy of his FRC / IREC approved proposal along with proof of his MTech:Chiropractic registration to the Clinic Administrators before he starts with her research in order that any special procedures with regards to his research can be implemented prior to the commencement of him seeing patients.

Thank you for your time.

Kind regards

[redacted]

[redacted]

Prof AHA Ross
Deputy Dean
Faculty of Health Sciences

Dr Charmaine Korporaal
Clinic Director : Chiropractic Day Clinic :
Chiropractic and Somatology

Cc: Mrs Linda Twiggs : Chiropractic Day Clinic
Dr L O'Connor : Research co-ordinator and supervisor
Prof T Puckree : Research co-supervisor

Appendix D: Permission to Conduct Research at the DUT

Directorate for Research and Postgraduate Support
Durban University of Technology
Tromso Annexe, Steve Biko Campus
P.O. Box 1334, Durban 4000
Tel.: 031-3732576/7
Fax: 031-3732946

9th May 2018

Mr Murray Mclaren
c/o Department of Chiropractic and Somatology
Faculty of Health Sciences
Durban University of Technology

Dear Mr Mclaren

PERMISSION TO CONDUCT RESEARCH AT THE DUT

Your email correspondence in respect of the above refers. I am pleased to inform you that the Institutional Research and Innovation Committee (IRIC) has granted full permission for you to conduct your research "The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome" at the Durban University of Technology.

We would be grateful if a summary of your key research findings can be submitted to the IRIC on completion of your studies.

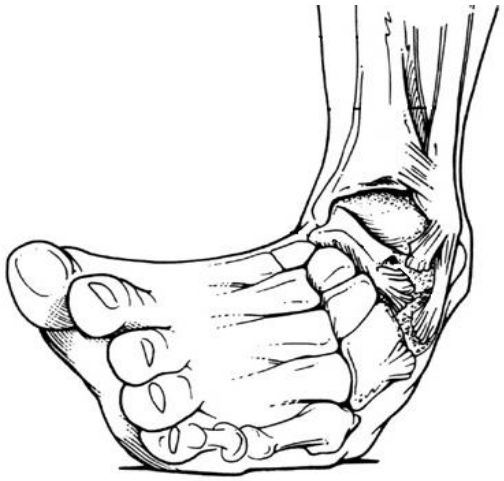
Kindest regards.
Yours sincerely

[redacted]

PROF CARIN NAPIER
DIRECTOR (ACTING): RESEARCH AND POSTGRADUATE SUPPORT DIRECORATE

Appendix E: Advertisement

- ✓ Do you suffer from recurring ankle sprains?
- ✓ Are you between the ages of 18-45?



Research is being carried out at the Durban University of Technology Chiropractic Day Clinic.

Free treatment!!

For more information contact Murray at 083 2612466

Appendix F: Informed Consent

Statement of agreement to participate in this study:

I..... (Participant's full name), ID number

....., have read the above written information (Letter of Information) in its entirety and understand its contents. Any questions have been answered and explained to me sufficiently by..... I am aware that the results of the study, including my personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report. I agree that the data collected during this study can be processed in a computerised system by the researcher. Furthermore, I understand that I may withdraw from this study at any stage without any consequences to me and my future health care. I therefore give my consent to fully participate in this research study.

Participant's name.....

Participant's signature..... Date.....

I,..... (name of researcher) herewith confirm that the above participant has been fully informed about the nature, conduct and risks of the above study.

Researcher's name.....

Researcher's signature..... Date.....

Witness' name.....

Witness' signature..... Date.....

Appendix G: Randomisation Table

Participant number	Group allocation (A or B)
1	A
2	B
3	A
4	A
5	A
6	B
7	B
8	B
9	B
10	B
11	A
12	B
13	B
14	A
15	B
16	A
17	A
18	A
19	A
20	A
21	A
22	A
23	B
24	B
25	A
26	A
27	B
28	A
29	B
30	A
31	B
32	B
33	B
34	A
35	A
36	B
37	A
38	B
39	B
40	B
41	B
42	A

Appendix H: Foot and Ankle Disability Index

Foot and Ankle Disability Index Items	Foot and Ankle Disability Index Sport Items
Standing	Running
Walking on even ground	Jumping
Walking on even ground without shoes	Landing
Walking up hills	Squatting and stopping quickly
Walking down hills	Cutting, lateral movements
Going up stairs	Low-impact activities
Going down stairs	Ability to perform activity with your normal technique
Walking on uneven ground	Ability to participate in your desired sport as long as you would like
Stepping up and down curves	
Squatting	
Sleeping	
Coming up on your toes	
Walking initially	
Walking 5 minutes or less	
Walking approximately 10 minutes	
Walking 15 minutes or greater	
Home responsibilities	
Activities of daily living	
Personal care	
Light to moderate work (standing, walking)	
Heavy work (push/pulling, climbing, carrying)	
Recreational activities	
General level of pain	
Pain at rest	
Pain during your normal activity	
Pain first thing in the morning	

*Subjects were given the following instructions: "Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark N/A." Subjects rate the activity as no difficulty at all (4 points), slight difficulty (3 points), moderate difficulty (2 points), extreme difficulty (1 point), unable to do (0 points), or N/A (not applicable). For pain related to the foot and ankle, subjects select no pain (4 points), mild (3 points), moderate (2 points), severe (1 point), or unbearable (0 points). The Foot and Ankle Disability Index scores are recorded as a percentage of 104 points. The Foot and Ankle Disability Index Sport scores are recorded as a percentage of 32 points.

Appendix I: Letter of Information

Dear participant,

Thank you for your interest in this research study.

Title of study: The effect of talocrural joint manipulation on muscle activity of the lower limb, balance, pain and disability in participants with chronic ankle instability syndrome.

Principle investigator: Murray McLaren

Co-investigators:

Dr L. O'Connor (M.Tech Chiropractic)

Prof. L. Puckree (PhD Exercise physiology)

Brief introduction and purpose of this study: You have been selected to participate in a study to investigate the effects of ankle joint manipulation on balance, pain, disability and the activity of the tibialis anterior, peroneal, gastrocnemius and soleus muscles in patients with chronic ankle instability syndrome. The results of this study will contribute to the knowledge of the effects of manipulation in the treatment of patients with chronic ankle instability syndrome.

Procedure: All participants will be randomly allocated into two groups, one group receiving manipulation and the other group receiving a sham intervention. Each group will undergo the same pre and post-intervention testing. Participants will be contacted 24 hours after the consultation to rate their pain and disability.

Risks and costs: The intervention is safe and is unlikely to cause any side effects, slight tenderness may be experienced, however, this is common post manipulation. The testing procedures are safe and will not give any discomfort. There will be no cost involved.

Benefits: You will receive no remuneration for taking part in this study. Your participation will aid in adding to the knowledge of the chiropractic profession, increasing the efficacy of treatment provided for chronic ankle instability syndrome. On completion of your participation you will be eligible for a free follow up treatment at the chiropractic day clinic (CDC) at the Durban University of Technology.

Withdrawal from the study: You are free to withdraw from the study at any stage.

Confidentiality: All patient information will be kept strictly confidential and stored in the CDC for a period of 5 years after which the files will be shredded. The results of the study will be made available in the Durban University of Technology's library in the form of a dissertation. No confidential patient documentation will be made available.

Persons to contact with any problems and questions:

Should you have any queries regarding the study, please feel free to contact my supervisor Dr O'Connor on lauraw@dut.ac.za or co-supervisor Prof. Puckree on puckreet@dut.ac.za. You can contact me at mclarenmurray1@gmail.com. Please feel free to forward any concerns to the Durban University of Technology Research Office, you may contact Prof. Moyo at moyos@dut.ac.za or on 0313732576.

Appendix J: Case History Form

CHIROPRACTIC PROGRAMME

CHIROPRACTIC DAY CLINIC
CASE HISTORY

Patient: _____ Date: _____

File #: _____ Age: _____

Sex: _____ Occupation: _____

Student: _____ Signature _____

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature:

Case History:

Examination:
Previous: Current:

X-Ray Studies:
Previous: Current:

Clinical Path. lab:
Previous: Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL:
Reason for Conditional:

Signature: Date:

Conditions met in Visit No:	Signed into PTT:	Date:

Case Summary signed off: Date:

Student's Case History:

1. **Source of History:**

2. **Chief Complaint: (patient's own words):**

3. **Present Illness:**

	Complaint 1(principle complaint)	Complaint 2 (additional or secondary complaint)
Location Onset : Initial: Recent: Cause: Duration Frequency Pain (Character) Progression Aggravating Factors Relieving Factors Associated S & S Previous Occurrences Past Treatment Outcome:		

4. **Other Complaints:**

5. **Past Medical History:**

General Health Status

Childhood Illnesses

Adult Illnesses

Psychiatric Illnesses

Accidents/Injuries

Surgery

Hospitalizations

6. Current health status and life-style:

Allergies

Immunizations

Screening Tests incl. x-rays

Environmental Hazards (Home, School, Work)

Exercise and Leisure

Sleep Patterns

Diet

Current Medication
Analgesics/week:
Other (please list):

Tobacco
Alcohol
Social Drugs

7. Immediate Family Medical History:

Age of all family members
Health of all family members
Cause of Death of any family members

	Noted	Family member		Noted	Family member
Alcoholism			Headaches		
Anaemia			Heart Disease		
Arthritis			Kidney Disease		
CA			Mental Illness		
DM			Stroke		
Drug Addiction			Thyroid Disease		
Epilepsy			TB		
Other (list)					

8. Psychosocial history:

Home Situation and daily life
Important experiences
Religious Beliefs

9. Review of Systems (please highlight with an asterisk those areas that are a problem for the patient and require further investigation)

General

Skin

Head

Eyes

Ears

Nose/Sinuses

Mouth/Throat

Neck

Breasts

Respiratory

Cardiac

Gastro-intestinal

Urinary

Genital

Vascular

Musculoskeletal

Neurologic

Haematological

Endocrine

Psychiatric

Appendix K: Physical Examination Form

DUT DURBAN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

PHYSICAL EXAMINATION: SENIOR

Patient Name: _____				**File no:** _____	**Date:** _____
Student:		**Signature:**			
VITALS:					
Pulse rate:				Respiratory rate:	
Blood pressure:	R	L		Medication if hypertensive:	
Temperature:				Height:	
Weight:	Any recent change?	Y / N	If Yes: How much gain/loss		Over what period
GENERAL EXAMINATION:					
General Impression					
Skin					
Jaundice					
Pallor					
Clubbing					
Cyanosis (Central/Peripheral)					
Oedema					
Lymph nodes	Head and neck				
	Axillary				
	Epitrochlear				
	Inguinal				
Pulses					
Urinalysis					
SYSTEM SPECIFIC EXAMINATION:					
CARDIOVASCULAR EXAMINATION					
RESPIRATORY EXAMINATION					
ABDOMINAL EXAMINATION					
NEUROLOGICAL EXAMINATION					
COMMENTS					
Clinician:			**Signature:**		

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Appendix L: Foot and Ankle Regional Examination

DUT DURBAN UNIVERSITY OF TECHNOLOGY | DEPARTMENT OF CHIROPRACTIC AND SOMATOLOGY

CHIROPRACTIC PROGRAMME

FOOT AND ANKLE
REGIONAL EXAMINATION

Patient:_____ File no:_____ Date:_____

Student:_____ Signature:_____

Clinician:_____ Signature:_____

Observation
Gait analysis (antalgic limp, toe off, arch, foot alignment, tibial alignment).

_____

_____

Swelling_____
Heloma dura / molle_____
Skin_____
Nails_____
Shoes_____
Contours (Achilles tendon, bony prominences)_____

Active movements

Weight bearing:	**R**	**L**	***Non weight bearing:***	**R**	**L**
Plantar flexion			50°		
Dorsiflexion			20°		
Supination					
Pronation					
Toe dorsiflexion			40°(mtp)		
Toe plantar flexion			40° (mtp)		
		Big toe dorsiflexion (mtp) (65-70°)			
		Big toe plantar flexion (mtp) 45°			
		Toe abduction + adduction			
		5° first ray dorsiflexion			
		5° first ray plantar flexion			

Passive movement motion palpation (Passive ROM quality, ROM overpressure, joint play)	**R**	**L**		**R**	**L**
Ankle joint: *Plantarflexion*			Subtalar joint: *Varus*		
Dorsiflexion			*Valgus*		
Talocrural: *Long axis distraction*			Midtarsal:*A-P glide*		
First ray: *Dorsiflexion*			*P-A glide*		
Plantarflexion			*rotation*		
Circumduction of forefoot on fixed rearfoot			Intermetatarsal glide		
			Tarso metatarsal joints: *A-P*		
Interphalangeal joints: *L-A dist*			Metatarsophalangeal dorsiflexion (with associated plantar flexion of each toe		
A-P glide					
lat and med glide					
rotation					

Resisted Isometric movements	R	L		R	L
Knee flexion			Pronation (eversion)		
Plantar flexion			Toe extension (dorsiflexion)		
Dorsiflexion			Toe flexion (plantar flexion)		
Supination (inversion)					

Neurological	R	L
Dermatomes		
Myotomes		
Reflexes		
Balance/proprioception		

Special tests	R	L
Anterior drawer test		
Talar tilt		
Thompson test		
Homan sign		
Tinel's sign		
Test for rigid/flexible flatfoot		
Kleiger test (med. deltoid)		

Alignment	R	L
Heel to ground		
Feiss line		
Tibial torsion		
Heel to leg (subtalar neutral)		
Subtalar neutral position:		
Forefoot to heel (subtalar & Midtarsal neutral)		
First ray alignment		
Digital deformities		
Digital deformity flexible		

Palpation	R	L
Anteriorly		
Medial malleoli		
Med tarsal bones, tibial (post) artery		
Lat. malleolus, calcaneus, sinus tarsi, and cuboid bones		
Inferior tib/fib joint, tibia, mm of leg		
Anterior tibia, neck of talus, dorsalis pedis artery		
Posteriorly		
Calcaneus, Achilles tendon, Musculotendinous junction		
Plantarily		
Plantar muscles and fascia		
Sesamoids		

Appendix M: Clinic Voucher

This voucher entitles the bearer to one free chiropractic treatment session at the Durban University of Technology Chiropractic Day Clinic. This voucher is valid for six months from

You **must** bring this voucher to reception to claim your free treatment.