JOINT MOBILISATION AND HOME-BASED REHABILITATION FOR THE TREATMENT OF CHRONIC ANKLE INSTABILITY: CLINICAL INVESTIGATION AND PRACTITIONER DEVELOPMENT

CHRISTOPHER JAMES HOLLAND

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original, except where indicated by specific references in the text. No part of the thesis has been submitted as part of any academic award. The thesis has not been presented to any other educational institution in the United Kingdom or overseas. Any views expressed in this thesis are those of the author and in no way represent those of the University.

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To those I've lost during my time on this journey, I will always miss you.

Scientific Conference Presentations

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LIST OF ABBREVIATIONS

ADL   Activities of daily living

AII   Ankle Instability Instrument

ANOVA   Analysis of variance

ANT   Anterior

AP   Anteroposterior

ATFL   Anterior talofibular ligament

BESS   Balance error scoring system

CAI   Chronic ankle instability

CAIT   Cumberland ankle instability tool

CFL   Calcaneofibular ligament

CI   Confidence interval

CNS   Central nervous system

COPV   Centre of pressure excursion velocities

CPD   Continuing professional development

DF   Dorsiflexion

DF-ROM   Dorsiflexion range of motion

DPC   Dynamic postural control

DPSI   Dynamic postural stability index

EBP   Evidence based practice

EMG   Electromyography

FAAM   Foot and ankle ability measure

FAAM-ADL   Foot and ankle ability measure – activities of daily living

FAAM-S   Foot and ankle ability measure – sport

FADI	Foot and Ankle Disability Index
FAOS	Foot and Ankle Outcome Score
FFI	Foot Function Index
FI	Functional instability
FWB	Full weight bearing
GRF	Ground reaction force
GTO	Golgi tendon organ
HRQL	Health-related quality of life
HVLA	High velocity low amplitude
IAC	International Ankle Consortium
ICC	Intra-class correlation coefficient
IdFAI	Identification of Functional Ankle Instability
IGF	Insulin-like growth factor
IPP	Injury prevention programme
JPS	Joint positioning sense
LAS	Lateral ankle sprain
NWB	Non-weight bearing
MCID	Minimal clinically important difference
MDC	Minimal detectable change
MI	Mechanical instability
MWM	Mobilisation with movement
MTJ	Mid tarsal joint
ROM	Range of motion
OA	Osteoarthritis
PCL model	Patient-clinician-laboratory model

PG	Posterior talar glide
PL	Posterolateral
PM	Posteromedial
PNF	Proprioceptive neuromuscular facilitation
PROM	Patient reported outcome measures
PTFL	Posterior talofibular ligament
RE-AIM	Reach Effectiveness Adoption Implementation Maintenance
ROM	Range of motion
SEBT	Star excursion balance test
SD	Standard deviation
STJ	Sub-talar joint
TCJ	Talocrural joint
TFJ	Tibiofibular joint
TPB	Theory of planned behaviour
TTS	Time to stabilisation
WB	Weight bearing
WB-DFROM	Weight bearing dorsiflexion range of motion
WBLT	Weight bearing lunge test

ABSTRACT

Background: Ankle sprains are the most common musculoskeletal disorder, accounting for 22% of all sports injuries (Fong *et al.*, 2007; Gribble *et al.*, 2016a). Despite the high prevalence and severity (Braun, 1999; Fong *et al.*, 2007) up to 70% of those sustaining a single sprain report residual symptoms, including recurrent instability, additional ankle sprains and reduced functional capacity (Wikstrom *et al.*, 2007). These negative antecedents form the primary characteristics of chronic ankle instability (CAI). CAI is linked to several mechanical and functional insufficiencies (Hertel, 2002). These include reduced dorsiflexion range of motion (DF-ROM) (Drewes *et al.*, 2009) and reduced posterior talar glide (Denegar, Hertel and Fonseca, 2002) which may disrupt the transmission of afferent information to the sensorimotor system, contributing to the functional impairments associated with CAI (Hoch and McKeon, 2011a). Joint mobilisations restore arthrokinematic movements that occur between joint surfaces (Green *et al.*, 2001) and consistently demonstrate acute improvements in DF-ROM and posterior talar glide in those with a history of ankle sprains (Green *et al.*, 2001; Reid, Birmingham and Alcock, 2007; Hoch *et al.*, 2014). The use of joint mobilisations to increase afferent input and their effect on dynamic balance and postural control has also been identified (Hoch, Staton and McKeon, 2011b; Hoch, Staton, *et al.*, 2012; Cruz-Díaz *et al.*, 2015). In addition the use of exercise and functional rehabilitation has been seen to be an effective approach to improve ankle function in those with CAI (Webster and Gribble, 2010). However, much of the research into the effective and efficient treatment of CAI is inconclusive. More research is needed to ensure the efficacy of joint mobilisations and functional

rehabilitation for those with CAI and to ensure that this knowledge is disseminated effectively to practitioners in order to influence practice.

Study 1 (Chapter 4a): Study 1 explored the effects of varying treatment durations of an anterior to posterior talar joint mobilisation on measures of DF-ROM, posterior talar glide, dynamic postural control and self-reported function. Participants completed 6 treatment sessions over a 2-week period with measures taken prior to the first treatment session and directly after the final one, with a one week follow up for self-reported function measures. The findings of the study indicate that joint mobilisations can significantly improve arthrokinematic motion, dynamic postural control and patient reported outcome measures (PROM). The longer treatment durations conferred the greatest improvements in these outcome measures.

Study 2 (Chapter 4b): Study 2 built upon the findings of study 1 using the same intervention and outcome measures to explore the within session effects of varying treatment durations. Participants completed 6 treatment sessions over a 2-week period and had measure taken prior to and directly after each treatment. The findings aligned with the conclusion from study 1, however, the greatest effect of the longer treatment duration was observed within the first week of treatment. This suggested that 120s treatment durations are more effective than shorter durations when applied within the first week of treatment.

Study 3 (Chapter 5): Study 3 sought to identify whether home-based rehabilitation could be used to augment the improvements elicited from the joint mobilisation recommendations in study 2. Participants completed 3 joint mobilisation treatment

interventions in the first week and were then instructed to complete a 4-week home-based rehabilitation programme. The results showed that the combination of joint mobilisation intervention and home-based rehabilitation programmes are effective at treating the deficiencies associated with CAI, and that the application of three, 120s joint mobilisations within the first week of intervention, followed by 2-weeks of daily rehabilitation exercises targeting self-mobilisation and dynamic postural control is an effective treatment strategy. In addition, the improvements elicited by joint mobilisations are lost if additional rehabilitation is not implemented.

Study 4 (Chapter 6): Study 4 attempted to disseminate the research information gained from the previous studies to develop practitioner's knowledge and influence their intended future practice. Participants attended a CPD workshop where the research recommendations were presented and explained. Measures were taken via questionnaire prior to the workshop to ascertain the practitioner's current knowledge and experience with CAI. Following the workshop an additional questionnaire was completed to identify the impact that the workshop had on the practitioner's knowledge and understanding, and to ascertain the extent to which the information provided would influence their future practice. The results showed that a CPD workshop is an effective means for knowledge dissemination within manual therapy practitioners, with a clear improvement in knowledge and understanding of CAI and treatment methods. In addition, the practitioner's behavioural intention to use the information was clear and shows that intended clinical practice can be enhanced through the use of workshop-based research dissemination.

Conclusion: The body of work contained within this thesis extends our understanding of the CAI pathology and its treatment. The results show that longer treatment durations of Maitland Grade IV anterior to posterior talar glide joint mobilisations are recommended when single sets are applied within the first week of treatment. These improvements are not maintained following treatment cessation, although function is kept above baseline levels. However, the inclusion of a home-based rehabilitative exercise programme focussing on dynamic postural control and self-applied ankle mobilisation can further augment these improvements. These results advocate that 120s of joint mobilisation treatment is applied in the first week of treatment, followed by an at home rehabilitative exercise programme for the proceeding 2-weeks. In addition, the thesis shows that CPD workshops are an effective way to present research information to improve the knowledge, understanding and intention to adopt new treatment strategies within healthcare professionals. These methods should be therefore adopted by researchers in order to disseminate research knowledge to influence practice and to bridge the gap between research and practice.

1.1. Background

More than 7.2 million females are currently involved in sport or regular physical activity (Sport England, 2016). As the popularity of female sport increases, the incidence of injury has become more apparent. Sports-related injuries can detrimentally affect quality of life for individuals who sustain them (Maffulli *et al.*, 2011). In gender comparable sports, female injury rates are higher than their male counterparts (Dehaven and Lintner, 1986; Deitch *et al.*, 2006; Ristolainen *et al.*, 2009). Much of the explanation for these higher rates of injury is attributed to the hazardous movement patterns that female athletes exhibit during sport specific tasks. These include increased knee valgus angle and knee abduction moments, and limited sagittal plane motion, particularly when landing from jumps (Hewett, Myer and Ford, 2004; Ford *et al.*, 2010). In comparison to their male counterparts, females exhibit significantly higher Q-angle and hip joint internal rotation angle as well as lower arch height index which leads to increased stress being exerted on the lower limbs during physical activity (Mitani, 2017). These potentially hazardous biomechanics commence during early puberty and can continue as the athlete matures, placing the female athlete at an increased risk of lower limb injury (Ford *et al.*, 2010). The neuromuscular control patterns of males and females diverge substantially during the maturation period, which explains these deficient movement patterns. Males demonstrate significant increases in neuromuscular control as they age which correlates with their maturation stage, whilst females show little change through the maturation period (Beunen and Malina, 1988; Kellis *et al.*, 1999). In addition, female athletes are thought to be at a

higher risk of injury due to fluctuations in oestrogen and progesterone during the menstrual cycle (Slauterbeck *et al.*, 2002).

1.1.1. Ankle Sprains and Chronic Ankle Instability

Ankle sprains account for between 3 and 5% of all injuries treated in emergency facilities in United Kingdom, equating to approximately 5,600 incidences per day (Cooke *et al.*, 2003). However, these healthcare statistics may be significantly underreporting the incidence of these injuries as it has been estimated that up to 55% of those who sustain an ankle sprain do not attend or seek treatment from healthcare professionals (Mckay *et al.*, 2001). Indeed, the prevalence of ankle sprains is amplified within those who are physically active and is the most common musculoskeletal disorder accounting for 22% of all sport related injuries (Fong *et al.*, 2007; Gribble *et al.*, 2016a). Despite the high-prevalence and severity of ankle sprains (Braun, 1999; Fong *et al.*, 2007), they are still often considered to be innocuous in nature with the belief that symptoms will resolve quickly with limited treatment (Birrer *et al.*, 1999). Within collegiate level cohort famle athletes have been shown to have a significantly higher incidence of foot and ankle injuries in comparison to males (4.07 vs 3.94 injuries per 1000 athlete-exposures) (Hunt *et al.*, 2017). In terms of specific lateral ankle sprain occurrence, female collegiate athletes have been reported to be at a 25% higher risk of sustaining a grade I injury when compared to male athletes (Hosea, Carey and Harrer, 2000). However, the relative risk for more serious grade II and III sprains has not been seen to be significantly different between the sexes. The degree of ligament laxity may have a part to play in the increased injury rate for the more minor grade I sprains. Studies have identified that the laxity of the ankle ligaments to anterior and lateral movement is significantly less in female athletes than males in the absence of

any previous ligamentous injuries (Wilkerson and Mason, 2000; Silke, Hertel and Wunderlich, 2011) . The association between these prognostic factors and recovery after lateral ankle sprain are largely inconclusive, with insufficient evidence to recommend any factor as an independent predictor (Thompson *et al.*, 2017). However, ankle sprains have been shown to have the highest recurrence rate of any musculoskeletal injury (Anandacoomarasamy, 2005). Up to 70% of those who sustain a single ankle sprain report residual symptoms, including recurrent bouts of instability, additional ankle sprains and reduced functional capacity (Wikstrom *et al.*, 2007). These negative antecedents form the primary characteristics of chronic ankle instability (CAI), which has been associated with an increased risk of developing co-morbidities such as post-traumatic ankle osteoarthritis (OA) (Valderrabano *et al.*, 2006), with at least half of CAI sufferers showing evidence of this condition (Hintermann, Boss and Schäfer, 2002). The factors that form the foundation of CAI have traditionally been separated into mechanical and functional deficiencies (Hertel, 2002). Mechanical impairments include range of motion deficits, pathologic joint laxity, synovial and degenerative changes to joint structures, and impaired arthrokinematics (Hertel, 2002). Functional impairments are deficits that affect stability during functional activities including altered neuromuscular control, impaired proprioception, strength deficits and reduced postural control (Hertel, 2002; Hopkins *et al.*, 2009). Although functional and mechanical instability may occur in isolation, it has been hypothesised that CAI is most likely a combination of the two (Hiller, Kilbreath and Refshauge, 2011). The alteration in joint mechanics associated with CAI have been studied extensively in an attempt to explain the pathology and aetiology (Hubbard and Hertel, 2006). With the high prevalence of ankle sprains and the increase in female sports participation, it

is important to develop health care practice in relation to treatment and rehabilitation, particularly in those who develop CAI symptoms.

1.1.2. Mechanical Positional Faults

A potential contributing factor to the loss of osteokinematic and arthrokinematic motion associated with CAI is an anterior positional fault of the talus (Figure 1.1). This concept was first proposed by Mulligan (Wikstrom and Hubbard, 2010) and is believed to be the result of an anterior subluxation of the talus on the tibia immediately after an inversion ankle sprain, resulting in an increase in anterior ligamentous laxity and restrictions in posterior non-contractile tissue (Denegar, Hertel and Fonseca, 2002). The anterior positional fault hypothesis has been identified in individuals with CAI using unstressed non-weight bearing radiographic imaging (Wikstrom and Hubbard, 2010). However, there is currently no consensus as to whether the differences in talar positioning is a result of repeated inversion ankle sprains or a predisposing factor to repeated episodes of injury. Although the origination of the anterior positional fault is yet to be determined, previous research has identified increased anterior laxity (Croy *et al.*, 2013) and decreased posterior talar glide in individuals with a history of inversion ankle sprains (Denegar, Hertel and Fonseca, 2002), whilst studies conducted on the use of anterior-to-posterior joint mobilisations have shown significant improvements in posterior talar glide (Vicenzino *et al.*, 2006b; Hoch and McKeon, 2011a). The anterior talar positional fault therefore likely has an association with the restrictions in posterior talar glide, which directly relates to the reductions in dorsiflexion range of motion (DF-ROM) associated with inversion ankle sprains and CAI (Hoch *et al.*, 2014). The deficits in DF-ROM can cause changes in gait patterns and landing biomechanics which can predispose individuals to further pathologies such as medial tibial traction periostitis,

metatarsalgia, Achilles tendinopathy, plantar fasciopathy and gastrocnemius strains (Young *et al.*, 2013). This is of particular importance to female sports participants who have been shown to already exhibit altered movement patterns in comparison to their male counterparts (Hewett, Myer and Ford, 2004; Ford *et al.*, 2010). These biomechanical changes lead to increased lower limb stress during physical activity (Mitani, 2017) which may be exacerbated further by additional alterations brought about by a reduction in DF-ROM following ankle injury. The reduction in DF-ROM may also be responsible for deficits in certain elements of dynamic postural control (e.g. jump landings, change of direction, cutting and unexpected player contact) as restrictions in ligamentous and capsular tissue have been shown to affect the transmission of afferent information (Myers *et al.*, 2003). This suggests that there is a clear connection between mechanical and functional impairments, with mechanical deficits being a contributing factor to the deficits in sensorimotor function experienced by those with CAI.

Figure 1.1. *Talar positional fault. (1) The distance between the anterior margin of the talar dome and (2) the inferior tibia in the sagittal plane (Wikstrom and Hubbard, 2010).*

1.1.3. Postural Control Deficits

Functional ankle instability has been linked to deficiencies in postural control (Hertel, 2002; Hopkins *et al.*, 2009) and has been identified as a fundamental impairment in individuals with a history of ankle sprain (Freeman, 1965; Freeman, Dean and Hanham, 1965). Poor postural control can be defined as the inability to maintain the body's centre of mass within a given base of support and can be classified as either static (maintaining postural control with minimal movement) or dynamic (maintaining postural control while completing a prescribed movement) (Winter, Patla and Frank, 1990). Whilst the results are mixed regarding the gender differences in postural control, it is generally accepted that females demonstrate differences in biomechanical and neuromuscular characteristics that are associated with an increased risk of injury (Rozzi *et al.*, 1999; Sell *et al.*, 2018). A number of systematic reviews and meta-analyses have determined that individuals with CAI exhibit deficits in static and dynamic postural control (McKeon and Hertel, 2008; Arnold *et al.*, 2009; Munn, Sullivan and Schneiders, 2010; Webster and Gribble, 2010; Wikstrom and Hubbard, 2010). The major findings of these studies indicate that it is both the limb with a history of ankle sprain and the uninvolved limb that demonstrate deficiencies, supporting the hypothesis of alterations in central processing following ankle injury (Bastien *et al.*, 2014). An additional factor commonly reported to contribute to the injury mechanism associated with inversion ankle sprains and CAI is an inappropriate positioning of the foot at the point of initial contact with the ground following a jump or during gait (Delahunt, Monaghan and Caulfield, 2006b, 2006a). Research using cadaveric models (Konradsen and Voigt, 2002) and muscle-driven computer simulations (Wright *et al.*, 2000) have shown that the risk of inversion ankle sprains are increased as the plantarflexion angle of the foot with the ground at the point of contact is increased.

The impairments in postural control associated with CAI and ankle sprains can be manipulated through treatment and rehabilitation due to the plasticity of the sensorimotor system (Webster and Gribble, 2010; Buch, Liew and Cohen, 2017). Individuals with a history of ankle sprains demonstrate changeable deficiencies in static postural control, as well as more dynamic measures. However, research indicates that there is a poor association between static and dynamic postural stability and may actually be measuring different aspects of postural stability (Sell, 2012). Furthermore, static tests may not be the best choice for athletes, or the physically active, who demonstrate higher balance ability, requiring a shift towards more dynamic tests. The rationale for this is due to the more challenging nature of these tests which has more similarities to athletic activity (Williams *et al.*, 2016).

The measurement of dynamic postural stability can be achieved in 2 ways. The first is where the base of support remains stationary whilst the subject moves within that base of support, such as during the Star Excursion Balance Test (SEBT). The second is through testing an individual's ability to maintain their stability following a change in their base of support, as with single-leg jump landings (Wikstrom *et al.*, 2005). Postural stability is then quantified with the Dynamic Postural Stability Index (DPSI), which measures the variability of ground reaction forces (GRFs) following landing using force plates. Although this method can be advantageous because it places additional demands on the neuromuscular system, replicating athletic tasks, the use within a clinical setting is limited. To compliment laboratory measures of postural control, non-instrumented, clinical measures have been developed to test dynamic postural control. The most researched and reliable being the SEBT (ICC = 0.86-0.92) (Munro and Herrington, 2010; Gribble *et al.*, 2013). The measure of dynamic postural control from

this test is inferred from the maximum distance a participant can reach in one of eight different directions whilst maintaining a base of support (Figure 1.2). Of the 8 reach directions that form the basis of the SEBT, it appears that the most significant are the anterior, posteromedial and posterolateral directions. Research has reported that the sum of these three reach directions are predictive of lower limb injury (Plisky *et al.*, 2006), whilst the anterior and posteromedial reach directions can be used to identify those with CAI (Hertel *et al.*, 2006; Hubbard *et al.*, 2007). This modified version of the SEBT substantially reduces the time necessary to perform the test, reduces the level of participant fatigue and the amount of redundant information obtained, and has shown good reliability in previous studies (ICC = 0.78-0.96) (Hertel, Miller and Denegar, 2000; Gribble, Hertel and Plisky, 2012). Individuals with CAI have shown significantly decreased reach distances when compared to healthy controls (Hoch, Staton, *et al.*, 2012; Pionnier *et al.*, 2016; McCann *et al.*, 2017). The diminished performance is particularly notable in the anterior reach direction (8%), with posteromedial and posterolateral reach distances being slightly lower (4.6% and 4.9% respectively) (Jaber *et al.*, 2018). The decreased reach distances indicate that a decrease in sensorimotor function may be evident in those with CAI (Pionnier *et al.*, 2016). This central nervous system adaptation may be a protective motor command based on an individual's past experiences of instability or injury. This would limit the risk of ankle instability that would be induced by dynamic movements such as those brought about during performance of the SEBT. The modified SEBT (anterior, posteromedial, posterolateral reach directions) therefore provides a good indication as to the ability of those with CAI to accomplish a specific movement goal through the organisation of range of motion and sensorimotor function. Due to the multifactorial nature of CAI, any intervention aimed at addressing this condition should address both

the functional and mechanical impairments in order to reduce recurrent sprains, restore functional loss, and prevent degenerative disease (Hertel, 2008).
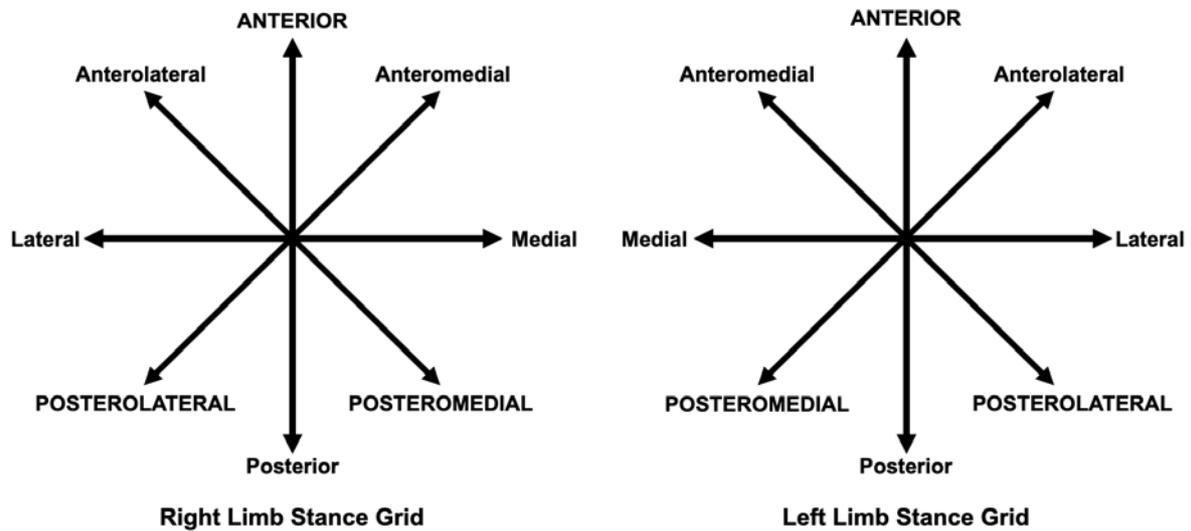
Figure 1.2. *Reach directions for the Star Excursion Balance Test (SEBT).*

1.1.4. Maitland Mobilisation

Manual therapy is a set of techniques primarily designed to minimise pain and restore mobility and function through the application of passive motion to joints or soft tissue (de Souza *et al.*, 2008). Joint mobilisations are an integral part of these techniques and are commonly used to treat patients with joint hypomobility through the restoration of accessory or arthrokinematic movements that occur between joint surfaces (Green *et al.*, 2001). This treatment technique has been proposed by Geoffrey Maitland (Hengeveld and Banks, 2005) and consists of the application of passive, oscillatory, rhythmical forces (Venturini *et al.*, 2007). The foundation of the Maitland technique is a grading system that varies from I to IV. Grades I and II are primarily used to treat painful conditions and consist of oscillatory movements performed before tissue resistance is attained. This refers to the point at which a significant resistance to

deformation is imposed by the tissue (Venturini *et al.*, 2007). Grades III and IV mobilisation are performed after this resistance point and may continue up to the point of maximal resistance that determines the end of range (Petty *et al.*, 2002).

The core tenet of Maitland joint mobilisations is a conceptual framework of clinical reasoning, which forms the basis for the selection of the specific direction, grade, oscillatory frequency, treatment duration and volume (Banks and Hengeveld, 2009). Joint mobilisations aim to increase ROM through the elongation and ultimate deformation of articular and periarticular tissue due to the repeated stretching applied, which increases the extensibility of joint structures. This alteration in ROM is well documented and is achieved through changes in the biomechanical integrity of the joint structures and associated tissue (Green *et al.*, 2001). It is postulated that the magnitude of these changes is influenced by the volume and duration of treatment, with Maitland (Hengeveld and Banks, 2005) stating that each treatment should be performed between 30 seconds and 2 minutes, with longer durations being recommended when tissue needs to be stretched or moved. In addition to restoring arthrokinematic range of motion, there is evidence to suggest that sensorimotor system function may also be enhanced by joint mobilisations (Hoch *et al.*, 2012). This is achieved through the oscillatory nature of the Maitland joint mobilisation technique, which stimulates the afferent pathways of mechanical receptors near the ankle joint, improving the afferent information of the talocrural articulation and the surrounding tissue (McKeon *et al.*, 2010).

1.1.5. Rehabilitation and Exercise

Rehabilitation of athletic injuries requires the prescription of specific exercises and activities that challenge the healing tissue without overstressing them. The effectiveness of which often determines the success of future function and athletic performance (Clanton *et al.*, 2012). The functional purpose of these interventions is to improve muscle strength, range of movement, and sensorimotor control, all of which are commonly impaired after ankle sprain (Perron *et al.*, 2007). Gender differences in musculoskeletal, biomechanical and neuromuscular characteristics that may predispose females for greater injury risk may also require additional or different rehabilitation protocols (Sell *et al.*, 2018).

Poor neuromuscular control, such as the inability to balance (Plisky *et al.*, 2006) or control the body during dynamic actions (Gribble and Robinson, 2009), increases the risk of lower extremity injury, particularly at the ankle. The development of exercise programs aimed at the prevention and recurrence of ankle injury has therefore focussed on proprioceptive, balance, neuromuscular and strengthening exercises (Eils and Rosenbaum, 2001; Kaminski and Hartsell, 2002; Coughlan and Caulfield, 2007). In a comprehensive systematic review of rehabilitation interventions for CAI, Webster & Gribble (2010) report that functional rehabilitation exercises were associated with improved dynamic postural control and self-reported function. Similarly, Schiftan et al (Schiftan, Ross and Hahne, 2015) identify that proprioceptive exercises are effective at reducing the rate of ankle sprains. In contrast, Postle et al (Postle, Pak and Smith, 2012) conclude that there is a lack of consensus as to the benefits of proprioceptive exercises for dynamic stability or ankle ROM.

Stretching of the muscle which act across the ankle joints has been considered an essential part of rehabilitation for improvement in ankle function (Knight *et al.*, 2001). Although the restrictions in dorsiflexion associated with CAI are often due to impaired arthrokinematics, these limitations may also be associated with tightness in the plantar flexors (gastrocnemius and soleus) (Hubbard and Hertel, 2006). As a result, stretches focussing on the gastrocsoleus complex are commonly prescribed in an attempt to increase dorsiflexion ROM, with systematic reviews recognising that stretching provides a statistically significant increase in ankle dorsiflexion (Radford *et al.*, 2006; Young *et al.*, 2013).

These reviews all suggest that exercises and functional rehabilitation, such as balance, range of motion, and strength training, may be the most effective approach to improve ankle function, but that the current evidence is inconclusive (Webster and Gribble, 2010). More research is needed to ensure the efficacy of functional rehabilitation following ankle ligament injury and in for those with CAI, and as yet no studies have identified the effects of combined joint mobilisation and exercise interventions in the treatment of this pathology.

1.2. The Problem

Up to 70% of individuals develop CAI following a single ankle sprain (Wikstrom *et al.*, 2009). Due to the increased ankle laxity identified in females (Wilkerson and Mason, 2000), they experience higher incidence rates of initial ankle sprains than males (Kobayashi *et al.*, 2020). It could therefore be postulated that the number of females going on to develop CAI could be higher than the 70% figure. Most interventions that are prescribed for individuals with this condition focus on the motor aspects of

rehabilitation and often negate to target sensory pathways. Joint mobilisations offer a means by which to stimulate mechanoreceptors at the articular level through the manipulation of non-contractile tissue (Hoch and McKeon, 2011a), whilst also increasing the extensibility of joint structures to restore ROM (Green *et al.*, 2001).

Joint mobilisations are grounded in relevant literature and informed by a conceptual framework of clinical reasoning, with current research on asymptomatic individuals indicated that as treatment duration is increased, greater improvements in ROM are produced (Holland, Campbell and Hutt, 2015). However, some researchers suggest that the choice of technique and duration of treatment has little influence on its effectiveness (van den Hout *et al.*, 2005; Vicenzino *et al.*, 2006a), with some concluding that manual therapy does not confer clinical or economic benefits beyond standard therapy practice (Lin *et al.*, 2008). This lack of consensus regarding the concomitant effect of mobilisation and exercise, and the paucity of comparison between treatment duration in those with CAI needs to be addressed in order to advance the knowledge and application of this technique.

Clinical research is essential to improving the care of patients. Indeed there is evidence that engagement by clinicians with research can improve healthcare performance (Boaz *et al.*, 2015). However, a potential problem is that research is often far removed from that of practice. Instead of seeing research and practice as mutually exclusive entities, a more progressive stance is to bring the two together in order for the research to make a difference within the real-world. The gap between health knowledge and the application in practice settings is due in part to ineffective dissemination (Brownson *et al.*, 2018). Improving the dissemination of evidence-based

practice (EBP) is paramount to reduce the gap between research and practice (Hayes, 2002).

The systematic exploration of the effects of joint mobilisation and home-based exercise to address the impairments associated with CAI is important to develop clinical knowledge and determine the efficacy of these interventions. This study proposes to investigate the effects of joint mobilisations and home-based rehabilitation exercises on ankle mechanics and sensorimotor function in females with CAI following multiple bouts of joint mobilisation treatment and exercise prescription using a repeated-measures design. Given that female sports participants often have limited access to medical support in comparison to males (Emmonds, Heyward and Jones, 2019), it is important to identify appropriate conservative treatment that is both time and cost effective for these athletes.In addition, the results will be presented to manual therapy practitioners in formally organised professional development sessions in order to inform and develop the practice of those involved in the treatment of CAI.

1.3. Clinical Implications

Joint mobilisations are a common manual therapy technique used for the treatment of local restrictions in range of motion and have been shown to have a positive effect when utilised at the ankle (Loudon, Reiman and Sylvain, 2014). These techniques are also affordable and undemanding in terms of equipment, offering the clinician a readily available means by which to help the patient. Although joint mobilisations are informed by a conceptual framework of clinical reasoning, there is a lack of consensus within the literature regarding their effectiveness as a clinical technique. Further, there is a paucity of methodologically rigorous research into the interaction between treatment

dose and ROM improvements. A comprehensive examination of the effects of treatment duration in those with CAI will provide meaningful results that can be utilised by clinicians and will add to the current framework for the practice of manual therapy.

It is recognised that favourable treatment outcomes for clinical interventions depend on patients attending their clinic appointments. However, clinicians and patients are often not in a position to partake in multiple treatment sessions over an extended period, due to both cost and time implications. As such, the use of home-based exercise is often advocated and can greatly accelerate the effectiveness of treatment. The use of home-based exercise programs has been shown to improve outcome measures associated with both inversion ankle sprains and CAI. However, to date there has been no research that has examined the effectiveness of such programmes following joint mobilisation treatment. This study will provide an insight into the use of a specific home-based exercise programme to augment the effects of joint mobilisation and will provide a significant enhancement in the treatment of CAI.

To examine the effects of joint mobilisation treatments and home-based rehabilitative strategies on those with CAI, both clinical and participant-based measures will be used. This will allow the research to identify local impairments in range of motion, global impairments within the sensorimotor system, and self-reported function during daily living at the level of the individual within their own environment. The aim is to provide a greater depth of understanding for the use of joint mobilisations to treat functional and mechanical impairments, and to improve self-reported levels of function in those with CAI. This will assist in the development of more effective and efficient treatment and rehabilitation strategies to address the recurrent episodes of ankle

trauma and reductions in functional capacity experienced by these individuals. In order to disseminate this knowledge to practitioners, specific development sessions will be offered to practitioners. These will be designed to propagate the findings of the research and to review the impact that this has on the attendee's clinical practice.

1.4. Objectives

The thesis has an overarching ambition to provide a comprehensive examination of the effect of varying treatment durations of a Maitland anterior-to-posterior talar mobilisations in those with CAI and to identify an effective and efficient clinical treatment method for improving the associated outcome measures, and to disseminate this information to practitioners. In order to achieve this ambition, there are 3 main objectives.

1. The first objective is to examine the effect of varying treatment durations during a 2-week talocrural joint mobilisation intervention on measures of DF-ROM, posterior talar laxity, dynamic postural control and self-reported function. This objective will focus on (1) the cumulative effects of treatment from the beginning to the end of the 2-week period, and (2) the within-session effects for each separate treatment session.

2. The second objective is to identify the extent to which improvements in outcome measures are sustained for a 4-week period following mobilisation treatment and the effect that an additional ankle specific exercise regime can have on these measures during the same time frame.

3. The third objective is to disseminate this information to practitioners and to identify the impact that this research will have on their clinical practice using the RE-AIM framework.

1.5. Aims and Hypotheses

Aim 1: Examine the (1) cumulative, and (2) within-session effects of different treatment durations during a 2-week talocrural joint mobilisation intervention on clinical and self-reported measures of function, in order to determine the treatment dose that elicits the greatest improvements in these measures.

Aim 2: Examine the combined effects of talocrural joint mobilisation and a specific 4-week home-based ankle exercise program on clinical and self-reported measures of function, to determine whether outcomes can be enhanced.

Aim 3: Identify the effective and efficient use of talocrural joint mobilisations and home-based exercise programs in the treatment of those with CAI and develop clear clinical recommendations for their use.

Aim 4: To disseminate the results of the study in an effective and efficient manner in order to develop the knowledge, intended adoption, and practice of those involved in the treatment of CAI.

Hypothesis for Aim 1: Following the 2-week talocrural joint mobilisation intervention, participants receiving longer treatment durations will demonstrate greater improvements in clinical and self-reported measures of function.

Hypothesis for Aim 2: Joint mobilisations will result in a sustained improvement in DF-ROM, laxity, dynamic postural control, and self-reported function following treatment cessation, and the application of a specific home-based ankle exercise programme will augment these improvements further.

Hypothesis for Aim 3: The use of longer talocrural joint mobilisation treatment durations and the inclusion of ankle specific home-exercise programmes will result in the greatest improvement in clinical and self-reported measures of function in those with CAI.

Hypothesis for Aim 4: The dissemination of the research results will result in the development of practitioner's knowledge, and intention to adopt and implement the recommendations of the study within their own future practice.

2.1. Anatomy

2.1.1 Arthrokinematics

The talocrural joint is one of the most congruent joints in the body (Hubbard and Hertel, 2006). The body of the talus has three articular surfaces. These are the superior, or trochlear surface, and the lateral and medial surfaces. The trochlear surface is convex in an anteroposterior direction with a depressed central groove that articulates with the corresponding inferior surface of the tibia. The trochlear surface does not run directly in the sagittal plane, but instead has a slight deviation anteriorly and laterally. The medial surface of the talus lies in the sagittal plane and articulates with the facet of the medial malleolus. The lateral surface deviates laterally from posterior to anterior and articulates with the facet of the lateral malleolus, which is separated from the tibia by the inferior tibiofibular joint. The talus is approximately 5mm wider anterior than posterior due to a bevelled surface of the lateral border. This shape means that in dorsiflexion the talus becomes wedged between the malleoli, allowing little or no inversion and eversion, and only small amounts of external rotation (Denegar and Miller, 2002).

The axis of rotation of the talocrural joint passes through the medial and lateral malleoli (Hertel, 2002). This axis is slightly posterior to the frontal plane as it passes through the fibula, and slightly anterior to the frontal plane as it passes through the tibia (Figure 2.1).
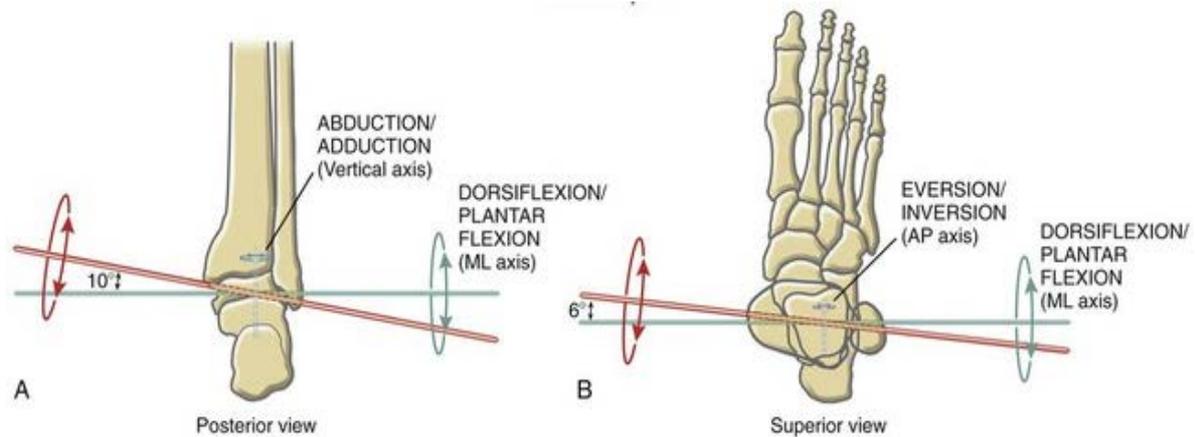
Figure 2.1. *Axis of rotation and osteokinematics of the talocrural joint (Neumann, 2016).*

Isolated movement occurs primarily in the sagittal plane, with small amounts of transverse and frontal plane motion occurring about the oblique axis of rotation (Lundberg *et al.*, 1989). During dorsiflexion of the talocrural joint the talus rolls anteriorly with slight external rotation, and glides posteriorly. In plantarflexion the talus glides anteriorly and internally rotates (Figure 2.2) (Soavi *et al.*, 2000).
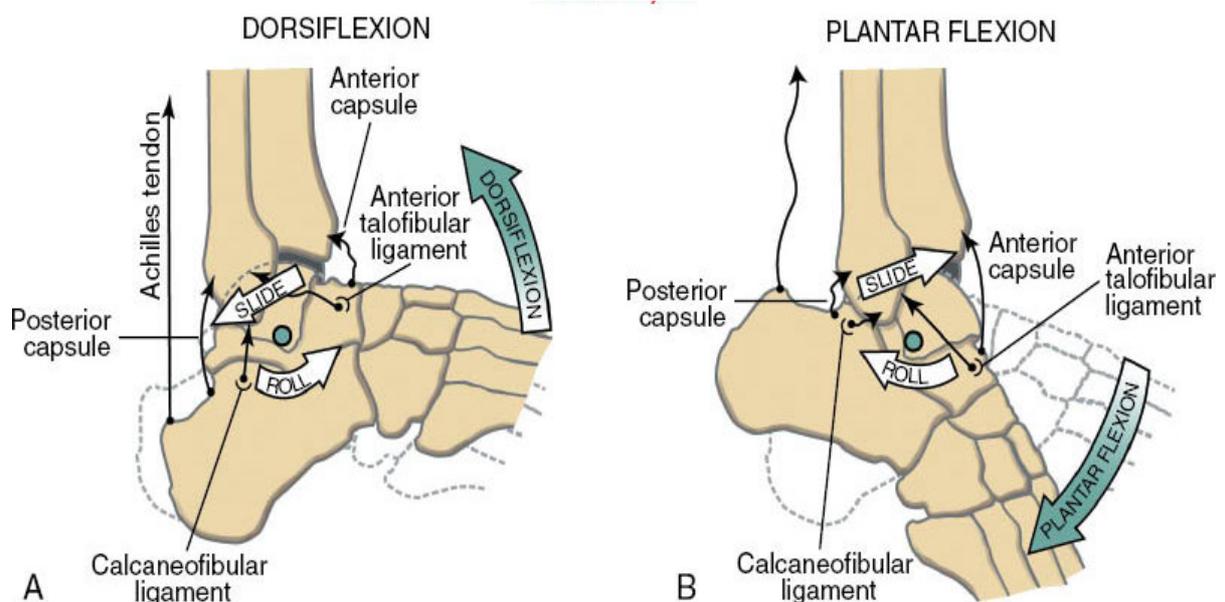
Figure 2.2. *Arthrokinematics of the talocrural joint during dorsiflexion and plantarflexion (Neumann, 2016).*

The motions of the talus in relation to the mortise produce a displacement of the distal fibula in relation to the tibia (Leardini *et al.*, 2000). The fibula glides superiorly during dorsiflexion and inferiorly during plantarflexion (Table 2.1) (Soavi *et al.*, 2000). Calcaneal inversion and eversion result in slight lateral and medial tilt of the talus respectively. Plantar flexion and dorsiflexion are limited by bony, capsular and ligamentous, and muscular factors.

Table 2.1. *Normal Ankle Mechanics*

Physiological motion	Talocrural arthrokinematic motion	Tibiofibular arthrokinematic motion
Dorsiflexion	Talus glides posteriorly and rotates externally	Fibula glides superiorly and moves laterally away from the tibia
Plantarflexion	Talus glides anteriorly and rotates internally	Fibula glides inferiorly

2.1.2 Ligamentous Restraint

The talocrural joint is supported by a number of ligaments which can be divided into three groups: the lateral collateral ligament complex, the medial collateral ligament complex, and the ligaments of the tibiofibular syndesmosis (Golanó *et al.*, 2010). The tibiofibular syndesmotic ligament complex consists of four main ligaments: the anterior inferior tibiofibular ligament, interosseous ligament or membrane, posterior inferior tibiofibular ligament, and inferior transverse tibiofibular ligament (Figure 2.3). These ligaments combined provide stability for the syndesmotic articulation between the distal tibia and fibula. It is this articulation of the tibia and fibular which is needed in order to adapt to the varying width of the upper articular surface of the talus, which is wider anteriorly than posteriorly. During dorsiflexion the tibia and fibular must separate in order to accommodate the upper articular surface of the talus and it is the

syndesmotic ligament complex that resists the axial, rotational, and translational forces that occur through this movement (Ogilvie-Harris, Reed and Hedman, 1994). The maximal stress placed upon these ligaments is achieved with external rotation of the foot as this forces the tibia and fibula to separate. During this movement, the application of additional dorsiflexion or plantarflexion movements may result in injury and damage to these structures. The most common mechanism of ankle syndesmosis injury is dorsiflexion and external rotation of the foot, and associated eversion of the talus within the ankle mortise. These injuries are commonly associated with a firmly planted foot, whereby the excessive external rotation of the foot is caused by an internal rotation of the tibia (Lin, Gross and Weinhold, 2006). The specific mechanistic examples of syndesmotic ankle injuries have been described by Boytim, Fischer and Neumann (1991) with regards to American Football. The mechanisms for excessive external rotation of the foot are either caused by a direct blow to the lateral leg of a downed player whose foot was held in external rotation, or a direct blow to the lateral aspect of the knee while the foot was planted in external rotation with the body rotating internally (Boytim, Fischer and Neumann, 1991). Estimates of the frequency of this pathology varying from 1 to 11% of all ankle injuries (Norkus and Floyd, 2001; Sman *et al.*, 2015).
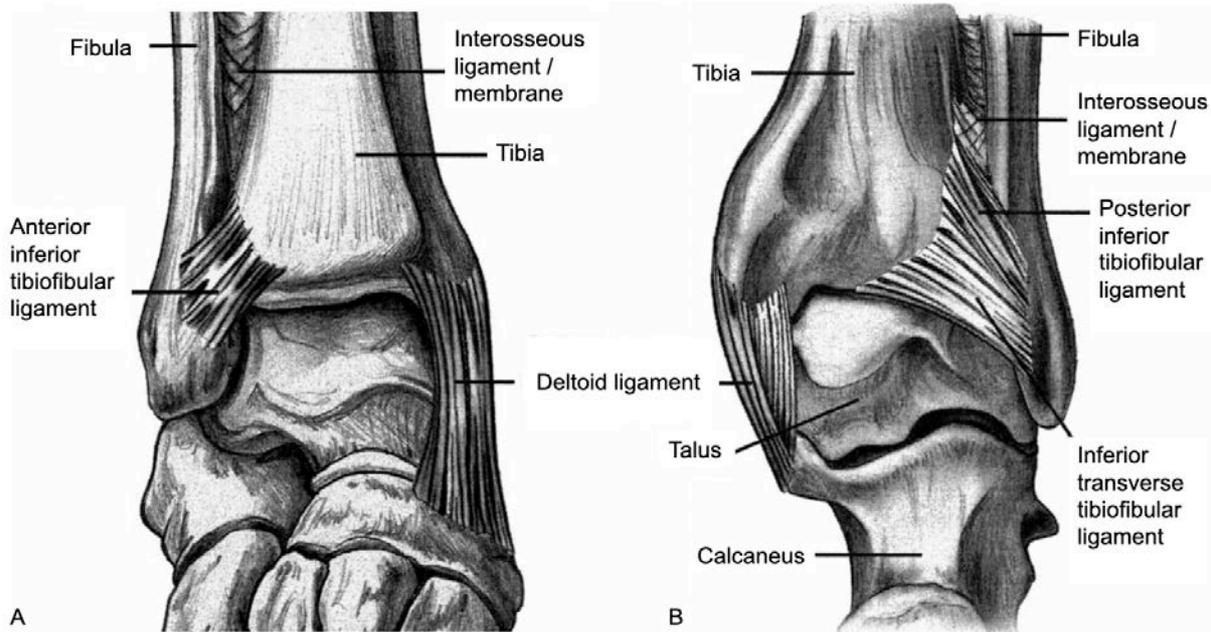
Figure 2.3. *Ankle tibiofibular syndesmosis. A. anterior view. B. posterior view. (Norkus and Floyd, 2001).*

The medial collateral ligaments are collectively known as the deltoid ligament, and consist of a multifascicular group of ligaments that can be divided into a deep and superficial group of fibres (Boss and Hintermann, 2002). The accepted description of these ligaments is that they consist of six bands (Figure 2.4), three of which are always present (tibiospring ligament, tibionavicular ligament, and deep posterior tibiotalar ligament), and three whose presence may vary (superficial posterior tibiotalar ligament, tibiocalcaneal ligament, and deep anterior tibiotalar ligament) (Milner and Soames, 1998). Whilst this is an accepted description of the medial collateral ligaments they are often considered as a group as even during dissection it is difficult to distinguish between the individual bands due to their close proximity and the propensity for the fibres to merge (Golanó *et al.*, 2010). Injuries to the deltoid ligaments occur through eversion trauma where the foot rotates externally whilst the tibia simultaneously rotates internally, with isolated injuries to these structures accounting for 3-4% of all ankle ligament injuries (Ribbans and Garde, 2013). The most common

injury mechanism of deltoid ligament sprains is player contact (Kopec *et al.*, 2017). Athletes who are involved in sports where player contact is common may therefore have an increased likelihood of this injury occurring. The specific mechanistic example of this injury is produced by a valgus force when players are struck on the lateral ankle by another player and creates enough eversion force to damage the deltoid ligaments (Kopec *et al.*, 2017). Around 80% of all ankle fractures occur due to supination-external rotation of the foot with the deltoid ligaments being involved in up to 40% of ankle fractures (Lötscher *et al.*, 2015). Due to the mechanically similar mechanism, combined injury to the deltoid and syndesmotic ligaments is also not uncommon (McCollum *et al.*, 2013).
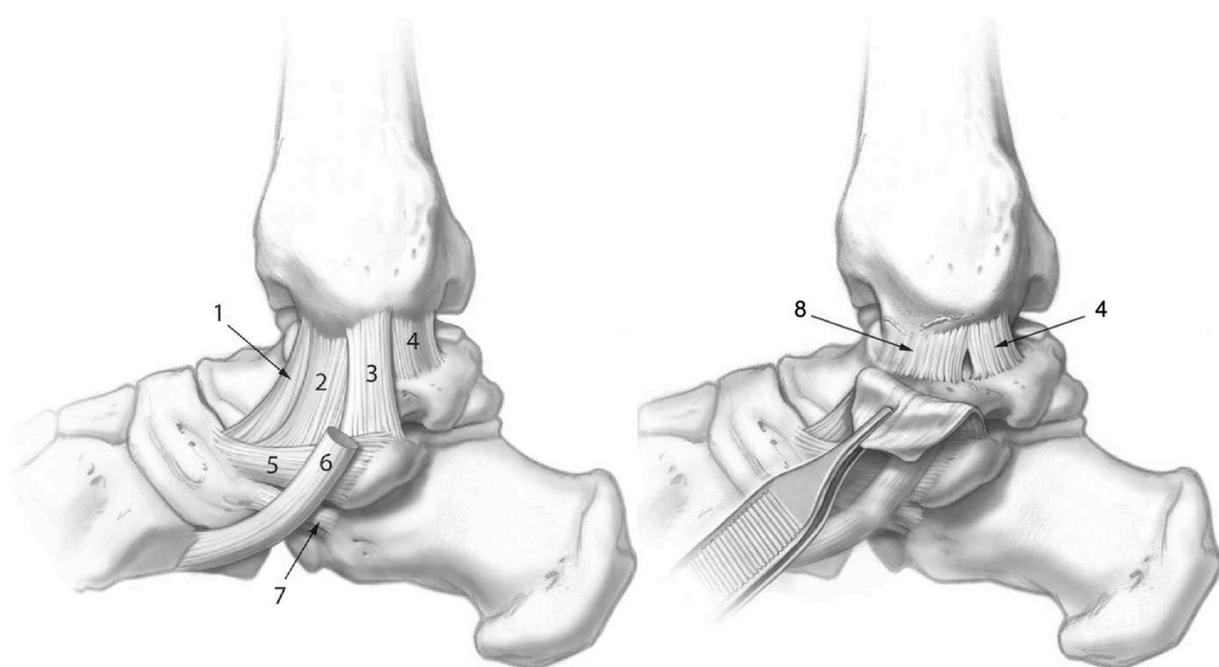
Figure 2.4. *Ankle deltoid ligaments (medial view). 1. Tibionavicular ligament 2. Tibiospring ligament 3. Tibiocalcaneal ligament 4. Deep posterior tibiotalar ligament 5. Superior calcaneonavicular ligament (component of the spring ligament) 6. Posterior tibial tendon 7. Plantar calcaneonavicular ligament (component of the spring ligament) 8. Deep anterior tibiotalar ligament (Savage-Elliott et al., 2013).*

The lateral collateral ligament complex consists of the anterior talofibular (ATFL), the calcaneofibular (CFL), and the posterior talofibular (PTFL) ligaments (Figure 2.5). The ATFL consists of a superior and inferior band that originates from the anterior margin of the lateral malleolus and runs anteromedially to its insertion on the neck of the talus. The positioning of the ATFL limits anterior displacement of the talus and plantarflexion of the ankle and is the most frequently injured ligament. The ligament most commonly comprises a double-banded (superior and inferior) morphology and is particularly vulnerable to injury when the foot is plantarflexed and inverted (Golanó *et al.*, 2010). Isolated injury to the ATFL occurs in around 70% of cases as it is the weakest of the lateral collateral ligaments (Dubin *et al.*, 2011). The CFL originates from the anterior part of the lateral malleolus and runs obliquely inferiorly and posteriorly to attach to the posterior region of the lateral calcaneal surface. The CFL is therefore the only ligament that bridges both the talocrural and subtalar joints. The CFL resists excessive inversion of the ankle and is further stressed at the end ranges of dorsiflexion (Beumer *et al.*, 2003). The ligament is approximately 2.5-3 times stronger than the ATFL and as such isolated injury to the CFL is very rare (Mangwani, Hakmi and Smith, 2001; Fong *et al.*, 2009), with combined injuries to the ATFL and CFL being reported in around 20% of cases (Brostrom, 1966; Dubin *et al.*, 2011). The PTFL originates from the lateral malleolar fossa and runs almost horizontally to insert onto the posterolateral talus. The PTFL resists posterior translation of the talus and is approximately twice as strong as the ATFL (Mangwani, Hakmi and Smith, 2001; Fong *et al.*, 2009). Injury to the lateral collateral ligament complex usually occurs when the individual's centre of gravity is shifted anteriorly and laterally over the border of the weight-bearing limb, resulting in a high velocity inversion and plantarflexion of the ankle (Dubin *et al.*, 2011). This common mechanism seldom stresses the PTFL and is the third sequential

ligament to be injured after the ATFL and CFL. These injuries are common in sports that involve running on uneven terrain, repetitive jumping, or frequent changes in direction (Dubin *et al.*, 2011). The specific mechanistic example of this type of injury may occur when a player lands awkwardly form a jump onto an opponent's foot, causing the ankle to roll inwards. Injury to the lateral ligament complex include sprains to the PTFL in less than 5% of all cases and are seldom reported unless the ankle undergoes dislocation (Golanó *et al.*, 2010; Dubin *et al.*, 2011).
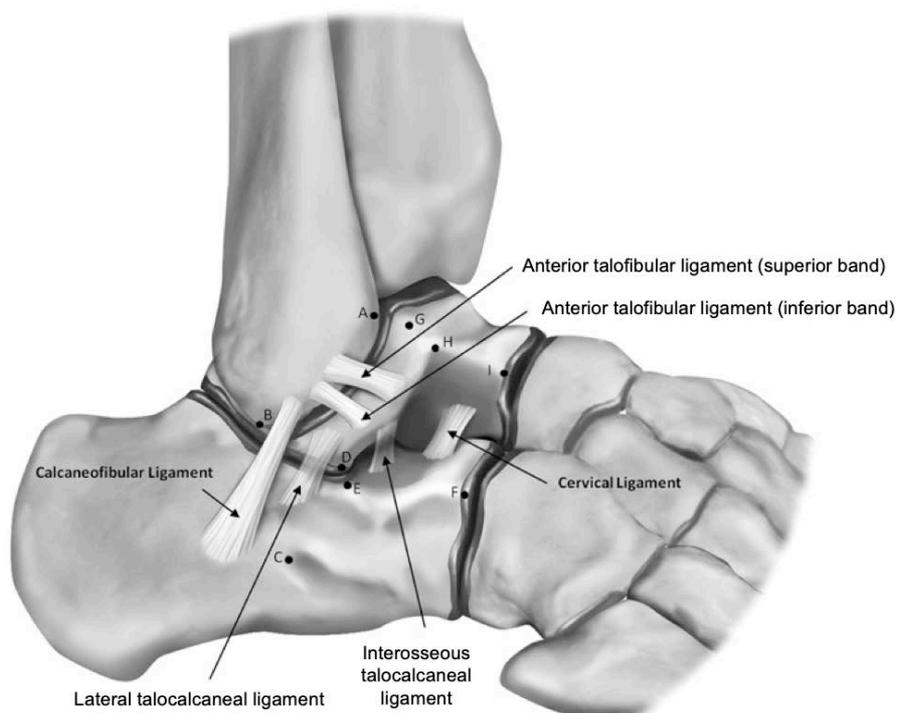
Figure 2.5. *Lateral ankle ligaments (lateral view) (Clanton et al., 2014).*

2.2. Lateral Ankle Sprains

Ankle sprains are one of the most frequently occurring musculoskeletal injuries within the physically active. Research suggests that between 3 and 5% of all injuries treated within accident and emergency departments in the United Kingdom are ankle sprains, and that over half of those who sustain such injuries do not seek medical attention for

such conditions (Mckay *et al.*, 2001). Within a sporting population the prevalence of ankle sprain increases and accounts for around 22% of all sports related injuries (Fong *et al.*, 2007; Gribble *et al.*, 2016a). Ankle sprains also have the highest recurrence rate of any musculoskeletal injury (Anandacoomarasamy, 2005),

The most common mechanism of ankle sprain injury is through excessive inversion and internal rotation of the ankle (Delahunt and Remus, 2019). Primarily this leads to structural damage to the ATFL, with additional damage to the CFL occurring in around 20% of cases (Brostrom, 1966; Dubin *et al.*, 2011). Lateral ankle sprains (LAS) such as this account for more than three quarters of all ankle injuries (Fong *et al.*, 2007; Roos *et al.*, 2017). The recurrence rates of LAS are also high with up to 70% of those who sustain a single ankle sprain going on to develop residual symptoms, including instability and reduced function capacity (Wikstrom *et al.*, 2007). This continued instability contributes to the ongoing disability and sensorimotor deficits which have been shown to be associated with a decreased quality of life and reduced levels of physical activity (Gribble *et al.*, 2016b). Post-traumatic osteoarthritis (OA) cases are prevalent within individuals with a history of LAS, with the onset also occurring much earlier in their lifespan. These post-traumatic OA cases comprise the majority of ankle joint OA surgical events (Delco *et al.*, 2017). The healthcare burden for LAS and subsequent CAI is often seen as insignificant, but when analysed becomes considerable. Whilst the initial costs for treatment of an isolated LAS are low, the long term care, management and indirect costs associated with loss of physical activity and treatment for post-traumatic OA add to the financial burden of what is often considered an innocuous injury (Birrer *et al.*, 1999; Gribble *et al.*, 2016b).

Following a single LAS adverse anatomical and/or neuromuscular changes can occur, with up to 40% of LAS patients developing CAI (Doherty *et al.*, 2014). This number is surprisingly low as up to 70% of those who sustain a LAS develop symptoms associated with the classification of CAI (Wikstrom *et al.*, 2007). The reason for this is due to the current definition of CAI, which is based upon the duration of symptoms which must persist for at least 1-year following the initial LAS. Research suggests that the majority of those who sustain a LAS do not seek medical attention or receive the recommended treatment and rehabilitation needed (Mckay *et al.*, 2001; Feger *et al.*, 2017). As such, LAS shares many of the same clinical characteristics as CAI, but individuals who sustain an acute LAS may not be classified as developing CAI due to the extensive duration that symptoms must persist. Clinicians, therapists and those involved in the treatment and rehabilitation of musculoskeletal injuries should be made fully aware of the shared characteristics of these two pathologies. Indeed, for the entire first year following a LAS, it is prudent to think of these individuals as having identifiable and treatable impairments of CAI, even though the inclusion criteria for CAI may not have been met from a research perspective.

2.3. Chronic Ankle Instability

The two most common mechanical changes associated with CAI are hypermobility and hypomobility. Hypermobility is a common mechanical change associated with LAS and CAI. This laxity results from a tear or lengthening of the ligamentous structures (ATFL and CFL) and inadequate healing of these injured tissues (Hertel, 2002). There is subsequently an increase in the accessory motion available at the joint, and an increase in the joints neutral zone. The neutral zone is the area of a joint where accessory motion is possible without ligamentous tensioning (Panjabi, 1992). The

increase in the accessory motion places further strain on the injured ligaments, which may also lead to the axis of rotation of the talocrural joint shifting in the coronal plane (Hubbard and Hertel, 2006). It is this change in the arthrokinematics of the talocrural joint which leads to the associated hypomobility. The most common physiological deficit is a reduction in DF-ROM (Denegar and Miller, 2002) which may cause changes in gait patterns and landing biomechanics, which can dispose individuals to additional pathologies such as medial tibial traction periostitis, metatarsalgia, Achilles tendinopathy, plantar fasciopathy and strain of the gastrocnemius (Young *et al.*, 2013). When ligaments become injured the mechanoreceptors may also become damaged, leading to an alteration in the proprioceptive input further disrupting the axis of rotation (Hertel, 2002). This may force the individual to compensate in order to maintain function as proprioceptive input from other tissues is altered due to abnormal stresses being placed upon them (Konradsen and Magnusson, 2000).

2.4. Mechanical Impairments Associated with Chronic Ankle Instability

The integrity and subsequent laxity of the ankle ligaments following LAS has been identified as a clear symptom of this injury. The ATFL is the weakest of the three lateral ligaments and is the first to become injured during a LAS followed by the CFL (Dubin *et al.*, 2011). Arthroscopic evaluation of the ATFL and CFL in those with CAI has identified the presence of structural changes, in terms of elongation or separation, in 86% and 64% of cases respectively (Hintermann, Boss and Schäfer, 2002). The ligamentous laxity associated with these findings can decrease the stability of the ankle joint. This has further implications for the ankle and can result in alterations in the arthrokinematics of the joint, as well as leading to post-traumatic OA (Valderrabano *et al.*, 2006).

The presence of pathologic laxity is well known within the research following LAS and in those with CAI. Damage to the ATFL results in an increase in laxity in the anterior direction or sagittal plane, and has been identified using manual stress tests (Hertel *et al.*, 1999; Croy *et al.*, 2013) and through diagnostic imaging (Lee *et al.*, 2014; Cho *et al.*, 2016). Similar increases in laxity in the frontal plane have been observed following damage to the CFL through analogous imaging (Sisson *et al.*, 2011; Seebauer *et al.*, 2013) and clinical tests (Lentell *et al.*, 1995; Hertel *et al.*, 1999).

Hypomobility of the talocrural joint can be physiologic or arthrokinematic in nature, and stem from intra or extra-articular mechanisms. Intra-articular sources of hypomobility usually alter the arthrokinematics of the joint producing restrictions of the accessory movements of glide and roll between joint surfaces. The most common physiological deficit is a decrease in DF-ROM (Denegar and Miller, 2002). Deficits within this physiological movement are often related to an anterior talar displacement and restricted talar glide (Hubbard and Hertel, 2006). This is a consequence of the damage to the ATFL associated with an inversion injury. As the ATFL inserts from the anterior margin of the fibular malleolus to the neck of the talus its main function is to restrict anterior subluxation of the talus, particularly during plantarflexion and inversion. Following injury, the ability of this ligament to restrict this motion is limited, leading to an anterior subluxed or malpositioned talus. This anterior positional fault theory has been identified using unstressed radiographic imaging (Wikstrom and Hubbard, 2010). Although anterior movement and talar tilt is no longer restrained by the ATFL or CFL, the anterior subluxed position of the talus results in restrictions in the posterior non-contractile tissue and decreases the posterior talar glide (Denegar, Hertel and Fonseca, 2002). During normal DF movements the convex talus should roll and glide

posteriorly and externally rotate in relation to the concave mortise (Vicenzino *et al.*, 2006a). The restrictions observed in posterior talar glide directly relate to the reductions in DF-ROM associated with LAS and CAI (Hoch *et al.*, 2014), with research showing that there is a significant relationship between posterior talar glide and DF-ROM (Cosby and Hertel, 2011).

Restrictions in ankle DF-ROM can lead to limitations in gait and other functional activities. Normal walking, descending stairs and kneeling requires at least 10^0 of dorsiflexion (Collins, Teys and Vicenzino, 2004), with between 20 and 30^0 needed during running (Chizewski and Chiu, 2012). It has been shown that individuals with DF deficits walk more slowly and take smaller steps, whilst contralateral step length and single support time is also influenced (Green, Refshauge and Crosbie, 1999). Alterations in landing biomechanics have also been observed which predisposes the individual to injury (Mason-Mackay, Whatman and Reid, 2017). In addition, limited DF has also been shown to increase the risk of future ankle sprains in both healthy and symptomatic populations (Willems *et al.*, 2002; De Noronha *et al.*, 2008).

Significant differences in DF-ROM within the CAI demographic have been quantified within the research. In a study by Hoch et al (2012), those with CAI demonstrated significantly reduced DF-ROM during the WBLT when compared to healthy individuals, with the mean difference between these groups being 1.74cm. In a methodologically similar study, differences between these groups during the WBLT were larger at 3.2cm (Plante and Wikstrom, 2013). Whilst the differences between those with CAI and healthy individuals does not appear to be large, research suggests that about 3.6^0 of DF-ROM occurs for every 1cm in distance away from the wall during

the WBLT (Bennell *et al.*, 1998). Consequently, for these two studies, this equates to an approximate difference of 6.3^0 and 11.5^0 for the Hoch et al (2012) and Plante and Wikstrom (2013) studies respectively. Individuals with CAI have also been seen to have significantly less DF-ROM (-4.83 ± 0.55^0) compared to healthy individuals during jogging (Drewes *et al.*, 2009) and those with less DF-ROM demonstrate poorer movement quality during the Lateral Step Down Test (Grindstaff, Dolan and Morton, 2017). Further research has also identified that those with CAI and associated reductions in DF-ROM demonstrate decreased variability at the hip and knee during single leg jump landings (Brown, Bowser and Simpson, 2012). This suggests an inability to effectively utilise proximal joints to perform appropriate landing strategies and may influence episodes of instability and increase the risk of subsequent injuries (Mason-Mackay, Whatman and Reid, 2017).

2.4.1. Measurement of Mechanical Impairments

The current methods used to measure ankle DF-ROM can be classified into three categories of either goniometry, weight-bearing, or instrumented. Although instrumented methods show high levels of accuracy, their use within a clinical setting can be questioned. This is due to the increased financial cost, complicated use, and often difficult transportation of these sophisticated measurement approaches (Wilken *et al.*, 2011). In addition, few of these ROM devices have demonstrated reliability or validity (Bennell *et al.*, 1998). The use of goniometry measurement and the weight-bearing lunge test (WBLT) are both commonly accepted methods for the assessment of ankle DF-ROM within clinical settings. This is due to their ease of application and need for only limited equipment. The WBLT has been shown to have excellent inter-clinician reliability (ICC = 0.80-0.99) and intra-clinician reliability (ICC = 0.65-0.99)

(Powden, Hoch and Hoch, 2015a), whilst goniometer measurement that follows the procedure proposed by Jonson and Gross (1997), has also shown high reliability through a high intra-class reliability coefficient of 0.98 (Venturini *et al.*, 2007). Although these methods of assessing DF-ROM are commonly accepted within the literature, there are a number of criticisms regarding their reliability as measurement tools. While the WBLT has been shown to be a reliable method of assessing dorsiflexion (Powden, Hoch and Hoch, 2015a) it is often criticised for its limited applicability in the early phases of healing or when clinical conditions restrict weight bearing. However, for the later stages of rehabilitation, or within healthy individuals, the weight bearing nature of this method makes it a more functional test. Although goniometry has been extensively utilised in the clinical measurement of DF-ROM, this method can also be critiqued. The primary objection to goniometry measurement is that its reliability can be questioned and results are often tester dependent (Wilken *et al.*, 2011). Even when a rigid methodology is applied there are a number of variables that cannot be controlled. If the foot is moved into a pronated position during dorsiflexion it opens up the midtarsal joint (MTJ) and increases the range of motion available (Tiberio, Bohannon and Zito, 1989). In addition, the amount of dorsiflexion available as the foot pronates/supinates is affected by the rotation of the tibia. If the tibia is allowed to internally rotate during dorsiflexion the foot becomes pronated, with a subsequent increase in the range of motion, whilst a decrease is observed if the foot becomes supinated through an externally rotated tibia (Dawe and Davis, 2011). However, research by Krause *et al.* (2011) identified that both intra-clinician and inter-clinician reliability coefficients (ICC) were excellent (>0.75). Intra-clinician reliability has also been reported at 0.83 (Youdas, Bogard and Suman, 1993) and 0.74 (Jonson and Gross, 1997). Inter-clinician reliability for dorsiflexion goniometry has also been further

reported by Jonson and Gross (1997) at 0.65, which is somewhat higher than the values reported by Elveru et al (1998) (0.50) and Youdas, Bogard and Suman (1993) (0.28). However, this difference may be due to some studies allowing maximal active dorsiflexion with additional manipulation of the foot by the clinician. Moreover, the intra-clinician reliability measures are far more applicable to standard clinical practice, where a single clinician is responsible for the treatment, rehabilitation and monitoring of the client, and shows that even with the possibility of foot pronation and supination occurring, the goniometer can still produce reliable measurements. It has been also been reported that knee position has a significant effect upon DF-ROM, with the knee extended position increasing the passive tension in gastrocnemius and the general stiffness of the ankle via its effects on the series elastic components of the muscle-tendon unit (Kovaleski et al., 2008; Krause et al., 2011). The position in which maximum active dorsiflexion is tested is therefore important, with greater results evident when the knee is flexed (Krause *et al.*, 2011). As such, a methodology standardisation is an important source of error control within studies that utilise this assessment method, especially when the measurements are conducted by a single clinical practitioner.

The posterior talar glide test is a clinical measurement that assesses the posterior limitations of the talus. This technique has been described in the literature and allows a clinician to evaluate the arthrokinematic motion of the talocrural joint in order to identify any pathological issues (Denegar, Hertel and Fonseca, 2002). The accepted method involves the clinician passively gliding the talus of the patient in a posterior direction in an open kinetic chain position. This results in passive dorsiflexion and passive knee flexion. As the two movements are proportional to one another, the angle

of passive knee flexion is used to estimate the amount of posterior talar glide which is occurring (Cosby and Hertel, 2011). The posterior talar glide test is a reliable clinical assessment tool but may be criticised due to its subjectivity in terms of the clinician's assessment of the capsular end feel. A more objective method utilised within the research is the instrumented ankle arthrometer, which has been used to measure posterior talar displacement and stiffness within individuals with varying ankle pathologies. Whilst this has been proven to be a highly reliable method (Intra-clinician reliability = 0.97, inter-clinician reliability = 0.91) (Kovaleski *et al.*, 2002), instrumented methods such as this are costly, complicated to use, and often difficult to transport, meaning that they are beyond the reach of the majority of clinicians (Wilken *et al.*, 2011). Although the posterior talar glide test can be seen as a more subjective clinical measure, it does not suffer from these limitations, and has been shown to provide a reliable estimate of posterior talar glide (ICC = 0.88-0.99) (Denegar, Hertel and Fonseca, 2002; Vicenzino *et al.*, 2006a).

The use of repeated measurements to gain an average value for statistical analysis is a regular occurrence within DF-ROM testing (de Souza *et al.*, 2008; Hoch and Mckeon, 2010; Yeo and Wright, 2011). However, the use of repeated measures can lead to a cumulative effect that alters range of motion. Within the active dorsiflexion measurements the concepts of autogenic and reciprocal inhibition can become evident if movements are repeated. The shortening contraction of the dorsiflexors (tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus tertius) leads to reduced activation levels within the plantarflexors (gastrocnemius, soleus, flexor hallucis longus, flexor digitorum longus, tibialis posterior). This occurs through the descending commands that provide excitatory input to Ia-inhibitory interneurons

that synapse onto the motorneurons of the plantarflexors resulting in elongation (Brodal, 2010). Repeating the movements which cause this reciprocal inhibition can therefore lead to increased range of motion measures for subsequent tests. The process of autogenic inhibition becomes evident if the concept of proprioceptive neuromuscular facilitation (PNF) is referred to. Following the DF-ROM movement there is a shortening contraction of the plantarflexors to put the foot back into its neutral position. If dorsiflexion is then measured again it may be expected that an increase in range of motion is elicited through the increased inhibitory input arising from Golgi tendon organs (GTOs) (Moore, 2007). Although a maximal contraction of the plantarflexors is often prescribed for this response to occur, research shows that GTOs are also sensitive to very low forces and that even open-chain resistance-free movements may be sufficient to elicit this response (Sharman, Cresswell and Riek, 2006). During the WBLT the gastrocnemius-soleus complex is progressively stretched until the maximal range of motion is achieved. Research has shown that even brief bouts of stretching such as this can result in a decreased resistance to stretch at the same range of motion (Ryan *et al.*, 2008). This decreased resistance would result in an increase in range of motion for subsequent tests and reduce the reliability of the data being obtained.

2.5. Functional Impairments Associated with Chronic Ankle Instability

The ability of the foot to detect motion and respond with postural adjustments is considered to be a crucial factor in the prevention of ankle injuries (Willems *et al.*, 2002). Konradsen & Voigt (2002) suggest that during the terminal swing phase of the gait cycle (Figure 2.6) a deficit in ankle joint proprioception results in the lateral border of the foot colliding with the support surface resulting in a forced inversion injury

(Konradsen and Voigt, 2002). This has been affirmed by Delahunt, Monaghan and Caulfield (2006) who identified that during the terminal swing phase, subjects with proprioceptive deficits have decreased foot-floor clearance when treadmill walking when compared to those with no deficit.

Double Support I		Single Support		Double Support II			
Initial Contact	Loading Response	Mid Stance	Terminal Stance	Pre-Swing	Initial Swing	Mid Swing	Terminal Swing
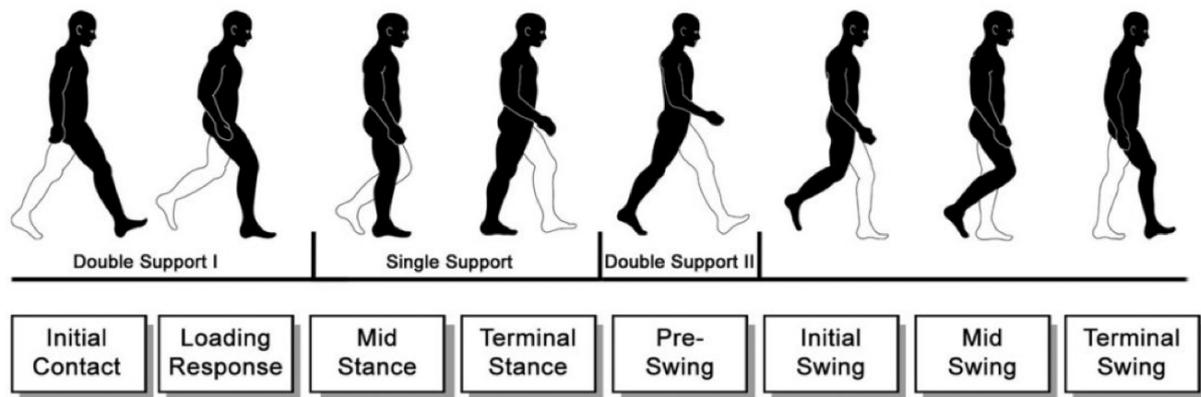
Figure 2.6. *The Gait Cycle (Stöckel et al., 2015).*

It was widely believed that damage to the lateral ligament complex produces deafferentation resulting in repeated episodes of LAS (Freeman, 1965). However, this has now been refuted, as joint position sense (JPS) has been shown to be unaffected by ankle joint anaesthesia (Konradsen, Ravn and Sorensen, 1993). It has been concluded that muscle and tendon mechanoreceptors subserve active proprioceptive function. The underlying mechanism of proprioception and neuromuscular control indicates that muscle afferents play the most important proprioceptive role (Refshauge and Fitzpatrick, 1995).

In addition, musculotendinous mechanoreceptors may also become altered following LAS and the subsequent hypomobility. The changes to the mobility of the talus stresses the joint capsule, which is relayed to the γ-motor neurons of the muscles and tendons of the joint. The γ-motor neurons may facilitate the development of greater

contraction of the stabilising muscles by influencing the activity threshold of the muscle spindles (Wilkerson and Nitz, 1994). The changes that then occur in muscle/tendon length and stiffness can alter the signals that are sent to the CNS by incorrectly stimulating the muscle spindles and Golgi tendon organ (GTO). The CNS will then send signals to the γ-motor neurons to adjust the firing patterns of the muscle, which may include early recruitment of proximal muscles such as the gluteal muscles to provide stability (Beckman and Buchanan, 1995; Gribble *et al.*, 2004; Kernozek *et al.*, 2008).

Many studies have identified neuromuscular deficits whilst investigating the response times of peroneal musculature to unexpected inversion perturbation in individuals with CAI. Reflex activity of the peroneus longus is unlikely to provide adequate protection of the joint during dynamic activities (Delahunt, 2007a). Indeed, during jump landings, no decrease in post-landing reactive muscle activity of the peroneal muscles has been identified (Caulfield *et al.*, 2004a; Delahunt, Monaghan and Caulfield, 2006a). However, a decrease in the muscle activity prior to ground contact has been identified. As such, a deficit in feed-forward neuromuscular control for individuals with CAI has been determined. Furthermore, a significant increase in coronal plane movement at the ankle joint prior to ground contact has also been found (Delahunt, Monaghan and Caulfield, 2006a). This coincides with an increase in ankle inversion due to a decrease in pre-contact peroneus longus muscle activity. This combination of neuromuscular deficits within the ankle could lead to re-injury, as the ankle joint may be forced into excessive inversion following unexpected ground contact and subsequent lateral ligament sprain (Holmes and Delahunt, 2009).

Postural control deficits have also been clearly identified in individuals with a history of ankle sprain (McKeon and Hertel, 2008; Arnold *et al.*, 2009). Several researchers have demonstrated deficits in static and dynamic postural control in those with CAI (McKeon and Hertel, 2008; Arnold *et al.*, 2009; Wikstrom *et al.*, 2009). These deficits are postulated to be secondary to a combination of impaired neuromuscular control and proprioception (Hertel, 2002). During single leg stance the controlled pronation and supination of the foot to maintain the body's centre of gravity over the base of support is termed 'ankle strategy' (Tropp, 2002). Those with CAI have been shown to lack the ability to utilise an efficient ankle strategy to maintain single leg stance. To achieve stability these individuals adopt a less efficient hip strategy, which creates large shear forces with the ground. This has the potential to increase ankle inversion and can lead to the ankle giving way. These postural alterations are thought to be a product of changes in central neural control in the presence of joint dysfunction (Hertel, 2002).

The deficits in postural control associated with CAI have been identified extensively within the research using a number of testing procedures. Deficits in static postural control have been shown using single leg balance tests (Zhang *et al.*, 2020). Dynamic postural control has been assessed by the use of time-to-stabilisation (TTS) (Ross, Guskiewicz and Yu, 2005; Brown and Mynark, 2007), centre of pressure (Hale, Hertel and Olmsted-Kramer, 2007), dynamic stability indices (Shiravi *et al.*, 2017) electromyography amplitude (Donovan *et al.*, 2016), the dynamic postural stability index (Wikstrom *et al.*, 2007), the Star Excursion Balance Test (SEBT) (Olmsted *et al.*, 2002; Gribble *et al.*, 2004; Hoch *et al.*, 2012), and various single-limb hop tests (Ross, Langford and Whelan, 2002; Reid *et al.*, 2007; Caffrey *et al.*, 2009; Wikstrom

et al., 2009; Munro and Herrington, 2011; Haitz *et al.*, 2014). Each of these tests have identified significant deficits in postural control in those with CAI.

2.5.1. Measurement of Functional Impairments

The functional impairments associated with CAI have often been measured with the use of either static or dynamic balance tests. However, within a physically active population, dynamic tests may be more relevant due to the similarity to athletic activity and the greater challenge that these tests provide (Williams *et al.*, 2016). As there is a poor association between static and dynamic tests (Sell, 2012), it makes sense to prioritise those which have more functional relevance to performance. Indeed, static measures of balance and stability may only be applicable in the early stages of rehabilitation when patients have just begun to fully weight bear.

Various methods of assessing dynamic balance have been proposed within the research, but generally fall into two main methods, with both aiming to assess the individual's ability to maintain their stability. The first method uses functional tasks, such as hoping or single-leg jump landings to alter the individual's base of support, whilst the second method maintains the base of support and has the individual move within that base of support (Wikstrom *et al.*, 2005). Previous research articles have used a wide array of outcomes measures to evaluate individual's dynamic balance, with many requiring a laboratory setting in order to accurately measure centre of pressure (Hale, Hertel and Olmsted-Kramer, 2007), time to stabilisation (Ross and Guskiewicz, 2006), dynamic stability indices (Shiravi *et al.*, 2017) electromyography amplitude (Donovan *et al.*, 2016) or the dynamic postural stability index (Wikstrom *et al.*, 2007). Whilst each of these outcome measures use functional tasks that replicate

athletic movements and are relevant to the mechanism and pathology of CAI, their use within clinical setting is limited. This is again related to the costly nature of these assessment systems and the complex nature and training requirements that are a fundamental component of obtaining reliable measures (Wilken *et al.*, 2011).

The use of non-instrumented measures of dynamic balance that mimic functional tasks and are accessible to clinicians is essential. These measures allow appropriate objective markers to be recorded and for the progression of patients with CAI to be followed by the treating specialist. A number of such tests have been developed and researched.

Functional performance tests such as unilateral hopping have been used within the research to establish deficits in neuromuscular coordination and joint stability. These tests have included hop tests for time (figure-eight hop, side-to-side hop, six-meter crossover and six-meter hop, and square-hop) and tests for distance (triple-crossover hop, triple hop, and single-leg hop) (Figure 2.7). These hop tests have demonstrated acceptable reliability in a number of studies. The between-session reliability of the single hop (ICC = 0.80-0.92), triple hop (ICC = 0.80-0.97), and triple crossover hop (ICC = 0.84-0.93) for distance have all been shown to demonstrate acceptable reliability (Ross, Langford and Whelan, 2002; Reid *et al.*, 2007; Munro and Herrington, 2011). Whilst the hop tests for time are usually observed to have similarly satisfactory levels of reliability, there is a much greater range of reliability scores reported (figure-eight hop ICC = 0.21-0.95; side-to-side hop ICC = 0.28-0.94; six-meter hop ICC = 0.60-0.92; square hop ICC = 0.83-0.90) (Caffrey *et al.*, 2009; Wikstrom *et al.*, 2009; Haitz *et al.*, 2014). As these are functional performance tests there is also the

possibility of the occurrence of a learning effect, which Munro and Herrington (2011) identified for all tests used within their study, finding that at least three trials were needed before the hop test scores stabilised. Learning effects which have not been accounted for may therefore confound the reliability values reported. Furthermore, the test-retest intervals used within many of these studies do not replicate those that would be adopted within the clinical setting. A time frame of one week between testing sessions would more closely replicate the time frames that are commonly used and would provide more real-world application of the reliability scores for the functional performance tests (Munro and Herrington, 2011).

Performance deficits in those with CAI have been established in the figure-eight hop and side hop tests (Docherty *et al.*, 2005; Sharma, Sharma and Sandhu, 2011; Linens *et al.*, 2014) and in six-meter-crossover and square hop tests (Caffrey *et al.*, 2009). However, no differences between those with CAI and uninjured controls have also been found following performance of the figure-eight hop (Wikstrom *et al.*, 2009), side-to-side hop (Wikstrom *et al.*, 2009), triple-crossover hop (Munn *et al.*, 2002; Wikstrom *et al.*, 2009), or single-leg hop (Buchanan, Docherty and Schrader, 2008; Wikstrom *et al.*, 2009; Sharma, Sharma and Sandhu, 2011) tests. These conflicting results suggest that hop tests may not be sensitive enough to detect functional performance improvements in those with CAI or be appropriate in all cases as a diagnostic tool to identify functional impairments. Indeed, there has been reported a large degree of heterogeneity and inconsistent reporting within research studies that have utilised these measures (Rosen, Needle and Ko, 2019), which potentially limits the clinical implementation of these functional performance tests.
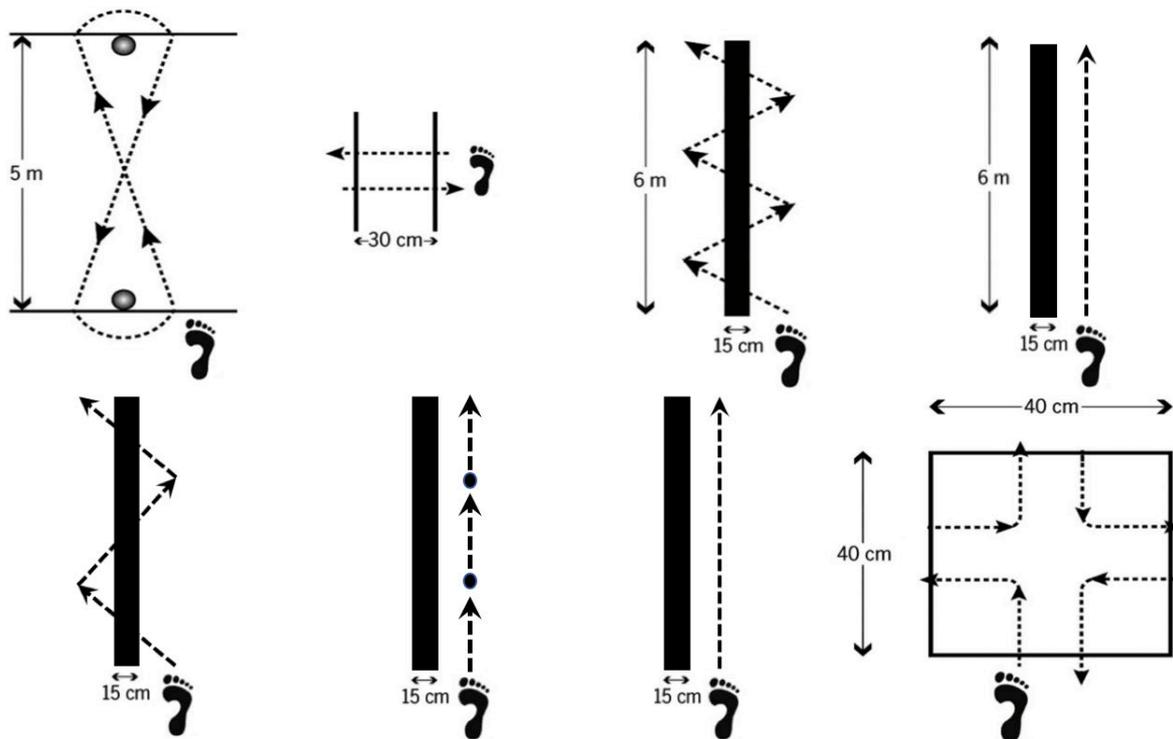
Figure 2.7. *Functional performance hop tests. Clockwise from top left; figure-eight hop for time, side-to-side hop for time, six-meter crossover hop for time, six-meter hop for time, square-hop test for time, single-leg hop for distance, triple hop for distance, triple-crossover hop for distance.*

The most researched and reliable of the clinical measures used to assess those with CAI is the Star Excursion Balance Test (SEBT) (Figure 2.8). The test involves unilateral stance while attempting maximal reach with the contralateral leg in eight different directions and has shown to be sensitive in detecting functional deficits related to CAI (Olmsted *et al.*, 2002; Gribble, Hertel and Plisky, 2012). The maximal reach distance requires a combination of balance, strength, flexibility, and motion of the contralateral stance limb, with greater distances identifying better functional performance. Reach distances are usually normalized to the subject's limb length, which allows direct comparison to published normative test scores. The SEBT has been shown to have excellent inter-clinician reliability (ICC = 0.88-0.91) (Gribble *et al.*, 2013) and intra-clinician-reliability (ICC = 0.78-0.96) (Hertel, Miller and Denegar, 2000), whilst there have also been seen to be excellent between session reliability

scores (ICC = 0.84-0.93) (Plisky *et al.*, 2006; Munro and Herrington, 2010). However, research has furthered suggested that the most significant reach directions of the SEBT are the anterior, posterolateral and posteromedial directions which are predictive of lower extremity injury (Plisky *et al.*, 2006). As such, the more time consuming eight-reach direction SEBT is often modified to use only these three reach directions. In their 2019 systematic review Powden, Dodds and Gabriel (2019), identified median ICC values for inter-clinician reliability of 0.88, 0.88 and 0.87 for the anterior, posterolateral and posteromedial direction respectively. For the same reach directions, intra-clinician median ICC values were 0.88, 0.90 and 0.88. The SEBT has also been shown to be sensitive in detecting reach deficits both within and between individuals with CAI (Olmsted *et al.*, 2002). There is therefore Grade A evidence to support the use of the SEBT in a clinical setting in order to assess dynamic balance. This method also provides a consistent and repeatable means to obtain results between one or more clinicians (Powden, Dodds and Gabriel, 2019).
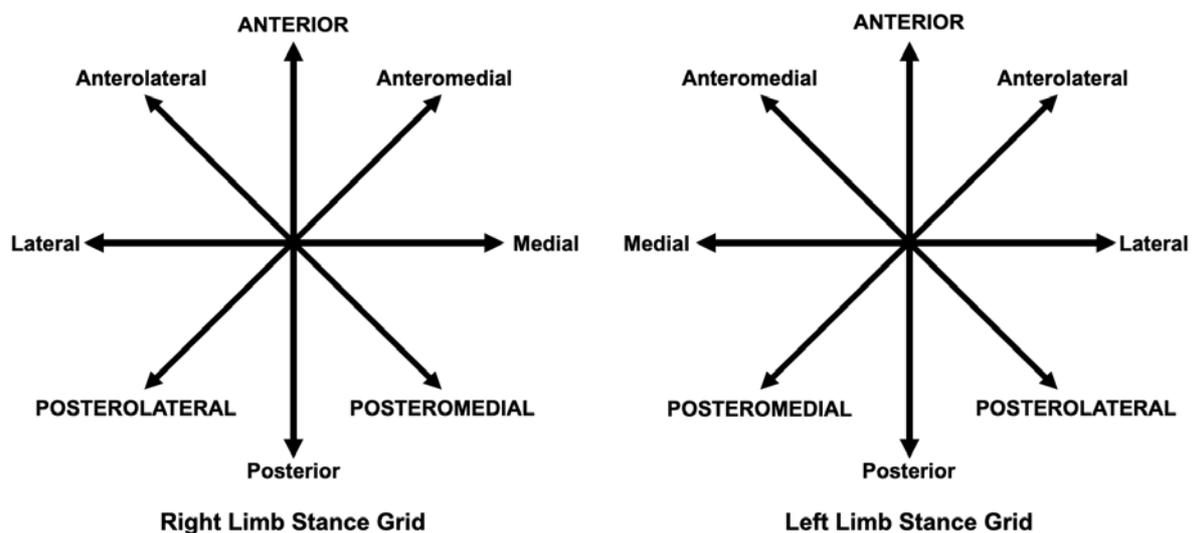
Figure 2.8. *Reach directions for the Star Excursion Balance Test (SEBT).*

2.6. Self-Reported Function

Ankle pathologies are conventionally diagnosed using clinical skills, imaging techniques and self-reported subjective questionnaires (Simon, Donahue and Docherty, 2014). Within the diagnosis and assessment of CAI self-reported function is often employed due to the pathology's specific symptom traits, with several questionnaires being designed to aid both clinicians and researchers. Patient reported outcome measures (PROM's) such as these seek to ascertain a patient's view of their symptoms, functional status, and their health-related quality of life (HRQL). By comparing the patient's self-reported health at different times during their rehabilitation, the outcome of the treatment received can be determined (Black, 2013). PROM's also have the benefit that they can be completed by the patient themselves which may reduce the burden on clinical resources. In addition, PROM's are able to obtain information regarding the long-term subjective satisfaction, which is an aspect often missing from the results of clinical evaluation (Greve *et al.*, 2018).

The assessment CAI has culminated in the production of a number of PROM's including the Ankle Instability Instrument (AII), the Cumberland Ankle Instability Tool (CAIT), the Identification of Functional Ankle Instability (IdFAI), the Foot Function Index (FFI), the Foot and Ankle Outcome Score (FAOS), the Foot and Ankle Disability Index (FADI), the Foot and Ankle Outcome Score (FAOS), and the Foot and Ankle Ability Measure (FAAM), with its Activities of Daily Living (ADL) and Sport (S) subscales. A number of these questionnaires have been endorsed by the International Ankle Consortium as a validated means to identify patients who fall within the heterogenous condition of CAI (Gribble *et al.*, 2014). Specifically, the International

Ankle Consortium recommend that CAI be confirmed using the AII, CAIT or IdFAI, and that the FAOS and FAAM be used to describe the level of disability.

The AII was developed in response to the variation in defining FAI as an objective means of assessing the functional deficits associated with CAI. The 12 item questionnaire provides an adequate starting point for identifying those with CAI and has been shown to be highly reliable for both the original English version (ICC = 0.95) (Docherty *et al.*, 2006) and when translated into other languages (ICC = 0.98) (Locquet *et al.*, 2020). Whilst the AII has been seen to be reliable, it only provides a limited evaluation of the severity of the patient's instability. As such, the CAIT is often seen as a more specific measure of CAI. The CAIT uses a numeric value to both classify and indicate the extent of the patient's pathology, where a score of less than 24 out of a possible 30 indicates the presence of the condition, and lower scores identify an increase in severity. As the CAIT is completed for the left and right ankles, it also provides a means by which bilateral comparisons can be made. The 12 item CAIT has been shown to be highly reliable (ICC = 0.96) (Hiller *et al.*, 2006), whilst the minimally clinically important differences (MCID), which are used to identify patient improvements over time, is ≥3 points (Wright, Linens and Cain, 2017). The IdFAI was developed based on these previous two instruments (AII and CAIT) in order to also detect whether patients meet a minimum criterion for inclusion in a CAI population. The IdFAI attempted to consolidate and combine the elements of each of the preceding instruments. However, whilst it has also been shown to be highly reliable (ICC = 0.96) (Gurav, Ganu and Panhale, 2014) there are currently no MCID values available, limiting the ability of the instrument to be used to detect meaningful changes following treatment interventions.

The FAOS was developed to assess patient's opinion about a variety of foot and ankle problems. These have been validated for conditions including hallux valgus, hallux rigidus, flatfoot, ankle instability and ankle arthritis (Hogan *et al.*, 2016). The questionnaire consists of 42 items as effect indicators for 5 subscale areas that assess a patient's perception of pain, other symptoms, activities of daily living, sport and recreational activities, and foot and ankle related quality of life, which are scored separately using a Likert response format (Roos, Brandsson and Karlsson, 2001; Martin and Irrgang, 2007). Although the reliability of the FAOS is acceptable, the ICC for the five subscales varies (ICC = 0.70-0.92) (Roos, Brandsson and Karlsson, 2001). Consequently, whilst the FAOS shows evidence to support its use for CAI, it has been more frequently used within the research to assess patients with other foot and ankle related pathologic conditions, with other PROM's such as the FAAM being used more extensively within the CAI research literature. The FAAM comprises of a 21 item Activities of Daily Living (ADL) and 8 item Sports (S) subscales, with each item being scored on a 5-point Likert scale. The item score totals are then transformed to percentage scores, with higher scores indicating advanced levels of function. The FAAM therefore possesses many of the clinometric qualities recommended for an outcome instrument (Carcia, Martin and Drouin, 2008). Whilst there is evidence to support the use of FAAM for a variety of foot and ankle disorders, it is commonly used for those with CAI. Research has shown that the FAAM and its subscales are a highly reliable patient orientated assessment tool (ADL ICC = 0.89; Sport ICC = 0.87), which are also sensitive to changes over time ($p \leq 0.05$) (Eechaute *et al.*, 2007). In the study by Carcia et al (2008), a relationship between calculated FAAM scores and the global rating of function for both the ADL ($r = 0.64$) and Sports ($r = 0.79$) subscales has also been found. Consequently, the FAAM has been shown to reflect changes that are

meaningful to the patient following a clinical intervention, with minimal clinically important difference (MCID) values of 8 and 9 points respectively for the ADL and Sport subscales (Eechaute *et al.*, 2007).

2.7. Talocrural Joint Mobilisation

A common treatment strategy used by clinicians to restore the mechanical and functional deficits associated with CAI are a set of manual therapy techniques known as joint mobilisations. The techniques aim to restore mobility and function through the restoration of the arthrokinematic restrictions that occur between joint surfaces (Green *et al.*, 2001). This is achieved by increasing the extensibility and flexibility of joint capsular and ligamentous tissues, promoting the alignment and tracking of joint surfaces, increasing sensory input and stimulating articular sensory receptors (Hengeveld and Banks, 2005). There are a number of differing techniques but one of the most widely used and researched is that proposed by Geoffrey Maitland and known as the Maitland technique. This technique uses a grading system of passive, oscillatory joint mobilisation in order to achieve the therapeutic effects. The application of this technique for the rehabilitation of LAS and CAI has shown it to be effective in restoring osteokinematic and arthrokinematic range of motion, and stimulating sensory receptors in order to enhance neuromuscular function, proprioception, balance and stability during functional tasks (Loudon, Reiman and Sylvain, 2014).

2.7.1. Range of Motion

The loss of DF-ROM is commonplace in those with CAI (Hoch, Staton, *et al.*, 2012). It has been postulated that this is due to anterior talar displacement and associated restrictions in posterior talar glide following damage to the ligamentous restraint and

joint capsule (Denegar, Hertel and Fonseca, 2002). In order to address the talar positional fault and restore the reduced range of motion, the Maitland technique suggests providing an anterior to posterior (AP) mobilisation of the talus in order to increase the extensibility of the posterior non-contractile tissue. Specifically, graded mobilisations should be used that focus on the end of the available arthrokinematic range and are intended to elongate connective tissue that may be abnormally restraining motion (Lundon, 2007). Connective tissue provides resistance to the forces acting on joints, and act in conjunction with the fibrocartilaginous structures and articular shape and orientation of the joint in order to establish the osteokinematic and arthrokinematic range of motion (Threlkeld, 1992). The higher grades of Maitland mobilisations (III and IV) affect the length of the connective tissue through a process of plastic deformation. This creates an internal microfailure mechanism at the cellular level that results in an increase in the resting length of the connective tissue (Ulrich *et al.*, 2010). This corresponds to a breaking of the cross-links of the periarticular tissue, and a disconnection of some of the individual collagen fibres and bundles due to the progressive loading and ultimate tissue deformation. This correlates to the linear to end-linear phase of the structures stress-strain curve (Schleip, 2003). In addition, the rapid stress-relaxation mechanism that is associated with oscillatory Maitland mobilisations causes tissue to more rapidly reach a ductile state than with sustained mobilisations, leading to the earlier attainment of plastic deformation (Bonutti *et al.*, 1994). The microfailure associated with plastic deformation affects the physical relationship between collagen, associated macromolecules, and the ground substance of the extracellular matrix, and is necessary to achieve permanent lengthening (Lundon, 2007). In addition, the collagen is also stretched along the lines of stress leading to collagen realignment. This process is known as Davis's law of soft

tissue remodelling, and is analogous to Wolff's law of bone remodelling (Hodgkins, Kennedy and O'Loughlin, 2008). Although this law is more often associated with muscle lengthening it implies that all soft tissue, including periarticular tissue, seeks metabolic homeostasis commensurate to the stresses being applied to it. As result of this realignment, and particularly the microfailure that has been induced, a known cycle of tissue inflammation, repair, remodelling and consolidation occurs. This subsequent cellular proliferation and matrix remodelling is mediated by the upregulation of insulin-like growth factor (IGF-I), along with cytokines and further growth factors (Olesen *et al.*, 2007). With an AP grade IV mobilisation of the talus, these adaptations result in an increase in the DF-ROM through a restoration of the accessory motion that has been limited by the restricted periarticular tissue (Collins, Teys and Vicenzino, 2004; van der Wees *et al.*, 2006). The benefits of which is a reduction in functional deficits, disability, and injury risk for both injured and healthy individuals (Davenport, Kulig and Fisher, 2010).

Treatment dose is a term used to describe the parameters of the applied mobilisation treatment, and includes the magnitude and direction of force applied, frequency, duration, and amplitude of oscillation (Petty *et al.*, 2002; Hengeveld and Banks, 2005). The clinical decision regarding the application of a suitable treatment dose is based on empirical evidence and theoretical concepts, which is made more difficult by the lack of research into the effects of different treatment doses. To date, only one research study has attempted to ascertain the effects of different treatment dose duration on ankle range of motion. Holland, Campbell and Hutt (2015) studied the effects of a 30 second, 60 second or 120 second, grade IV AP talar joint mobilisation to improve DF-ROM. Range of motion improvement was assessed following a single

application of this technique and resulted in greater improvements being elicited within their asymptomatic participants as the duration of treatment increased. For the non-weight bearing measure of DF-ROM this equated to a 14.2%, 21.6% and 32.8% improvement for the 30 second, 60 second and 120 second treatment respectively, whilst improvement in the WBLT were 5.0%, 7.6% and 10.9%. However, the authors concluded that the changes in WBLT were below the calculated minimal detectable change (MDC) scores needed to conclude that the improvements were not a consequence of measurement error. Whilst this study identified statistically significant improvements in range of motion for all treatment groups, it could be hypothesised that greater improvement would be evident if a symptomatic population were studied, as individuals who have sustained LAS often have DF-ROM below 0^0 (Soucie *et al.*, 2011). Indeed the authors did conclude that the baseline characteristics of their cohort were analogous to normative ranges of that found in healthy adults (Hoch and McKeon, 2011b).

Within published research various treatment doses have been utilised in order to study the effects of AP mobilisation of the talus on DF-ROM. Hoch and McKeon (2011) identified an increase of about 1.5-2.0^0 of DF-ROM using the WBLT in subjects with self-reported CAI following two sets of 120 seconds of grade III talar mobilisation. In a later, smaller cohort study, Hoch *et al.* (2012) again observed significant increases in performance on the WBLT of 1.4cm, which equates to approximately 5^0 when using the calculation identified by Bennell et al (1998), where about 3.6^0 of DF-ROM occurs for every 1cm distance away from the wall during the WBLT. However, within this study the treatment duration had been increased to four sets of 120 second grade III mobilisations with subjects being treated six times over a two-week period. There was

also the addition of grade II talocrural joint tractions which occurred for two sets of 120 seconds during each treatment session. Consequently, the full extent of the effect that the AP mobilisation had on DF-ROM cannot be accurately identified due to the addition of the joint traction treatment. An early randomised controlled trial by Green *et al.* (2001) investigated the effects of a mid-grade mobilisation of three sets of 60 second treatments. Although all subjects had experienced LAS less than 72 hours prior to treatment, the mobilisation produced a statistically significant improvement of 4.3% measured using the Lidcombe template following the first treatment session. In a methodologically similar study with sub-acute LAS subjects (Yeo and Wright, 2011) concluded an average increase of 0.96cm (3.5^0) on the WBLT. Additional research by Venturini *et al.* (2007) investigated the force applied and effects of two sets of 30 seconds of grade III AP mobilisation of the talus. Although the treatment provided was conducted by alternating therapists they concluded that a 2.0^0 improvement in DF-ROM using standard goniometry measurement was produced. An asymptomatic population was used within this study which may limit the potential for improvements due to the absence of any true osteokinematic or arthrokinematic restrictions.

Research suggests that even low doses of mobilisation treatment can produce significant changes in DF-ROM. Landrum *et al.* (2008) recorded a 4.4^0 increase in DF-ROM following a single 30 second application of a grade III AP talar mobilisation. However, the participants had all experienced at least 14 days of ankle immobilisation, which would mean significant reductions in arthrokinematic motion due to the observed dysfunction in articular and extra-articular tissues of diarthrodial joints (Bączkowicz *et al.*, 2020). Validation for this assertion is highlighted in the study by de Souza *et al.* (2008) who demonstrated only a 0.81^0 improvement in dorsiflexion in an

asymptomatic study group using the same treatment parameters. Whilst the improvements were statistically significant, the asymptomatic ankles used within the study again limit the clinical relevance of the findings. In addition, the importance of such a small change can be questioned as a clinically successful objective outcome of the treatment and may not be beyond that of standard measurement errors. Indeed, the standardised mean difference (SMD) and 95% confidence interval (CI) for the de Souza et al. (2008) study has been calculated to be 0.19 (95% CI = -0.37 to 0.75), which was deemed to be non-statistically significant as the 95% CI contained zero (Young *et al.*, 2013).

Whilst the acute effects of talocrural joint mobilisation have been well reported in the literature, there is a want for more studies that identify the cumulative and chronic effects of this treatment intervention. In their 2012 study, Hoch et al identified a 1.35cm (4.9^0) improvement in dorsiflexion during the weight bearing lunge test after six treatment sessions, which was maintained in the one-week follow up measures. These treatments were equally spaced over a two-week period and consisted of four applications of 120 seconds of grade III talocrural joint mobilisations. Whilst this improvement was statistically significant and beyond the calculated minimal detectable change scores, participants also received grade II joint traction treatments during each intervention session. Consequently, the improvements observed cannot be solely attributed to the anterior-to-posterior mobilisation conducted on the talus, and no conclusion can be drawn from this study regarding the interaction between these two mobilisation techniques. Following the same treatment regime, Silva *et al.* (2017) concluded that three sets of 30 seconds of talocrural joint mobilisation improved DF-ROM by 4.1^0, with a further 0.5^0 increase observed during the two-week follow up.

Whilst the DF-ROM measure was different to the previous study, utilising a non-weight bearing measurement, the comparable improvement questions both the addition of joint traction treatment, and the greater treatment duration utilised by Hoch *et al.* (2012). Indeed, studies which have used high velocity, low amplitude (HVLA) techniques in the form of caudal thrusts to produce a cavitation of the talocrural joint have concluded a failure to improve DF-ROM in subjects who have sustained LAS more than six months prior to testing (Andersen, Fryer and McLaughlin, 2003), as well in asymptomatic controls (Nield *et al.*, 1993; Fryer, Mudge and Mclaughlin, 2002).

The available literature highlights the preference for research to utilise grade III mobilisations in the treatment of talocrural joint restrictions, with a paucity of research regarding the use of grade IV interventions. Whilst the two techniques proport to have similar effects, the grade IV mobilisation works at the end of the available range and produces a greater microfailure of the connective tissue that is restricting motion, promoting greater increases in DF-ROM. It has been shown that grade IV mobilisations produce a greater mean force than grade III, as well as greater oscillatory frequency (Silvernail *et al.*, 2011). This means that the joint is experiencing greater loads that will lead to increased plastic deformation of the connective tissue, which is of particular importance when treating range of motion deficits. The success of higher-grade mobilisations is therefore dependent upon the interaction between elastic and plastic deformation, creep and hysteresis. Post mobilisation measurement of ROM is an accepted method to determine treatment success, but this does not fully assess whether the deformation is permanent or not as due to creep and hysteresis the tissue may return to a shorter length over time (Ulrich *et al.*, 2010). Cumulative and repeated measurements that allow for a wash-out period of these components

are therefore needed to fully measure whether permanent changes in ROM have occurred.

2.7.2. Sensorimotor Function

In addition to the accepted mechanical effects of joint mobilisation, this technique has also been observed to enhance sensorimotor function within individuals with CAI (Hoch *et al.*, 2012). Such an effect suggests that the mobilisation treatment has the potential to excite the sensory motor receptors located within the ligaments and joint capsule (Hengeveld and Banks, 2005). The primary mechanoreceptors located within the noncontractile tissue surrounding a joint are Ruffini endings and Pacinian corpuscles (Figure 2.9). Ruffini endings generate afferent information both at rest and during movement. During movement there is a proportional increase in the impulse discharge frequency of the Ruffini endings in relation to the stretch of the joint capsule. These mechanoreceptors are primarily located within joints involved in locomotion. Due to the slow adaptation to stimulus the Ruffini endings produce a maximal response following prolonged application of tension (Kahanov and Kato, 2007). Pacinian corpuscles respond to mechanical deformation with their activation relating to the velocity of joint motion at the beginning and end of displacement. A large number of Pacinian corpuscles are found within the ankle due to this joint requiring fine motor control. Consequently, these mechanoreceptors respond best to joint mobilisations which involve a rapid oscillation technique at the beginning and end ranges of motion (Kahanov and Kato, 2007).
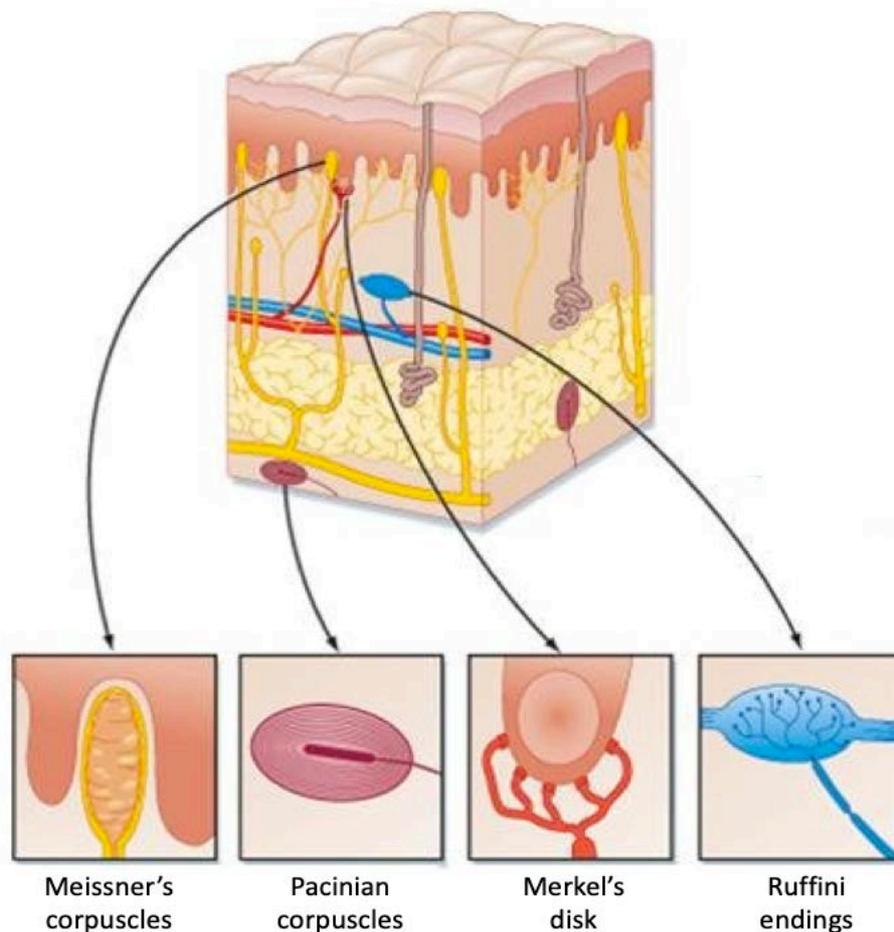
Figure 2.9. *Schematic illustration of mechanoreceptors consisting of Meissner corpuscles, Pacinian corpuscles, Merkel's disks, and Ruffini endings (Levy, Koeppen and Stanton, 2006).*

These receptors transmit afferent information via the dorsal column medial lemniscus pathway to the lower medulla where it terminates in the dorsal column nuclei. There is a topographical organisation of axons within the dorsal column nuclei, such that receptors conveying information from the lower limbs synapse in the gracile nucleus, whereas those originating from upper limbs synapse within the cuneate nucleus (Purves *et al.*, 2004).

Hoch and McKeon (2011a) investigated the effects of a single Maitland Grade III anterior-to-posterior mobilisation on measures of static and dynamic postural control.

They concluded a significant improvement in static postural control during eyes open time-to-boundary measures in the anteroposterior direction. However, no significant improvements were observed in the medial-lateral direction or the normalised reach distances of the SEBT. Similar results were also observed by Harkey *et al* (2014) following the same mobilisation treatment delivered over three 60-second bouts. They concluded that the excitability of spinal reflex and corticospinal pathways, and dynamic postural control was unaffected by the intervention. This suggests that whilst there may be immediate improvements in sensorimotor function following joint mobilisation, multiple treatment sessions may be needed in order for changes in dynamic postural control to manifest (Vallandingham, Gaven and Powden, 2019). Such an assertion is highlighted by Hoch *et al* (2012) who established that a two-week joint mobilisation that targeted the anterior-to-posterior glide of the talus produced significant improvements in the anterior, posterolateral and posteromedial reach directions of the SEBT. Whilst this study utilised an additional joint traction treatment alongside the talar glide mobilisation, it supports the supposition that joint mobilisation can enhance sensorimotor system function.

Improvements in postural control using a Mulligan mobilisation-with-movement (MWM) treatment have also shown mixed results. Cruz-Díaz *et al* (2015) identified a significant improvement in all reach directions of the SEBT following two treatment sessions a week for three weeks. However, in a much smaller cohort study where participants with CAI received three sessions of MWM over a one-week period showed no improvements in dynamic balance (Gilbreath *et al.*, 2014). Whilst MWM treatments differ from Maitland mobilisations in terms of their application and theoretical underpinnings, the joint movement produced by both techniques have the potential to

stimulate the sensory motor receptors (Ruffini endings and Pacinian corpuscles) located within the ligaments and joint capsule and enhance sensorimotor function. However, the oscillatory nature of a Maitland mobilisation in comparison to the sustained glide adopted in a MWM may provide a greater stimulation to the joint mechanoreceptors, and in particular the Pacinian corpuscles which respond best to rapid oscillation at the beginning and end ranges of motion (Kahanov and Kato, 2007).

Improvements in dynamic balance following joint mobilisation intervention may increase an individual's balance confidence and lead to a potential reduction in injury reoccurrence. This may assist the individual to progress more safely to more advanced functional exercises within the rehabilitation process. The application of Maitland oscillatory techniques would appear to be a more effective joint mobilisation treatment method to enhance balance function due to the response of the Pacinian corpuscles to mechanical deformation. Furthermore, grade IV mobilisations have been shown to produce a greater oscillatory frequency (2.1 to 2.4 Hz) than grade III (0.9 to 1.2 Hz) (Silvernail *et al.*, 2011), which has the potential to provide a greater stimulation to the sensorimotor system as the Pacinian corpuscles respond best to rapid oscillation at the end ranges of motion (Kahanov and Kato, 2007).

2.8. Neuromuscular Rehabilitation

Neuromuscular control is the unconscious activation of dynamic restraints that occurs in preparation for and in response to joint motion and loading. The purpose of which is to maintain and restore functional joint stability (Riemann and Lephart, 2002). The deafferentation theory of functional instability identifies that delayed and diminished reflex responses in the ankle evertor muscles is produced following damage to the

ligaments and capsule of the ankle joint (Freeman, 1965). Consequently, a number of researchers have attempted to identify the impact that neuromuscular training programmes have upon the CAI pathology.

2.8.1. Proprioception and Balance Training

Balance and proprioceptive training have been seen to produce notable improvements in function (Giboin, Gruber and Kramer, 2015), and have been used widely to improve sports performance (Zech *et al.*, 2010), reduce sports injury risk (Hübscher *et al.*, 2010), and for fall prevention (Sherrington *et al.*, 2011). The incorporation of balance training for the rehabilitation of those with CAI is almost universal. Given the extent to which balance training is included within CAI rehabilitation, it is important that clinicians have a clear understanding and guidance as to effective protocols to be used to address the issue. Unfortunately, the implementation of evidence-based practice for clinicians is difficult for a number of reasons. Firstly, the methodology used within published studies differs in relation to criteria such as mode, frequency and duration of practice. Secondly, the specific interventions for rehabilitation of CAI show a large variety of exercises. It is therefore essential that clinicians are given clear clinical guidance as to some standardised protocols for the treatment of the CAI pathology.

Eils and Rosenbaum (2001) examined the effects of a six-week multi-station proprioceptive exercise programme in subjects (18 female, 12 male) with self-reported ankle instability. The thirty participants were split into exercise (n = 20) and control (n = 10) groups. They identified significant improvements in JPS, postural sway and muscle reaction times within the intervention group. The results of a one-year follow up questionnaire also indicated a reduction in ankle inversion episodes of almost 60%.

The participants also reported a feeling of improved stability and security. This suggests that enhanced postural sway and increased JPS may reduce the incidence of recurrent ankle joint injuries. It was concluded that a multi-station proprioceptive exercise programme could be recommended for prevention and rehabilitation of recurrent ankle inversion injuries. The relatively low training frequency of once per week may also advantage this programme over others as research highlight that grey and white brain matter rapidly adapt in response to balance training programmes and can show detectable structural changes in as few as two training sessions (Taubert *et al.*, 2010). Furthermore, it appears to be that the number of times that a movement is practiced, as opposed to the amount of time that has passed, that determines the level of adaptation (Huang and Shadmehr, 2007).

A more comprehensive rehabilitation program targeting ROM, strength, neuromuscular control and functional tasks has been proposed by Hale, Hertel and Olmsted-Kramer (2007). Within their study, twenty-nine individuals (19 females, 10 males) with CAI were randomly assigned to a rehabilitation (10 females, 6 males) or control (9 females, 4 males) group. The rehabilitation group followed an extensive set of home-based rehabilitation exercises performed five times a week over a four-week period. The results showed that improvements in reach distance and perceived deficits in ADLs and sport specific tasks could be identified following exercise adherence. However, the authors also identified that no significant changes occurred in centre of pressure excursion velocities (COPV) and postulated that this may be a result of the postural control tasks being only a small part of the program. This links to the assertion that it is the number of times that a movement is practiced that determines the level of adaptation (Huang and Shadmehr, 2007) and that learning is often very specific to the

trained regimen and transfer to even qualitatively similar tasks may be limited (Green and Bavelier, 2008). In addition, combining interventions in this way make it difficult to attribute the changes to one specific cause. Indeed, there is the possibility that compensation may arise in which the effects of the different interventions influence, or even cancel out, each other. Thus, it is unclear as to whether a single intervention or the combination of various exercises is primarily responsible for the observed effects.

The direct comparison of research findings in relation to balance training also becomes problematic due to the variability of the prescribed training programs. The majority of researchers appear to utilise training durations of four-weeks to ascertain whether improvements in function can be elicited from neuromuscular training interventions (Hale, Hertel and Olmsted-Kramer, 2007; Mckeon *et al.*, 2008; Collins, Masaracchio and Cleland, 2014; Hale *et al.*, 2014; Kim *et al.*, 2014; Anguish and Sandrey, 2018). However, interventions of 6 (Cruz-Diaz *et al.*, 2015) and 8 weeks (De Ridder *et al.*, 2015) have also been seen to be effective. The prescribed interventions appear to be primarily based on single limb balance tasks that are repeated throughout the duration of the study, and which are completed multiple times per week. Interestingly, the majority of studies utilise rehabilitation programmes which are supervised within the laboratory environment. Whilst this is an effective means to ensure adherence to the programme, it does not adequately reflect the clinical practice of the majority of practitioners. For these practitioners, unless they are working within a full-time professional sports environment, the contact they have with clients will be sporadic and may only involve intermittent face-to-face consultations. Research which investigate the use of home-based rehabilitation programmes may therefore be more relevant to the clinical environment. De Ridder et al (2015) utilised a progressive eight-

week home-based rehabilitation intervention within their study. Results indicated that a significant change could be elicited in subjective measures of ankle function following the programme, but that specific improvements in postural control during dynamic landing tasks were not observed. The authors concluded that the failure to enhance postural control during the performed dynamic task may be due to the balance training programme not being specific enough. This again gives credence to the observed phenomena that improvements in performance that are induced by balance training are mostly specific to the task trained (Green and Bavelier, 2008).

Following their 2017 meta-analysis, Powden, Hoch and Hoch concluded that among the different methods of neuromuscular rehabilitation, it is balance training which demonstrates the largest summary effect, and is hence the most appropriate strategy to implement in order to improve the health related quality of life of those with CAI (Powden, Hoch and Hoch, 2017). However, many of the research studies which have attempted to ascertain the effectiveness of these training programmes have been criticised with regards to the selection of the specific rehabilitation exercises and the ability of the identified outcomes measures to detect change (O'Driscoll and Delahunt, 2011). It is therefore recommended that future studies consider the importance of mode specificity of the rehabilitation intervention and the utilisation of outcome measures which have been shown to have adequate sensitivity to detect the intervention effect (O'Driscoll and Delahunt, 2011).

2.8.2. Strength and Stability Training

A review of the potential causes of functional ankle instability, identifies deficits in joint position sense (JPS), muscular strength, altered peroneal nerve function, and delayed

peroneal muscle reaction times (Hertel, 2000). Consequently, ankle joint strengthening and stability programmes have been examined in regard to their effect on these deficits and have identified some positive findings.

Sekir *et al.* (2007) identified a significant improvement in evertor muscle strength for those with FAI following an isokinetic exercise protocol. The ankle evertor muscles are often suggested to be important in the prevention of LAS, with the peroneal muscle groups providing support to the lateral ligaments. Improvement in the strength of these muscles may be effective at countering the inversion mechanism associated with recurrent LAS and CAI. Following the isokinetic strength training statistically significant improvements in proprioception were also identified. Similar improvements in eversion strength and JPS following a six-week progressive resistance strength training programme have also been observed by Docherty, Moore and Arnold (1998). It is hypothesised that a strengthening protocol may increase γ-efferent activity, which may render the muscle spindles more sensitive to stretch, resulting in greater acuity in sensing joint position (Docherty, Moore and Arnold, 1998).

Strength training utilising resistance bands has also been seen to be an effective method for improving evertor strength, as well as balance and functional performance (Hall *et al.*, 2018). In this study thirty-nine participants with CAI were randomly assigned to equal groups (n = 13) for balance training, strength training, and a control. Participants in the strength training group (5 females, 8 males) were given a progressive strength training protocol over a six-week period that was completed three times per week. The authors identified a clear improvement in both concentric and eccentric evertor strength measured using the average peak torque at 90^0/s on a

Cybex dynamometer. concluding that this may give participants a greater ability to eccentrically control the eversion stress associated with LAS. In addition, improvements were also observed in static and dynamic balance following performance on the SEBT and balance error scoring system (BESS), although only a moderate effect size ($g = 0.6$) was identified for these tasks. In contrast, Kaminski et al. (1999) concluded that six-weeks of strength and proprioceptive training produced no significant improvement in strength in those with unilateral FAI. It was suggested that unless evertor muscle strength is observed to be weakened, strength training would not be an effective rehabilitation paradigm (Kaminski, Perrin and Gansneder, 1999). The clinical assessment of strength deficits for those with CAI may therefore be an important consideration for the selection of appropriate rehabilitation strategies.

Research has identified that functionally unstable ankles display delayed muscle latencies and electromechanical delay deficits which contribute to the injury recurrence within these individuals (Hopkins *et al.*, 2009). Clark and Burden (2005) examined the effects of a four-week wobble board balance training programme on the subjective perception of stability in nineteen male participants. Using surface electromyography (sEMG), the onset latency of the tibialis anterior and peroneus longus muscles in response to a sudden 20^0 inversion were also recorded. The intervention group (n = 10) completed two sets of 5 different wobble board exercises performed three times per week. Results showed that the intervention group had significant improvement ($p \leq 0.05$) in muscle latency times for both tibialis anterior (29.9%) and peroneus longus (31.2%) when compared to pre-intervention scores. Subjects within this group also reported significant improvement ($p \leq 0.01$) in their subjective perception of stability scores (28.4%). Although the exercise programme is

unlikely to enhance the torque producing capabilities of the tibialis anterior and peroneus longus muscles, the observed decrease in latency could signify that the muscles become intrinsically stiffer. It has been demonstrated that stiffer muscles can enhance muscle spindle activation via the feed-forward mechanism of neuromuscular control, leading to a decreased time to initiation of the reflex response (Riemann and Lephart, 2002). Such an outcome can reduce the incidence of inversion injuries by reducing the time taken to respond to the inversion perturbation that is associated with LAS. Interestingly, research has also suggested that a specific balance training programme can also be effective at reducing the peroneal and tibialis anterior peak latencies and onset times (Akhbari *et al.*, 2007). Within this study, fifteen participants (8 female, 7 male) with functionally unstable ankles completed a four-week balance training programme on the Biodex Stability System. The training sessions were prescribed for three sessions per week and lasted 12 minutes. As there was no long-term follow up or measures of perceived ankle joint stability the clinical significance of the observed decreases in peak latency and onset times requires consideration. Whilst the research has clearly identified improvements in the reflex response of the peroneal and tibialis anterior muscles, there have been question raised as to the credibility of the theory of articular deafferentation and reflex stabilisation in those with FAI (Holmes and Delahunt, 2009). It appears that the reflex response of the ankle evertors may not be fast enough to provide adequate joint protection in response to rapid inversion movements (Delahunt, 2007b). Indeed, research has begun to suggest that it is the feed-forward mechanism of neuromuscular control that is of interest. Both Caulfield *et al.* (2004b) and Delahunt, Monaghan and Caulfield (2006b) have identified that those with FAI exhibit reduced activation of the peroneals in the period immediately leading up to ground contact. This leads to an impairment in the ability to

stabilise at impact which may predispose the athlete to further injury (Ross, Guskiewicz and Yu, 2005).

2.9. Practitioner Development

Dissemination is the targeted distribution of information to a clinical practice audience, with the intent being to spread knowledge and evidence-based interventions. However, the results of health science research often appear to remain unused by clinicians. Despite a large quantity of research evidence for the treatment of CAI, little is disseminated beyond fellow researchers, and therefore not often applied in practice (Cabana *et al.*, 1999). It has been identified that it can take up to 17 years for research to make its way into practice, with a significant loss of detail within this time, leaving only 14% of the research evidence being used to benefit health (Balas and Boren, 2000). There is therefore an insufficient dissemination of research evidence which results in new discoveries and clinical guidance not being adopted and benefitting those in need (Tabak *et al.*, 2015). Indeed, there is a clear indication that engagement by clinicians with research can improve healthcare performance (Boaz *et al.*, 2015).

The dissemination and implementation of new knowledge gained through research is essential, particularly when research is designed to improve health and health related outcomes. The gap between health research knowledge and its application in practice settings is often due to the ineffective dissemination (Brownson *et al.*, 2018). The effective distribution of contemporary research is critical to the development of evidence-based practice (EBP) and when this is lacking, the research may be considered to be wasteful in terms of its inability to influence health outcomes in a positive manner, as well as being a waste of resources (Derman and Jaeger, 2018).

This research-practice gap exists across all fields of medical practice and public health provision, and can result in significant health deficits and increased healthcare costs (Green *et al.*, 2009; Brownson *et al.*, 2018). Improving the dissemination of evidence-based practice (EBP) is paramount to reduce the gap between researchers and practicing clinicians (Hayes, 2002). The approach used to generate EBP should include appropriate research which is then vetted and disseminated to clinicians (Green *et al.*, 2009). This should then be framed in such a way that it evokes emotion and interest, and demonstrates usefulness for the target audience, and be based on the best research evidence available (Milkman and Berger, 2014). One of the greatest challenges for healthcare researchers is to relate the research to what goes on in 'real world' practice. In order for this to occur research must be designed around the 'real world' environment, with the end goal being to accurately and effectively disseminate the findings to their target audience in order to influence future practice (Hayes, 2002; Brownson *et al.*, 2018). One of the most effective ways in which clinicians learn about research is through short courses and seminars. Whilst there is a myriad of formats that these sessions can take, there is limited evidence as to the most effective format, although several key elements have emerged. The train-the-trainer approach shows potential as a means by which to enhance the reach and replication potential of the information presented, whilst the principles of adult learning are essential to the effective design of these sessions. Indeed, an appreciation of Knowles (1984) theory of adult education and 'Andragogy' provides a clear insight into the motivation that most adult learners have when presented with learning opportunities (Table 2.2).

Table 2.2. *Knowles theory of adult learning (Knowles, 1984).*

1. Self-concept	As a person matures their self-concept moves from one of being a dependent personality toward one of being a self-directed human being.
2. Experience	As a person matures, they accumulate a growing reservoir of experience that becomes an increasing resource for learning.
3. Readiness to learn	As a person matures their readiness to learn becomes oriented increasingly to the developmental task of their social role (work or personal life).
4. Orientation to learning	As a person matures their orientation toward learning shifts from one of subject-centredness to one of problem-centredness.
5. Motivation to learn	As a person matures their motivation to learn becomes internal.

It is therefore important that the theory of EBP and adult learning are incorporated in both the initial research design and subsequent design of dissemination materials and methods. By applying these ideas, scientific discoveries will no longer be resigned to academic publications, but will influence real-world practice and enhance health related outcomes (Brownson *et al.*, 2018).

2.10. Summary

There is a clear body of literary evidence to indicate that joint mobilisation is an effective means of treating acute LAS and CAI. The evidence suggests that these techniques can benefit the joint arthrokinematics in order to restore the mechanical deficits associated with the pathology. Further research indicates that functional changes may also be brought about by this treatment intervention through improvements to sensorimotor function via increased proprioception, joint position

sense and increased postural control. However, further research is needed to identify the dosage of treatment that is required to produce these effects and the improvements that can be elicited through cumulative treatments, similar to the practices adopted in clinical settings. Neuromuscular rehabilitation has also been shown to enhance the impairments seen in those with CAI, with balance training demonstrating the largest summary effect. As these methods are often based on exercises that an individual can do at home, there integration into a comprehensive CAI treatment regime is warranted. However, whilst research suggests that combined methods of treatment may be advantageous in eliciting the largest improvements, the effectiveness of individual components needs to be clearly identified first. In addition, neuromuscular and balance training must be relevant to the tasks which are being assessed and be related to the targeted outcomes of the clinical intervention treatment. The limitations identified in the literature support the need for the systematic exploration of the effects of joint mobilisation treatment dose on the impairments associated with CAI, along with the validity of combining mobilisation interventions with rehabilitation exercises in the treatment of this pathology. There is also the need to present this information in a format that is accessible to practicing clinicians in order to enhance their practice and the future treatment of CAI sufferers.

The following section provides the generalised methods utilised for the studies within chapter 4a, 4b and 5. Specific information pertaining to the individual study methodology is given within the respective chapters.

3.1. Study Design

Each investigation employed a randomised parallel group study design. The independent variables were time, group and limb. The dependent variables were selected from standardised measures of arthrokinematic motion, dynamic postural control and self-reported function, based on the individual study design. Participants reported to same clinical laboratory for all testing sessions (baseline, testing and follow-up).

3.2. Participant Screening and Selection

Female collegiate level team sports players with self-reported CAI were approached using the internal email system and advertisements posted throughout the University of Worcester. In order to recruit participants who fell within the heterogenous condition of Chronic Ankle Instability (CAI), the inclusion and exclusion criteria followed the standard endorsed by the International Ankle Consortium for enrolling patients in controlled research (Appendix 1) (Gribble et al., 2014). Inclusion criteria consisted of a history of at least one significant ankle sprain within the last 12 months. An ankle sprain was defined as a traumatic injury to the lateral ankle ligament complex as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot and results in some initial deficits of function and disability

(Delahunt *et al.*, 2010). This includes a combination of pain, swelling and time lost or modification to normal function for ≥1 day (Hertel, 2002). The Cumberland Ankle Instability Tool (CAIT) (Appendix 2) was used to determine the extent of an individual's pathology, where a score of less than 24 out of a possible 30 was used to indicate the presence of the condition. Participants completed the CAIT bilaterally. This ensured that the uninjured extremity could be used as a control, as answers to questions on the CAIT were assessed to ensure participants only had unilateral CAI symptoms. The Foot and Ankle Ability Measure (FAAM) (Appendix 3) was used to assess self-reported foot and ankle function of the injured limb, where a score of <90% and <80% on the Activities of Daily Living (ADL) scale and Sport (ADL-S) scale was required respectively (Gribble *et al.*, 2014). Exclusion criteria consisted of the subject reporting a history of previous surgery to the musculoskeletal structures of the lower extremity, a history of fracture in either lower extremity requiring realignment, or a history of acute musculoskeletal injury to the lower extremity in the previous 3 months, which impacted joint integrity and function and resulted in at least 1 interrupted day of desired physical activity (Gribble *et al.*, 2014).

Following enrolment and screening each participant had the study explained to them and was given an information sheet giving them written details of the study (Appendix 4 & 5). Following the study explanation, participants were required to complete a health and consent form (Appendix 6) in order for written consent to be gained. Participants were further reminded that they could withdraw from the study at any time. All data was anonymised and stored securely on a password protected computer, to comply with the Data Protection Act (1998). Ethical approval for all studies was

provided following ethical review by the School of Sport and Exercise Research Ethics Panel (SSE-REP) at the University of Gloucestershire.

3.3. Testing Procedures

Prior to testing and treatment intervention, baseline measures of limb length were obtained for all participants. Leg lengths were measured bilaterally using a tape measure from the anterior superior iliac spine (ASIS) to the distal tip of the medial malleolus. The limb lengths were used to calculate normalised reach distances on the SEBT.

All participants completed testing sessions based upon the individual study design (see Chapter 4a, 4b and 5), where measurements of posterior talar glide, ankle dorsiflexion and dynamic postural control were recorded for both limbs (injured and uninjured). Participants were blinded from all outcome measures to ensure that results were not artificially augmented and were encouraged to provide their maximal effort on each test. All testing sessions were completed at similar times of the day to limit any diurnal effects on test results. Participants were instructed to maintain normal physical activity and activities of daily living and did not receive any other forms of treatment or rehabilitation during their involvement in the studies.

Throughout the studies, participants also had all measurements taken on their non-injured ankle as well. These measurements primarily acted as a control for the intervention, whilst also being compared to normative data. This allowed the study to identify whether the use of an uninjured ankle can effectively be utilised for control purposes, or whether there is a compensatory mechanism at play. Participants were

blinded from all objective test scores to ensure that results were not artificially augmented. To reduce any inter-tester reliability issues, all mobilisation treatments were conducted by the same therapist who has over 10 years' experience in peripheral mobilisation techniques.

3.4. Measurement of Posterior Talar Glide

Posterior talar glide (PG) was assessed using the posterior drawer test (Figure 3.1). The test was performed with the subject seated on the edge of the couch with knees at 90^0. A digital inclinometer (DWL80E, Digi-Pas, USA) was positioned with a restraining strap secured just above the talocrural joint to measure the degree of knee flexion. With the subject relaxed and foot placed into subtalar neutral position, the talus was gently glided posteriorly. The first measurement was taken at initial soft tissue restriction and the angle of knee flexion recorded in degrees from a reading of the inclinometer. The talus was then glided further posteriorly until a firm capsular end feel was encountered and the degree of knee flexion again recorded (Denegar, Hertel and Fonseca, 2002). The angle of passive knee flexion provides an estimate of posterior talar glide as when the talus can no longer be posteriorly displaced, the ankle can no longer be dorsiflexed and further passive knee flexion is limited (Denegar, Hertel and Fonseca, 2002; DeStefano and Greenman, 2011). Measurements were taken and recorded once to ensure that there was no cumulative effect upon ROM from repeated assessment.

Figure 3.1. *Posterior drawer test used to assess posterior talar glide.*

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3.5. Measurement of Dorsiflexion Range of Motion

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Prior to treatment, non-weight bearing (NWB) and weight bearing (WB) DF-ROM were measured. NWB DF-ROM was assessed with the participant in prone on an examination table with their knee at 90^0 of flexion (Figure 3.2). Research has identified that knee position directly influences DF-ROM, with greater ROM achieved with 90^0 of knee flexion (DiGiovanni *et al.*, 2002). This position reduces the influence of passive tension within the gastrocnemius and the general stiffness of the ankle via its effect on the series and elastic components of the muscle-tendon unit (Kovaleski *et al.*, 2008; Krause *et al.*, 2011). Measurements were taken using a digital goniometer (Jamar Plus Digital Goniometer, Patterson Medical, UK). The stationary arm of the goniometer was positioned in line with the fibular head and lateral malleolus, whilst the moving arm

was placed parallel to the longitudinal axis of the fifth metatarsal, with the fulcrum just distal to the lateral malleolus (Norkin and White, 2011). Participants were then instructed to actively dorsiflex the foot from a resting position to their maximal position. The motion was visually monitored to ensure that it was performed in the sagittal plane avoiding pronation or supination.

Figure 3.2. *Non-weight bearing dorsiflexion range of motion assessed using a digital goniometer.*

The weight-bearing lunge test was used to measure weight bearing DF-ROM, utilising the knee-to-wall principle (Denegar, Hertel and Fonseca, 2002; Hoch and McKeon, 2011a) (Figure 3.3). Participants were asked to stand facing a wall with the second toe, centre of the heel, and knee perpendicular to the wall. The opposite limb was positioned approximately one foot length behind the test foot in a comfortable stance with hands placed on the wall. This ensured that an upright balanced position was maintained. Subjects were then instructed to perform a lunge in which the knee was

flexed in order to make contact between the anterior knee and the wall, whilst the heel remained firmly planted on the floor. The test foot was progressed away from the wall when subjects were able to maintain knee and heel contact. Progressions were made in 1cm increments until the heel and knee contact could not be maintained. Smaller increments were then used to achieve the maximum distance from the wall whilst continuing to maintain the heel and knee contact positions. Maximum lunge distance was measured using a limb measurement tape measure from the base of the wall to the tip of the great toe. Foot pronation and supination were again monitored to ensure that movements occurred solely in the sagittal plane. This method produces a greater DF-ROM measurement than any other position (Malliaras, Cook and Kent, 2006) and demonstrates an excellent intra-class correlation coefficient of 0.97-0.99 (Chisholm *et al.*, 2012). For all measurements of DF-ROM only a single measurement was taken to ensure there is no cumulative effect upon ROM from repeated assessment.

Figure 3.3. *The weight-bearing lunge test used to assess weight-bearing dorsiflexion range of motion.*

3.6. Measurement of Dynamic Postural Control

Dynamic postural control was assessed using the anterior, posteromedial and posterolateral directions of the Star Excursion Balance Test (SEBT) (Hertel, 2008). Participants were positioned with equal halves of the length and width of the involved foot in each quadrant of the SEBT. This ensured accurate repositioning over the testing sessions. Participants were then instructed to perform maximal reaches in the three directions with the uninvolved limb followed by a single light toe touch on the tape measure. A trial was discarded if the participants' hands did not remain on the hips, stance foot position was not maintained, the heel lost contact with the floor, or balance was lost. Distances were measured in centimetres using a limb measurement tape measure, which was then normalised to the subject's leg length, and multiplied by 100 (Gribble and Hertel, 2003). Participants were given three practice attempts to reduce the learning effect, as research suggests that SEBT scores are reliably consistent from the fourth trial onwards (Munro and Herrington, 2010). The average of three subsequent trials in each reach direction was then calculated and used for statistical analysis with each reach direction independently examined. The use of an average of three practice trials is common practice when using the SEBT (Gribble *et al.*, 2013) and this method has been shown to be highly reliable with an intraclass correlation coefficient for normalised maximum reach distances ranging from 0.86-0.92 (Munro and Herrington, 2010; Gribble *et al.*, 2013).
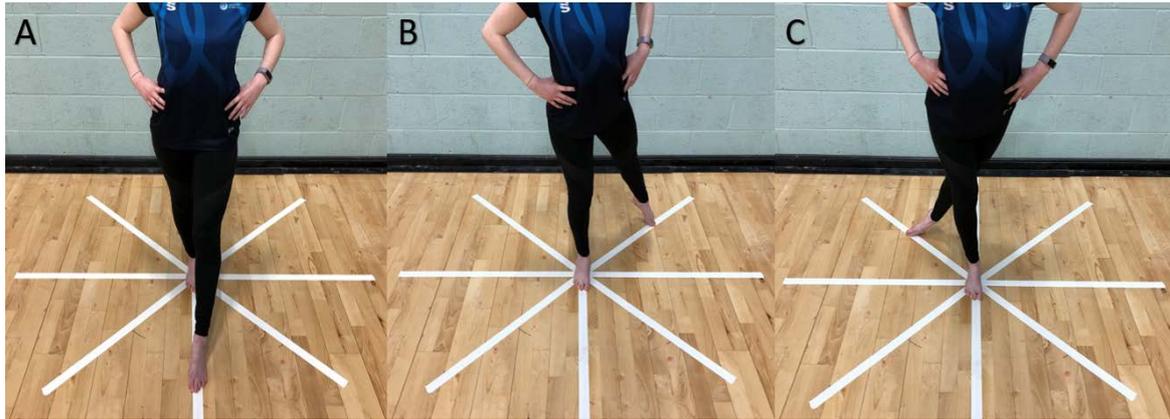
Figure 3.4. *Star excursion balance test directions and foot placement. Directions are described in relation to the stance foot. (A) Anterior, (B) Posterolateral, (C) Posteromedial.*

3.7. Joint Mobilisation Intervention

The joint mobilisation was performed with the participant in supine with their foot comfortably positioned over the end of the plinth (Table 3.1) (Figure 3.5). The ankle was placed at 20^0 to plantar flexion in order to achieve the loose-packed position of the talocrural joint (Mulligan, 2011; Magee, 2014). In this position, the talus is held slightly anterior to the mortise, allowing greater pressure application during the mobilisation, the force of which is transmitted to the posterior periarticular tissues (Wright *et al.*, 2000). The stabilising hand was placed proximal to the malleoli to stabilise the distal leg, whilst the mobilising hand cupped the anterior talus using the 1st web space. The talus was then glided posteriorly with downward force applied by the mobilising hand (Houglum, 2016). The joint mobilisation was operationally defined as a grade IV, 1 second rhythmic oscillation with translation taken to tissue resistance (Landrum *et al.*, 2008). This oscillatory technique was been chosen in order to load and unload the tissue in a similar way to that which would occur functionally (Banks and Hengeveld, 2009).

The efficacy of joint mobilisation treatments depends upon the intensity and reproducibility of force applied during mobilisations by the practitioner. The reliability of the force applied is an aspect determined by practitioner experience and their perception of the resistance felt during the movement (Gagnon *et al.*, 2016). Whilst research into the reliability of practitioner's force application during mobilisations of the ankle is limited, studies have identified the stability of force application by individual practitioners (Venturini *et al.*, 2007). Excellent intrarater reliability (ICC = 0.96-0.98) has been identified during a Maitland grade IV anteroposterior mobilisation of the talus (Resende *et al.*, 2006). Similar values have been observed for the maximum and minimum forces applied by practitioners respectively for both intrarater (ICC = 0.78 and 0.83) and interrater (ICC =0.95 and 0.97) reliability (de Souza *et al.*, 2008). Whilst the force applied by a practitioner will differ depending on the resistance encountered within individual joints, the application of mobilisation techniques can be see as reliable. However, to reduce any inter-tester reliability issues, all mobilisation treatments were conducted by the same practitioner who has over 10 years' experience in peripheral mobilisation techniques.

Table 3.1. *Technique for talocrural joint mobilisation (Adapted from Houglum, 2016)*

Client Position	Supine, ankle off plinth
Resting Position	Ankle positioned at 20^0 to plantar flexion
Therapist and Hand Position	Proximal hand: Grasp proximal to malleoli to stabilise distal leg. Mobilising hand: Cup anterior talus using 1st web space
Application	Using the distal mobilising hand perform an AP glide of the talus.
Oscillatory Grade	IV
Frequency	1 second rhythmic oscillations
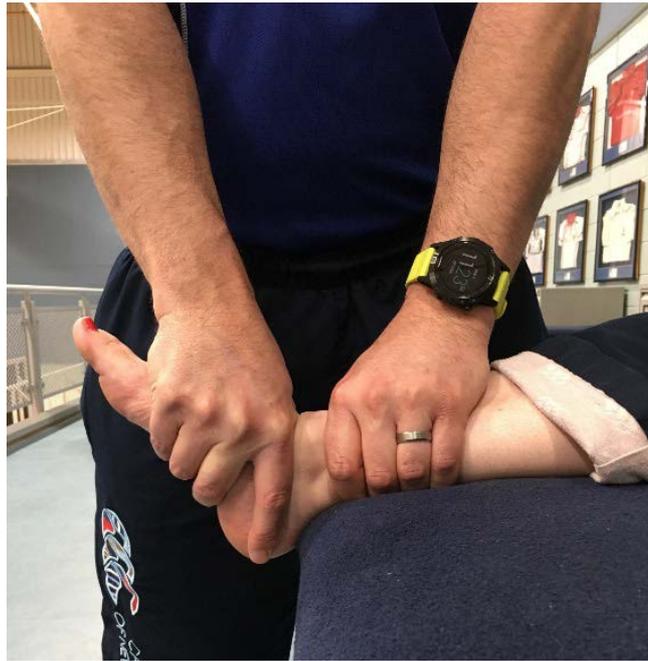
Figure 3.5. *Talocrural joint mobilisation intervention.*

3.8. Statistical Analysis

Statistical analysis was conducted using IBM Statistical Package for the Social Sciences version 23.0 (IBM, Armonk, NY) and Excel version 15.41 (Microsoft, Redmond, WA). The significance level for all analyses was set *a priori* at $p \leq 0.05$, although significance levels greater than this were also reported. Effect sizes (ES) were calculated using a bias-corrected Hedge's g based on the mean difference and the pooled weighted standard deviation of differences of repeated measures using the following formula:

$$\text{Hedges' } g = (M_1 - M_2) / SD_{pooled}$$

Where:

$M_1 - M_2$ = difference in means

SD_{pooled} = pooled and weighted standard deviation

ES were interpreted using the revision to the standard descriptors for magnitudes of effect sizes proposed by Sawilosky (2009) (Table 3.2).

Table 3.2. *Descriptors for effect size magnitudes of g = 0.01 to 2.0. Adapted from Cohen (1988) and Sawilowsky (2009).*

Effect size	*g*
Very small / negligible	0.01
Small	0.20
Medium	0.50
Large	0.80
Very Large	1.20
Huge	2.0

All data from the dependent variables was inspected for outliers via visual checking of the boxplot for values greater than 1.5 box lengths from the edge of the box. As the outliers were not a result of data entry error or measurement error they were not rejected as invalid and were hence included in the statistical analysis.

The assessment of normality of the data was assessed using the Shapiro-Wilk's test, with the hypothesis of normality being rejected when the *p*-value was less than or equal to 0.05. However, as the ANOVA statistical test is fairly "robust" to deviations from normality, particularly if the sample sizes are equal such as within this study, the test was still used (Lix et al, 1996). Non-normality of this type of data does not affect Type I error rate substantially and the ANOVA can be considered robust to deviations from normality (Maxwell & Delaney, 2004).

In order to address deviations of data from normality, the log transformation of data is widely used to address non-normality in research statistics but can lead to misinterpretation of experimental results and can potentially skew the data further (Robert & Casella, 2004). In addition, an inverse transformation (anti-log) is often

performed to model the means of the initial transformed data. This inversion of the transformed mean value does not result in an appropriate estimate of the mean of the original data (Feng et al., 2014). As this research was attempting to make inferences regarding the clinical relevance of treatment duration it was important that the original data was used where possible.

CHAPTER 4A. CUMULATIVE EFFECTS OF JOINT MOBILISATION ON RANGE OF MOTION, JOINT LAXITY, DYNAMIC POSTURAL CONTROL, AND SELF-REPORTED FUNCTION IN FEMALES WITH CHRONIC ANKLE INSTABILITY

4a.1. Introduction

Ankle sprains are the most common musculoskeletal disorder, accounting for 22% of all sports injuries (Fong *et al.*, 2007; Gribble *et al.*, 2016a). Despite the high prevalence and severity (Braun, 1999; Fong *et al.*, 2007), they are often considered innocuous injuries and treated with limited time and resources (Birrer *et al.*, 1999). However, ankle sprains have the highest recurrence rate of any musculoskeletal injury (Anandacoomarasamy, 2005). Up to 70% of those sustaining a single sprain report residual symptoms, including recurrent instability, additional ankle sprains and reduced functional capacity (Wikstrom *et al.*, 2007). These negative antecedents form the primary characteristics of chronic ankle instability (CAI).

CAI is linked to several mechanical and functional insufficiencies (Hertel, 2002). The primary mechanical impairments include reduced dorsiflexion range of motion (DF-ROM) (Drewes *et al.*, 2009), reduced posterior talar glide (Denegar, Hertel and Fonseca, 2002) and increased anterior joint laxity (Croy *et al.*, 2013). Following an inversion ankle sprain the talus is subluxed creating an anterior positional fault, resulting in anterior ligament laxity, restrictions in posterior noncontractile tissue and observed decreases in DF-ROM (Hoch *et al.*, 2014). The reduction in ROM may disrupt the transmission of afferent information to the sensorimotor system, contributing to the functional impairments associated with CAI (Hoch and McKeon, 2011a). Damage to ligamentous and capsular tissues causes partial deafferentation

of mechanoreceptors resulting in a loss of somatosensory information to the CNS (Hertel, 2008). Changes in arthrokinematic function frequently results in alterations to sensory input, suggesting a synergistic relationship between mechanical and functional impairments (Myers *et al.*, 2003).

Poor sensorimotor control and reductions in DF-ROM significantly increases the risk of lower extremity injury (Hertel, 2002). Interventions that address multiple aspects of impairment are necessary to alleviate the risks and limitations to activity experienced with CAI. As impairments are purported to be arthrogenic, interventions need to address the noncontractile tissue restrictions (Denegar, Hertel and Fonseca, 2002).

Joint mobilisations restore arthrokinematic movements that occur between joint surfaces (Green *et al.*, 2001). This is achieved through an increase in the extensibility of noncontractile tissues, increasing the extensibility of joint structures. Joint mobilisations also stimulate joint mechanoreceptors which improves the transmission of afferent information (McKeon *et al.*, 2010; Hoch and McKeon, 2011a). Mobilisations consistently demonstrate acute improvements in DF-ROM and posterior talar glide in those with a history of ankle sprains (Green *et al.*, 2001; Reid, Birmingham and Alcock, 2007; Hoch *et al.*, 2014). The use of joint mobilisations to increase afferent input and their effect on dynamic balance and postural control has also been identified (Hoch, Staton and McKeon, 2011a; Hoch, Staton, *et al.*, 2012; Cruz-Díaz *et al.*, 2015).

The core of the Maitland manual therapy technique is a conceptual framework of clinical reasoning, which forms the basis for the selection of the specific grade, oscillatory frequency, treatment duration and volume (Hengeveld and Banks, 2005).

The magnitude of change associated with the application of these techniques is influenced by the treatment duration. Research has shown that significant improvements in outcome measures can be elicited from dosages ranging from 30 to 120 seconds (Green *et al.*, 2001; Landrum *et al.*, 2008; Cosby *et al.*, 2011; Hoch, Staton, *et al.*, 2012). Although the selection of manual therapy protocols is grounded in relevant literature, due to the methodological differences the most effective parameters to be used remains unclear. Consequently, there is a clear lack of consensus among practitioners, with some concluding that the choice of technique and duration of treatment has little influence on its effectiveness (van den Hout *et al.*, 2005; Vicenzino *et al.*, 2006b). This lack of agreement, and an absence of comparison between treatment durations needs to be addressed in order to advance the knowledge and application of this technique. Given that injury treatment usually involves repeated therapy sessions, it is also important to examine the effect that cumulative treatment has upon outcomes in those with CAI.

4a.2. Methods

4a.2.1. Experimental Design

This investigation employed a randomised parallel group study design. The independent variable was time (pre-intervention, post intervention, follow up), group (30s, 60s, 120s) and limb (injured, uninjured). The dependent variables were DF-ROM, WBLT, posterior glide, normalised reach distances (ANT, PM and PL) of the Star Excursion Balance Test (SEBT), and self-reported function (CAIT, FAAM-ADL and FAAM-S). Participants reported to the research laboratory for enrolment and baseline testing, then for 6 separate testing and joint mobilisation treatment sessions across a 2-week period, before returning 1 week after cessation of the treatment to complete the study.

4a.2.2. Participants

A total of 56 female collegiate level team sports players with self-reported CAI were screened for inclusion from the University of Worcester using the internal email system and advertisements posted throughout the University.

Following the completion of the CAIT, FAAM-ADL and FAAM-S, 48 female team sports players (mean ±SD: age 22.8 ±4.8yrs; height 171.1 ±6.1cm; mass 70.8 ±7.4kg) completed the study (Appendix 8).

4a.2.3. Testing Procedures

After enrolment, each participant had the study explained to them and was given an information sheet giving them written details of the study (Appendix 4). Following the study explanation, participants were required to complete a health and consent form

(Appendix 6) in order for written consent to be gained. Participants were then randomly allocated to balanced treatment groups (n=16) of 30 seconds, 60 seconds or 120 seconds using a computer-generated simple random allocation sequence (Appendix 7). Participants and the researcher were blinded from the group allocation until after the first pre-intervention tests were completed. All participants completed their first testing session prior to treatment session 1 (pre-intervention). The 2nd testing session (post-intervention) occurred immediately after the final treatment intervention (session 6). Participants also attended a further data collection session one week after the final treatment where follow up measures of self-reported function were completed (CAIT, FAAM-ADL and FAAM-S) (Figure 4a.1).

| Enrolment / Informed consent Baseline Testing | Pre-intervention testing | Joint mobilisation treatment 1 | Joint mobilisation treatment 2 | Joint mobilisation treatment 3 | Joint mobilisation treatment 4 | Joint mobilisation treatment 5 | Joint mobilisation treatment 6 | Post-intervention testing | 1-week follow up data collection |

2-Week Joint Mobilisation Treatments

Figure 4a.1. *Study timeline representing the six joint mobilisation treatment sessions over a 14-day period, with a 1-week follow up.*

4a.2.4. Statistical Analysis

The percentage improvement for DF-ROM, WBLT, PG and normalised reach distances of the SEBT were calculated from pre-intervention 1 to post-intervention 6 and used for all data analysis due to its clinical relevance and immediate accessibility to clinicians (Vickers, 2001). Data for each dependent variable was assessed for outliers by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Data was also checked for normality of distribution by the Shapiro-

Wilk test ($p \leq .05$). As ANOVA's are fairly robust to deviations from normality, and have shown that the false positive rate is not affected very much by violations of the assumption (Glass, Peckham and Sanders, 1972; Lix, Keselman and Keselman, 1996) they were used for all statistical analysis. One-way ANOVAs ($p \leq 0.05$) were used to examine the differences in dependent variables separately. The independent variable for each analysis was group (30s, 60s, 120s) and limb (injured, uninjured). The Welch ANOVA was used for any data which violated the assumption of homogeneity of variances as assessed by Levene's test ($p \leq 0.05$). Post hoc comparisons were completed using the Games-Howell test to determine where exactly the differences were.

Mixed model ANOVAs ($p \leq 0.05$) were used to examine the differences in CAIT, FAAM-ADL and FAAM-S dependent variables separately from baseline to follow up. Percentage improvements in these metrics were not calculated prior to analysis due to the FAAM-ADL and FAAM-S already being presented as percentage scores. The independent variable for each analysis was time (baseline, follow up), group (30s, 60s, 120s) and limb (injured, uninjured). Post hoc comparisons were completed using Tukey's HSD in the presence of a group effect. Mauchly's sphericity test was conducted on all ANOVA measures with the Greenhouse-Geisser adjustment included for all significant outputs.

Effect sizes (ES) were calculated between injured limb and uninjured control using a bias-corrected hedge's g with 95% confidence intervals. ES was interpreted as negligible (0-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) very large (1.2-1.99) and huge (≥ 2.0) (Sawilowsky, 2009).

4a.3. Results

All data from the dependent variables were inspected for outliers via visual checking of the box-plots, with values greater than 1.5 box-lengths being considered outliers. As the identified outliers were not a result of data entry error or measurement error they were not rejected as invalid and were hence included in the statistical analysis.

Following checks for normality and homogeneity of variance, all dependent variable data was found to be non-normally distributed and the assumption of homogeneity of variance was violated, as assessed by Shapiro-Wilk and Levene's test respectively ($p \leq .05$). As non-normality of this data does not affect Type I error rate substantially and the ANOVA is deemed fairly 'robust' to deviations from normality, the ANOVA was used for all subsequent analysis.

Mean percentage increase ± standard deviation for all dependent variables are listed in Tables 4a.1, 4a.2 and 4a.3. Group differences and 95% confidence intervals for the percentage improvement in DF-ROM, WBLT, PG, ANT, PL and PM are shown in Tables 4a.4-9.

Table 4a.1. *Mean percentage change and standard deviation for dorsiflexion range of motion (DF-ROM), weight bearing lunge test (WBLT) posterior glide (PG), and anterior (Ant), posteromedial (PM) and posterolateral (PL) directions of the Star Excursion Balance Test (SEBT) across the study timeline.*

Variables	Treatment group					
	30s		60s		120s	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
DF-ROM	**24.57 ± 6.16^c**	-0.31 ± 1.34	**37.57 ± 16.51^c**	0.90 ± 1.42	**77.88 ± 27.12^{ab}**	0.54 ± 1.53
WBLT	**24.95 ± 6.28^c**	-0.27 ± 1.43	**37.49 ± 16.47^c**	0.82 ± 1.42	**78.11 ± 27.22^{ab}**	0.57 ± 1.32
PG	**24.16 ± 6.08^{bc}**	0.29 ± 1.22	**35.51 ± 9.44^{ac}**	0.96 ± 1.05	**75.93 ± 22.39^{ab}**	0.49 ± 0.56
SEBT-Ant	**5.42 ± 1.94^{bc}**	0.25 ± 0.67	**10.87 ± 1.74^{ac}**	-0.07 ± 0.39	**18.77 ± 1.92^{ab}**	0.04 ± 0.07
SEBT-PL	7.78 ± 0.65^{bc}	6.67 ± 2.04	11.43 ± 0.90^{ac}	11.18 ± 1.19	**14.03 ± 0.60^{ab}**	12.29 ± 0.82
SEBT-PM	3.31 ± 0.40^{bc}	3.17 ± 0.86	8.41 ± 1.40^{ac}	7.28 ± 2.32	**10.30 ± 0.74^{ab}**	8.66 ± 1.31

^{a} significant compared to the 30 second group; ^{b} significant compared to the 60 second group; ^{c} significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.

Table 4a.2. *Mean score and standard error for the Cumberland Ankle Instability Tool (CAIT) for treatment and control groups from baseline to follow-up.*

Variables		Treatment group					
		30s		**60s**		**120s**	
		Injured	**Uninjured**	**Injured**	**Uninjured**	**Injured**	**Uninjured**
CAIT	Baseline	13.31 ± 1.20	27.88 ± 0.44	12.00 ± 0.91	28.38 ± 0.46	13.50 ± 1.07	27.69 ± 0.44
	Follow-up	14.44 ± 1.06	28.06 ± 0.43	13.94 ± 0.80	28.56 ± 0.40	16.56 ± 1.04	27.88 ± 0.34
	Difference	**1.13 ± 0.20**	0.18 ± 0.14	**1.94 ± 0.19**	0.18 ± 0.16	**3.06 ± 0.11**	0.19 ± 0.16

a significant compared to the 30 second group; b significant compared to the 60 second group; c significant compared to the 120 second group; bold font indicates significant change from baseline to follow-up.

Table 4a.3. *Mean score and standard error for the Foot and Ankle Ability Measure Activities of Daily Living (FAAM-ADL) and Sport (FAAM-S) subscales for treatment groups from baseline to follow-up.*

Variables		Treatment Group		
		30s	**60s**	**120s**
		Injured	**Injured**	**Injured**
FAAM-ADL	Baseline	73.13 ± 1.64	73.13 ± 2.37	73.44 ± 1.75
	Follow-up	78.44 ± 1.63	81.25 ± 2.39	83.75 ± 1.61
	Difference	**5.31 ± 0.55**	**8.13 ± 0.64**	**10.31 ± 0.55**
FAAM-S	Baseline	54.63 ± 4.49	54.06 ± 4.50	54.38 ± 4.00
	Follow-up	63.44 ± 4.49	65.31 ± 4.17	67.81 ± 4.08
	Difference	**8.81 ± 0.73**	**11.25 ± 0.85**	**13.44 ± 0.88**

a significant compared to the 30 second group; b significant compared to the 60 second group; c significant compared to the 120 second group; bold font indicates significant change from baseline to follow-up

4a.3.1. Arthrokinematic Motion and Dynamic Postural Control

The percentage improvements were statistically significantly different for all groups for DF-ROM (Welch's F (5, 40.474) = 85.930, $p \leq 0.001$), WBLT (Welch's F (5, 40.484) = 85.195, $p \leq 0.001$), PG (Welch's F (5, 38.890) = 119.884, $p \leq 0.001$), ANT (Welch's F (5, 35.658) = 419.988, $p \leq 0.001$), PL (Welch's F (5, 41.412) = 169.141, $p \leq 0.001$) and PM (Welch's F (5, 40.170) = 203.637, $p \leq 0.001$).

Games-Howell post hoc analysis revealed that there was a statistically significant improvement in the 120 second treatment group compared to the 60 second treatment group, and the 30 second treatment group for DF-ROM, WBLT, PG, ANT, PL and PM ($p \leq 0.001$). A statistically significant improvement was also seen in the 60 second treatment group compared to the 30 second treatment group for PG, ANT, PL and PM ($p \leq 0.001$). Differences between the 60 second and 30 second treatment groups were not observed for DF-ROM or WBLT ($p \geq 0.05$). All treatment group showed statistically significant improvements when compared to the uninjured controls for DF-ROM, WBLT, PG and ANT ($p \leq 0.001$). There was a statistically significant difference between the 120 second treatment group and uninjured control for PL and PM ($p \leq 0.001$). The difference in PL reach distance was not statistically significant between the 30 second treatment group and uninjured control ($p = 0.343$) or the 60 second treatment group and uninjured control ($p = 0.984$). This was also true for the PM reach distance and the 30 second treatment group and uninjured control ($p = 0.997$) and the 60 second treatment group and uninjured control ($p = 0.823$) (Tables 4a.2-7).

Table 4a.4. *Group differences and 95% confidence interval of the percentage improvement in DF-ROM between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-13.01	-53.33*	24.87*
60s injured	13.01		-40.31*	36.67*
120s injured	53.33*	40.31*		77.34*

* indicates statistical significance

Table 4a.5. *Group differences and 95% confidence interval of the percentage improvement in WBLT between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-12.55	-53.16*	25.22*
60s injured	12.55		-40.61*	36.68*
120s injured	53.16*	40.61*		77.54*

* indicates statistical significance

Table 4a.6. *Group differences and 95% confidence interval of the percentage improvement in PG between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-11.35*	-51.76*	23.87*
60s injured	11.35*		-40.40*	34.55*
120s injured	51.76*	40.40*		75.42*

* indicates statistical significance

Table 4a.7. *Group differences and 95% confidence interval of the percentage improvement in anterior reach distance of the SEBT between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-13.01	-53.33*	24.87*
60s injured	13.01		-40.31*	36.67*
120s injured	53.33*	40.31*		77.34*

* indicates statistical significance

Table 4a.8. *Group differences and 95% confidence interval of the percentage improvement in posterolateral reach distance of the SEBT between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-12.55	-53.16*	25.22*
60s injured	12.55		-40.61*	36.68*
120s injured	53.16*	40.61*		77.54*

* indicates statistical significance

Table 4a.9. *Group differences and 95% confidence interval of the percentage improvement in posteromedial reach distance of the SEBT between treatment groups and uninjured controls.*

	30s injured	*60s injured*	*120s injured*	*Group uninjured*
30s injured		-11.35*	-51.76*	23.87*
60s injured	11.35*		-40.40*	34.55*
120s injured	51.76*	40.40*		75.42*

Effect size statistics showed that for the 120 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT and PL, with a 'very large' effect ($g \geq 1.20$) for PM. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT and PL, with a 'small' effect ($g \geq 0.20$) for PM. For the 30 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT and PL, with a 'very small negative' effect ($g \geq -0.01$) for PM (Figure 4a.11).
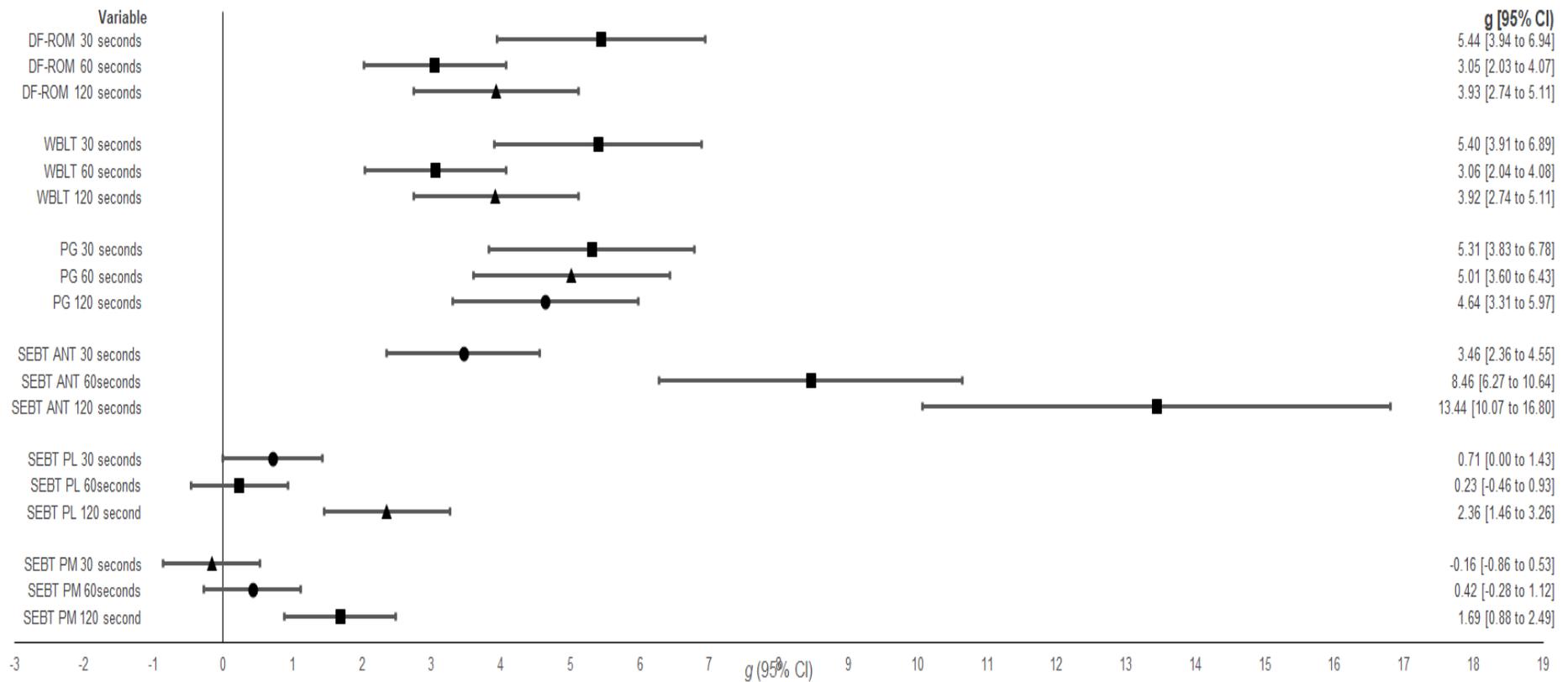
Figure 4a.2. *Forest plot (g ± 95% CI) of injured versus uninjured limb for dorsiflexion range of motion (DF-ROM), weight bearing lunge test (WBLT), posterior glide (PG), and anterior (ANT), posteromedial (PL) and posterolateral (PM) directions of the Star Excursion Balance Test (SEBT) across the study timeline.*

4a.3.2. Self-Reported Function

The two-way ANOVA for the CAIT revealed a statistically significant main effect for treatment group (F (5, 90) = 100.156, $p < 0.001$, partial η^2 = 0.848) and measurement time (F (2, 90) = 275.658, $p < 0.001$, partial η^2 = 0.754). There was also a significant interaction effect between the treatment and time on CAIT scores (F (5, 90) = 52.146, $p < 0.001$, partial η^2 = 0.743).

The two-way ANOVA for the FAAM-ADL revealed a statistically significant main effect for treatment group (F (5, 90) = 100.156, $p < 0.001$, partial η^2 = 0.848) and measurement time (F (1, 45) = 562.597, $p < 0.001$, partial η^2 = 0.926). There was also a significant interaction effect between the treatment and time on FAAM-ADL scores (F (2, 45) = 18.799, $p < 0.001$, partial η^2 = 0.455).

The two-way ANOVA for FAAM-S revealed a statistically significant interaction effect between the treatment and time on FAAM-S scores (F (2, 45) = 7.875, $p < 0.005$, partial η^2 = 0.259), and measurement time (F (1, 45) = 550.375, $p < 0.001$, partial η^2 = 0.924). There was no statistically significant main effect for treatment group ($p \geq .05$).

Following baseline testing, simple main effects for treatment group revealed statistically significant differences in CAIT scores (F (5, 90) = 102.037, p ≤ 0.001, partial η^2 = 0.850). These CAIT scores were significantly different for all treatment groups when compared to their uninjured controls (p ≤ 0.001), although there were no statistically significant differences between the intervention groups ($p \geq 0.05$). Following baseline testing, there were no statistically significant differences in FAAM-ADL scores (F (2, 45) = 0.009, p = 0.991, partial η^2 = 0.000) or FAAM-S scores (F (2,

45) = 0.004, p = 0.996, partial η^2 = 0.000). At follow-up, simple main effects for group revealed a statistically significant difference in CAIT scores (F (5, 90) = 96.678, p ≤ 0.001, partial η^2 = 0.843). These CAIT scores were significantly different for all treatment groups when compared to their uninjured controls (p ≤ 0.001), although there were no statistically significant differences between the intervention groups (*p* ≥ 0.05). At follow-up there were no statistically significant differences in FAAM-ADL scores (F (2, 45) = 1.929, p = 0.157, partial η^2 = 0.079) or FAAM-S scores (F (2, 45) = 0.267, p = 0.767, partial η^2 =0 .012).

There was a statistically significant effect of time (pre1 to follow-up) in the 120 second treatment group for the CAIT (F (1, 15) = 766.277, p ≤ 0.001, partial η^2 = 0.981), FAAM-ADL (F (1, 15) = 347.553, p ≤ 0.001, partial η^2 = 0.959) and FAAM-S (F (1, 15) = 233.067, p ≤ 0.001, partial η^2 = 0.940). This was also evident for the 60 second treatment group (CAIT - F (1, 15) = 100.804, p ≤ 0.001, partial η^2 = 0.870; FAAM-ADL - F (1, 15) = 169.000, p ≤ 0.001, partial η^2 =0 .918; FAAM-S - F (1, 15) = 173.571, p ≤ 0.001, partial η^2 =0 .920) and 30 second treatment group (CAIT - F (1, 15) = 31.154, p ≤ 0.001, partial η^2 = 0.675; FAAM-ADL - F (1, 15) = 92.234, p ≤ 0.001, partial η^2 = 0.860; FAAM-S - F (1, 15) = 145.117, p ≤ 0.001, partial η^2 = 0.906).

For the CAIT, effect size statistics showed that there was a 'huge' effect for the 120 second (*g* = 4.99) and 60 second treatment groups (g = 2.38), whilst a 'very large' effect size was evident for the 30 second treatment group (*g* = 1.33) (Figure 4a.12.).
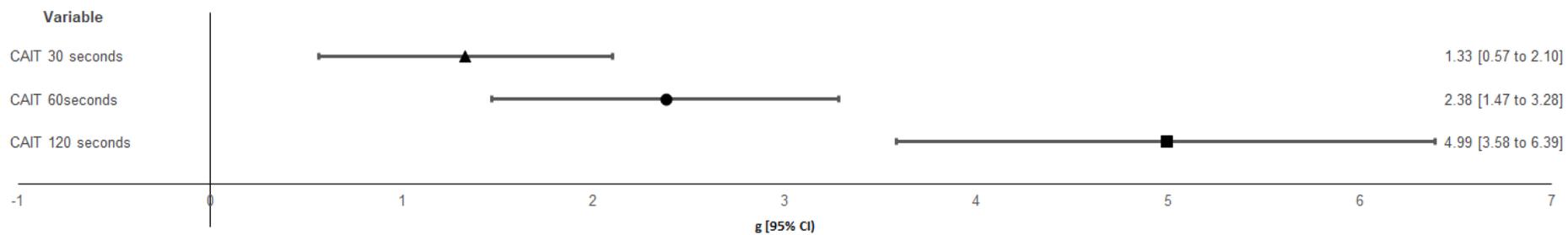
Figure 4a.3. *Forest plot (g ± 95% CI) of injured versus uninjured limb for the Cumberland Ankle Instability Tool (CAIT) across the study timeline.*

4a.3.3. Results Summary

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for DF-ROM, WBLT, PG and ANT in the 30s, 60s and 120s treatment groups.

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for PL and PM in the 120s treatment group.

- Mean percentage change was greater in the 120s group when compared to the 60s and 30s groups for all outcome measures

- Mean percentage change was greater in the 60s group when compared to the 30s group for PG, ANT, PL and PM.

- Mean score changes for the CAIT, FAAM-ADL and FAAM-S were significant for the 30s, 60s and 120s treatment groups.

- No significant differences in mean score changes for the CAIT, FAAM-ADL and FAAM-S were observed between the treatment groups.

4a.4. Discussion

The results of this study showed that joint mobilisation treatment can significantly improve arthrokinematic motion and dynamic postural control when delivered over a 2-week period. This shows that an effective improvement in patient-oriented and clinician-oriented measures of function can be elicited for those experiencing the CAI pathology.

Comparisons with other research into the effects of joint mobilisation is limited due to the lack of methodologically rigorous research into the effects of cumulative treatment on CAI outcome measures. Indeed, at the time of writing only five studies pertain to this type of study design in relation to improving outcome measures in those with CAI. Of these studies, four studies analyse the effect of talar mobilisation on arthrokinematic motion (Hoch *et al.*, 2012; Hoch *et al.*, 2014; Cruz-Díaz *et al.*, 2015; McKeon and Wikstrom, 2016), three on dynamic postural control (Hoch *et al.*, 2012; Gilbreath *et al.*, 2014; Cruz-Díaz *et al.*, 2015), and four on self-reported function (Hoch *et al.*, 2012; Gilbreath *et al.*, 2014; Cruz-Díaz *et al.*, 2015; McKeon and Wikstrom, 2016)

4a.4.1. Arthrokinematics

The current study highlights significant improvements in arthrokinematic motion (DF-ROM, WBLT and PG) across all three treatment groups. As the changes in both DF-ROM and WBLT corresponded to similar changes in PG for all treatment groups it could be concluded that these improvements are a direct result of the restoration of the accessory motion of the talus. The ability of the talus to glide posteriorly is an integral component of ankle dorsiflexion with this motion having a significant

relationship with range of motion (Vicenzino *et al.*, 2006b; Cosby and Hertel, 2011). For the current study improvement in WBLT for the 120 second group was 78.1%, with a 37.5% improvement for the 60 second group and a 25.0% improvement for the 30 second group. For each, effect sizes were also 'huge' (>2.0). These improvements were well beyond those observed by Hoch et al (Hoch *et al.*, 2012) that identified an improvement in the WBLT of 12.5% with effect size of >3.0. Additional studies utilising similar joint mobilisation interventions have also demonstrated improvements in WBLT beyond that observed by Hoch et al (2012). In a study by McKeon and Wikstrom (2016) participants with CAI were seen to improve by 27.3% on the WBLT. This is of particular note as the latter study utilised only 2 sets of 2 minutes of grade III joint mobilisation, whereas the earlier study doubled this to 4 sets of 2 minutes with the addition of 2 sets of 2 minutes of grade II joint tractions. This does add some further credence to the Maitland concept's protocol for grades selection, as the additional grade II mobilisation will primarily stimulate mechanoreceptors in order to relieve pain as opposed to influencing ROM. With this in mind, the current study's utilisation of grade IV mobilisation may explain the supercilious results obtained even though the treatment durations were shorter. Grade IV mobilisations produce a far greater oscillatory frequency and mean force than grade III which is translated to the tissue restricting motion (Silvernail *et al.*, 2011). A proportional relationship is evident between the deformation experienced by the tissue and the applied stress within its elastic limit, and is explained by Hooke's law. Grade IV moves beyond the elastic limit to the yield point and into the plastic range, where a permanent elongation of the tissue is observed due to failure of the collagen's force-relaxation response when a load is applied, or when the creep response causes deformation to occur too rapidly (Houglum, 2016). As this deformation can occur from both the greater load being

applied and accumulated stress it goes someway to explaining the greater improvements observed in the current study and the increased improvements elicited as the treatment duration progressed. Improvements in WBLT have also been observed following Mulligan mobilisation-with-movement (MWM) after similar cumulative treatment sessions. Cruz-Diaz et al (2015) observed a 12.7% increase following 2 sets of 10 repetitions given twice weekly over a three-week period to those with CAI. This treatment method consisted of a sustained anterior-to-posterior glide of the talus whilst the participants performed an active weight-bearing lunge, mimicking the movement needed for the WBLT. The differences in mobilisation method may explain the smaller observed changes in ROM. Whilst the sustained mobilisation of the talus during MWM may result in tissue creep and the observed changes in arthrokinematic movement, creep is time dependent and the short period of mobilisation may be insufficient to cause large effects. Repeated loading and unloading of tissue, as demonstrated during oscillatory mobilisations techniques such as the Maitland method, shifts the stress-strain curve to the right, producing a reduction in the stiffness of the tissue and leading to a more rapid failure rate of the collagen matrix (Savio *et al.*, 2007).

The ability of the talus to glide posteriorly during dorsiflexion is important for full motion to occur (Soavi *et al.*, 2000). Those with CAI often experience restrictions in this movement due to damage to the ligamentous restraint and an observed anterior displacement of the talus (Wikstrom and Hubbard, 2010). During normal DF movements the convex talus should roll and glide posteriorly in relation to the concave mortise (Vicenzino et al., 2006a). As such, the significant improvement in PG observed in the present study are unsurprising with research showing that there is a significant

relationship between posterior talar glide and DF-ROM (Cosby and Hertel, 2011). Similar improvements were not observed by Hoch et al (2014) who observed a non-significant decrease in PG with an effect size of -0.51. Whilst the overall treatment durations were considerably greater in the Hoch et al study (4 x 2 minutes of grade III talar mobilisations and 2 x 2 minutes of grade II joint tractions), the lower grades could again explain the differences in observed improvement and the lack of such within this earlier study.

4a.4.2. Dynamic Postural Control

Following the joint mobilisation interventions, significant improvements in ANT, PL and PM reach distances were identified in the 120 second treatment group. For the 60 second and 30 second treatment groups significant improvements, in comparison to the uninjured control limb, were only observed for the ANT reach distance. This may be explained by the observed increases in PL and PM reach distances that were observed in the uninjured control limbs for both of these measures. Longer joint mobilisation treatment durations therefore appear to improve dynamic postural control in those with CAI, but there appears to be some crossover effect to the untreated limb.

The magnitude of improvements within each of the reach directions is notably larger in the current study when compared to previous methodologically similar research. Statistically significant improvements in ANT of 8.36% (Cruz-Díaz *et al.*, 2015) and 2.12% (Hoch, Andreatta, *et al.*, 2012) have been observed which is surpassed by both the 60 second and 120 second treatment groups. This is also evident for PM, with the same studies concluding improvements of 4.26% and 4.37% respectively. Further, all treatments groups showed a greater level of improvement within the PL reach distance

when compared to the Cruz-Diaz et al (3.52%) and Hoch et al (4.77%) studies. The additional study by Gilbreath et al (2014) showed no significant improvement in any of the reach distances following 3 sessions of MWM treatment. Interestingly, the uninjured control groups have shown improvements that are greater than those elicited in the treatment groups of the previous studies for both PL (all groups) and PM (60 second and 120 second groups).

The increases in DF-ROM and WBLT provides a logical explanation for the increase in ANT reach distance as there is a direct positive correlation between these measures (Hoch, Staton and McKeon, 2011b). In addition, improvements were also seen in the PL and PM reach direction which would suggest that the joint mobilisation intervention is enhancing mobility beyond the talocrural joint. As joint ROM was not measured at other joints within the study, the suggestion that joint mobility may be the foundation of the increases in PL and PM cannot be determined. However, around 78% of the variance in maximal reach distance for performance on the SEBT can be ascribed to proximal joint motion at the hip and knee (Robinson and Gribble, 2008). As there is a known coupling relationship between hip and knee flexion, and DF-ROM (Denegar, Hertel and Fonseca, 2002) it can be postulated that increases in DF-ROM and WBLT following the joint mobilisation treatment may have resulted in simultaneous increases in hip and knee flexion. This may provide a rational explanation for the increases in dynamic postural control as measured by the SEBT. The improvements witnessed in the non-treated control limbs may have been due to the mobilisation treatment having a bilateral effect through a 'cross-education' of the neural mechanisms (Carroll *et al.*, 2006; Lee and Carroll, 2007). Motor activity interventions have been shown to enhance performance in an untreated or untrained contralateral homologous limb

when only the ipsilateral limb is treated (Schlenstedt *et al.*, 2017). It is postulated that this may be the result of cortical and spinal adaptations which allows a 'spill over' of neural drive to the contralateral limb (Ruddy and Carson, 2013), or through 'bilateral access', where neurological adaptations are accessible for the contralateral limb (Carroll *et al.*, 2006). The longer durations of mobilisation treatment would therefore result in greater improvements in the performance of the contralateral limb as previous studies have demonstrated that the magnitude of bilateral transfer is proportional to the improvement experienced in the treated limb (Kidgell, Stokes and Pearce, 2011). However, whilst the effect appears as small, familiarisation with the testing procedures may bias the contralateral effects observed (Carroll *et al.*, 2006).

4a.4.3. Self-Reported Function

Following the joint mobilisation intervention, participants from all three treatment groups reported an increase in self-reported function as assessed by the CAIT, FAAM-ADL and FAAM-S. There were no significant differences between the treatment groups for the increases in CAIT, FAAM-ADL or FAAM-S. However, effects sizes for the CAIT were 'huge' ($\geq$2.00) for both the 120 second and 60 second treatment groups, whilst the 30 second group demonstrated a 'very large' effect size ($\geq$1.20). It can be concluded that joint mobilisation treatment for those with CAI produces meaningful improvements in self-reported function when assessed using accepted patient-reported outcome measures (PROMs).

Whilst the improvement in FAAM-ADL and FAAM-S scores were not statistically significant between groups, the magnitude of change did appear to be a greater as the duration of treatment increased (Table 4a.9). Improvements in these two self-

reported measures have been seen in other studies. McKeon and Wikstrom (2016) reported a 4.58% and 10.93% increase in the FAAM-ADL and FAAM-S respectively, which was surpassed by Hoch et al. (2012) with 9.03% and 15.10% for the same measures. However, no significant changes in these outcomes were reported by Gilbreath et al (2014). Within the current study the improvements in the FAAM-ADL were 5.31% for the 30 second group, 8.13% for the 60 second group, and 10.31% for the 120 second group, with improvements in the FAAM-S of 8.81%, 11.25% and 13.44% for the same groups. These improvements are comparable to the positive outcomes reported previously and are above the minimal detectable change scores that were identified by McKeon and Wikstrom (2016) of 4.8% for the FAAM-ADL and 7.6% for the FAAM-S. This demonstrates that there is a clear improvement in self-reported function following joint mobilisation interventions. For the CAIT scores improvements of 1.13 (30 seconds), 1.94 (60 seconds) and 3.06 (120 seconds) were seen for each treatment group. This is considerably lower than that reported by Cruz-Diaz et al (2015) of 6.63. This is surprising as the Cruz-Diaz et al study showed lower improvements scores on the objective clinical measures of DF-ROM and dynamic balance than the current study. However, the comparison of these different outcome measures may not be appropriate as PROMs capture a different aspect of the outcome than the objective performance measures do (Hamilton, Giesinger and Giesinger, 2017). Consequently, the subjective nature of the CAIT may go some way to explain these differences.

4a.4.4. Recommendations for Future Research

The use of a female collegiate level cohort within the current study may limit the ability of the current study to be generalised to a wider population. This is due to the changes in the biomechanical properties of connective tissue associated with ageing (Weppler and Magnusson, 2010) and fluctuations in oestrogen and progesterone during the menstrual cycle (Slauterbeck *et al.*, 2002). Consequently, the application and effectiveness of this intervention may be different for males or an older female population. Whilst this may require further investigation it could be hypothesised that results would be comparable as the purported physiological effects of mobilisations have not been identified as either gender or age specific. Whilst improvements in the CAIT, FAAM-ADL and FAAM-S were all observed, the mean values post intervention would mean that the participants would be classified as still having CAI. This shows that whilst joint mobilisation can improve outcome measure associated with CAI, it needs to be integrated with other rehabilitation strategies in order to restore full function. An integration of this treatment technique with balance training, self-mobilisation, stretching or task-orientated rehabilitation may provide greater improvements for those with CAI and requires further investigation to determine when and if this pathology can be reversed. In addition, the application of joint mobilisation may provide a transient stimulation of sensory input, which if conducted immediately prior to balance training could increase the effectiveness of the balance exercises. If identified through research this could provide a synergistic coupling of interventions that would complement each other and provide a more complete strategy of rehabilitation for those with CAI.

4a.5. Conclusion

These findings show that the application of joint mobilisations over a 2-week period enhances the mechanical and functional capacity of those with CAI by increasing activity and sports participation as indicated by the observed changes in arthrokinematic motion, dynamic postural control and self-reported function. Increased treatment durations appear to confer greater improvements in outcomes measures. Joint mobilisation interventions should therefore be an integral part of the treatment regime for those with CAI due to its ability to address mechanical and functional impairments and enhance clinician and patient oriented outcome measures.

CHAPTER 4B. WITHIN-SESSION EFFECTS F JOINT MOBILISATION ON RANGE OF MOTION, JOINT LAXITY, AND DYNAMIC POSTURAL CONTROL IN FEMALES WITH CHRIONIC ANKLE INSTABILITY

4b.1. Introduction

Ankle sprain injuries have been seen to be a common lower limb injury in the general (Bridgman *et al.*, 2003; Shah *et al.*, 2016), athletic (Gribble *et al.*, 2016a) and military populations (Waterman *et al.*, 2010) . These injuries are often considered benign with no lasting consequences, suggesting that the resolution of the overall health condition is merely dependent on the dissipation of acute symptoms (Shah *et al.*, 2016). However, at least a third of individuals who sustain a lateral ankle sprain will experience long lasting symptoms and recurrent sprains which is associated with the development of CAI (Roos *et al.*, 2017).

The development of CAI is thought to be a multi-factorial phenomenon and is linked to changes in the mechanical and functional characteristics of the ankle complex (Hertel, 2002). Whilst some researchers have claimed that mechanical and functional instability are relatively unique entities, the majority of CAI sufferers experience a combination of both conditions (Hiller, Kilbreath and Refshauge, 2011). Mechanical instability (MI) involves the movement of the ankle joint and the observed reduction in DF-ROM, posterior talar glide and increased joint laxity, while functional instability (FI) relates to proprioceptive and neuromuscular dysfunction and the subjective feeling of instability (Denegar, Hertel and Fonseca, 2002; Hertel, 2002).The interaction between the functional impairments in proprioception, postural control and neuromuscular control of FI and the alterations in joint laxity, arthrokinematics and degenerative

structural changes of MI are likely responsible for the repetitive ankle trauma and long term reduction in functional performance experienced by those with CAI (Hiller, Kilbreath and Refshauge, 2011).

Joint mobilisations have been used extensively within the research to address MI and FI insufficiencies and are one of the few treatment modalities that have been shown to positively effect both disorders (Hoch *et al.*, 2014; Cruz-Díaz *et al.*, 2015). Previous studies have demonstrated that single joint mobilisation treatments can provide initial resolution of mechanical and functional impairments associated with CAI (Hoch and McKeon, 2011a; Harkey *et al.*, 2014). In addition, a number of studies have identified improvements in these outcome parameters following cumulative joint mobilisation treatments delivered over an extended period of time (Hoch, Andreatta, *et al.*, 2012; Cruz-Díaz *et al.*, 2015; McKeon and Wikstrom, 2016). The application of joint mobilisation treatment follows the parameters defined by the individual technique in question. For the Maitland manual therapy technique there is specific guidance for the selection of direction, grade, oscillatory frequency, treatment duration and volume (Hengeveld and Banks, 2005). However, much of this is influenced by the Manual Therapist's clinical reasoning and as such open to interpretation resulting in non-standardised practice. There is therefore a need for research to identify how alterations in any of these treatment parameters can influence their effectiveness, particularly in regard to specific pathologies.

The limitation of the research evidence associated with the use of joint mobilisation to treat CAI is the lack of studies which have examined the within-session effect of treatment over multiple sessions. Examining these effects would enhance the clinical

application of this intervention by allowing conclusions to be drawn as to whether improvements in outcome measures are commensurate among sessions or whether successive sessions yield a variation in the effectiveness of the treatment. In addition, there is limited research to address the effect that different treatment durations have upon improvements in function of those with CAI. Given that Manual Therapists will usually see patients on multiple occasions and utilise clear objective markers within each session, it is important to examine the effect of joint mobilisation within each treatment and whether this is maintained through accumulated sessions.

4b.2. Methods

4b.2.1. Experimental Design

This investigation employed a randomised parallel group study design. The independent variable was time (session 1, 2, 3, 4, 5, 6), group (30s, 60s, 120s) and limb (injured, uninjured). The dependent variables were DF-ROM, WBLT, posterior glide, and normalised reach distances of the Star Excursion Balance Test (SEBT). Participants reported to the research laboratory for 6 separate testing and joint mobilisation treatment sessions across a 2-week period to complete the study.

4b.2.2. Participants

A total of 56 female collegiate level team sports players with self-reported CAI were screened for inclusion from the University of Worcester using the internal email system and advertisements posted throughout the University.

Following the completion of the CAIT, FAAM and FAAM-S, 48 female team sports players (mean ±SD: age 22.8 ±4.8yrs; height 171.1 ±6.1cm; mass 70.8 ±7.4kg) completed the study (Appendix 8: Figure 1).

4b.2.3. Testing Procedures

After enrolment, each participant had the study explained to them and was given an information sheet giving them written details of the study (Appendix 4). Following the study explanation, participants were required to complete a health and consent form (Appendix 6) in order for written consent to be gained. Participants were then randomly allocated to balanced treatment groups (n=16) of 30 seconds, 60 seconds or 120 seconds using a computer-generated simple random allocation sequence (Appendix

7). Participants and the researcher were blinded from the group allocation until after the first pre-intervention tests were completed. All participants completed their first testing session prior to treatment session 1 (pre-intervention testing 1). Following the treatment intervention participants underwent a 2nd testing session (post-intervention testing 1). Participants were then required to return to the clinic for five additional testing (pre, post) and treatment sessions over the following 2 weeks (Figure 4b.1).
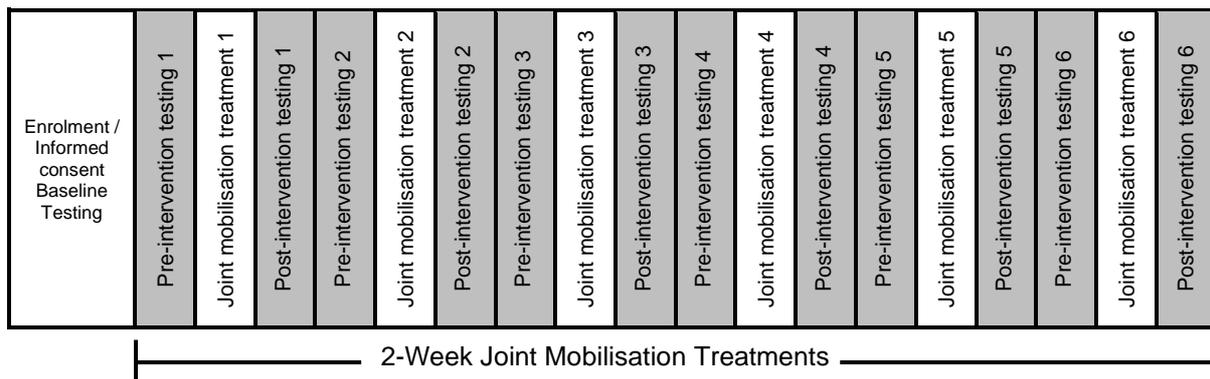
Figure 4b.1. *Study timeline representing the six joint mobilisation treatment and testing sessions over a 14-day period.*

4b.2.4. Statistical Analysis

The percentage improvement for each dependent variable was calculated within each treatment session and used for all data analysis due to its clinical relevance and immediate accessibility to clinicians (Vickers, 2001). Mixed model ANOVAs ($p \leq 0.05$) were used to examine the differences in dependent variables separately. The independent variable for each analysis was time (session 1, 2, 3, 4, 5, 6), group (30s, 60s, 120s) and limb (injured, uninjured). Post hoc comparisons were completed using Tukey's HSD in the presence of a group effect. Although the ANOVA is relatively robust to violations it must meet the assumption of sphericity (Rutherford, 2011). This requires that the measures demonstrate both homogeneity of variance and homogeneity of covariance (Vincent, 2005). To test whether the assumption of sphericity had been violated a Mauchly's sphericity test was conducted within the

statistical analysis. If the notion of sphericity does not hold true, the probability of making a type I error increases. In these instances, the use of the Greenhouse-Geisser adjustment has been suggested that alters the degrees of freedom and produce an F-ratio where the Type I error rate is reduced (Bathke *et al.*, 2009). Where the output of the Mauchly's sphericity test was deemed to be significant ($p \leq 0.05$), this adjustment was included within the statistical analysis of the data. Effect sizes (ES) were calculated between injured limb and uninjured control using a bias-corrected hedge's *g* with 95% confidence intervals. ES was interpreted as negligible (0-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) very large (1.2-1.99) and huge ($\geq$2.0) (Sawilowsky, 2009).

4b.3. Results

All data from the dependent variables were inspected for outliers via visual checking of the box-plots, with values greater than 1.5 box-lengths being considered outliers. As the identified outliers were not a result of data entry error or measurement error they were not rejected as invalid and were hence included in the statistical analysis.

Following checks for normality and homogeneity of variance, all dependent variable data was found to be non-normally distributed and the assumption of homogeneity of variance was violated, as assessed by Shapiro-Wilk and Levene's test respectively ($p \leq .05$). As non-normality of this data does not affect Type I error rate substantially and the ANOVA is deemed fairly 'robust' to deviations from normality, the ANOVA was used for all subsequent analysis.

Mean percentage increase ± standard deviation for the dependent variables across the 6 treatment sessions are listed in Tables 4b.1-6.

Table 4b.1. *Percentage change and standard deviation for dorsiflexion range of motion (DF-ROM) for each treatment group across the 6 treatment sessions.*

| Variables | Treatment group | | | | | |
| | 30s | | 60s | | 120s | |
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	**6.16 ± 0.95^c**	-0.36 ± 0.97	**9.91 ± 9.93**	0.73 ± 0.39	**15.20 ± 6.98^a**	0.58 ± 0.74
Session 2	4.52 ± 3.00^{bc}	0.94 ± 1.23	**8.43 ± 4.14^{ac}**	0.20 ± 0.67	**14.68 ± 6.48^{ab}**	-0.64 ± 1.53
Session 3	**4.58 ± 2.60^{bc}**	0.34 ± 1.24	**8.40 ± 4.04^{ac}**	-0.44 ± 1.50	**13.90 ± 4.90^{ab}**	-1.10 ± 0.43
Session 4	**8.29 ± 4.73**	0.91 ± 0.85	**8.91 ± 4.76**	-0.20 ± 1.14	**10.32 ± 1.85**	0.28 ± 0.91
Session 5	**8.43 ± 3.18**	0.82 ± 0.80	**9.13 ± 4.97**	0.41 ± 0.91	**9.99 ± 2.34**	-0.46 ± 1.70
Session 6	**7.16 ± 2.19**	0.68 ± 0.93	**6.77 ± 2.88**	0.68 ± 0.92	**5.78 ± 2.69**	-0.31 ± 1.17

^{a} significant compared to the 30 second group; ^{b} significant compared to the 60 second group; ^{c} significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.

Table 4b.2. *Percentage change and standard deviation for the weight-bearing lunge test (WBLT) for each treatment group across the 6 treatment sessions.*

| Variables | Treatment group | | | | | |
| | 30s | | 60s | | 120s | |
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	**6.53 ± 1.35^c**	-0.24 ± 0.90	**9.80 ± 10.19**	0.87 ± 0.47	**15.09 ± 6.78^a**	0.69 ± 0.87
Session 2	4.56 ± 3.20^{bc}	0.96 ± 1.07	**8.61 ± 4.53^{ac}**	0.14 ± 0.63	**14.53 ± 6.60^{ab}**	-0.74 ± 1.79
Session 3	**4.68 ± 2.69^{bc}**	0.09 ± 1.36	**8.29 ± 4.04^{ac}**	-0.19 ± 1.41	**14.00 ± 4.96^{ab}**	-1.17 ± 0.71
Session 4	**8.49 ± 4.67**	0.75 ± 1.00	**8.86 ± 4.58**	-0.06 ± 1.09	**10.39 ± 1.89**	0.12 ± 0.56
Session 5	**8.51 ± 3.19**	0.69 ± 0.66	**9.22 ± 4.89**	0.31 ± 0.93	**9.99 ± 2.45**	-0.69 ± 1.58
Session 6	**7.26 ± 2.23**	0.60 ± 1.13	**6.76 ± 2.73**	0.43 ± 0.92	**5.98 ± 2.63**	-0.29 ± 1.32

^{a} significant compared to the 30 second group; ^{b} significant compared to the 60 second group; ^{c} significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.

Table 4b.3. *Percentage change and standard deviation for posterior glide (PG) for each treatment group across the 6 treatment sessions.*

Variables	Treatment group					
	30s		60s		120s	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	**5.94 ± 1.50c**	0.12 ± 1.21	**7.89 ± 6.33c**	0.67 ± 0.59	**14.97 ± 6.17ab**	0.25 ± 1.14
Session 2	4.28 ± 3.39bc	0.96 ± 1.20	**8.59 ± 4.20ac**	0.22 ± 0.74	**13.28 ± 6.85ab**	-0.36 ± 1.23
Session 3	**4.55 ± 2.82bc**	0.05 ± 1.39	**8.72 ± 4.02ac**	-0.42 ± 1.34	**13.83 ± 4.72ab**	-1.24 ± 0.82
Session 4	**8.31 ± 4.87**	0.91 ± 0.91	**8.60 ± 3.91**	-0.16 ± 1.15	**10.06 ± 1.68**	0.34 ± 1.29
Session 5	**8.32 ± 3.15**	0.87 ± 0.84	**8.66 ± 3.90**	0.57 ± 1.03	**10.05 ± 2.44**	-0.26 ± 2.02
Session 6	**7.16 ± 1.09**	0.81 ± 1.09	**6.67 ± 2.74**	0.73 ± 0.97	**5.67 ± 2.77**	-0.19 ± 1.49

a significant compared to the 30 second group; b significant compared to the 60 second group; c significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.

Table 4b.4. *Percentage change and standard deviation for the anterior reach distance (ANT) of the Star Excursion Balance Tests for each treatment group across the 6 treatment sessions.*

Variables	Treatment group					
	30s		60s		120s	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	**1.13 ± 0.30bc**	-0.11 ± 0.23	**2.13 ± 0.60ac**	-0.14 ± 0.24	**3.02 ± 0.51ab**	0.02 ± 0.18
Session 2	**1.62 ± 0.40bc**	0.08 ± 0.43	**2.11 ± 0.23ac**	0.21 ± 0.18	**3.46 ± 0.42ab**	0.02 ± 0.18
Session 3	**1.83 ± 0.67bc**	-0.40 ± 0.41	**2.48 ± 0.17ac**	-0.12 ± 0.26	**3.77 ± 0.60ab**	0.02 ± 0.18
Session 4	**1.55 ± 0.47bc**	-0.25 ± 0.36	**2.39 ± 0.34ac**	-0.10 ± 0.18	**4.16 ± 0.57ab**	0.02 ± 0.18
Session 5	**1.86 ± 0.74bc**	0.24 ± 0.37	**2.85 ± 0.52ac**	-0.09 ± 0.09	**4.71 ± 1.18ab**	0.02 ± 0.18
Session 6	**1.88 ± 0.82bc**	0.61 ± 0.90	**2.68 ± 0.36ac**	-0.01 ± 0.19	**3.67 ± 0.24ab**	0.02 ± 0.18

a significant compared to the 30 second group; b significant compared to the 60 second group; c significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.

Table 4b.5. *Percentage change and standard deviation for the posterolateral reach distance (PL) of the Star Excursion Balance Test for each treatment group across the 6 treatment sessions.*

Variables	Treatment group					
	30s		60s		120s	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	**1.58 ± 0.36**[bc]	1.05 ± 0.29	2.33 ± 0.39[a]	2.01 ± 0.59	2.64 ± 0.15[a]	2.26 ± 0.48
Session 2	1.60 ± 0.93[bc]	1.60 ± 0.21	2.47 ± 0.18[a]	2.11 ± 0.27	2.86 ± 0.38[a]	2.94 ± 0.96
Session 3	1.55 ± 0.46[bc]	1.31 ± 0.36	2.54 ± 0.53[a]	2.38 ± 0.34	2.82 ± 0.22[a]	2.61 ± 0.40
Session 4	1.88 ± 1.15[bc]	1.50 ± 0.22	**3.27 ± 0.79**[a]	2.33 ± 0.44	2.80 ± 0.35[a]	2.40 ± 0.29
Session 5	1.54 ± 0.33[bc]	1.46 ± 0.33	2.75 ± 0.95[a]	2.25 ± 0.52	2.91 ± 0.28[a]	2.41 ± 0.20
Session 6	1.50 ± 0.46[bc]	1.62 ± 0.22	2.04 ± 0.44[ac]	2.45 ± 0.43	2.76 ± 0.19[ab]	2.42 ± 0.71

[a] *significant compared to the 30 second group;* [b] *significant compared to the 60 second group;* [c] *significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.*

Table 4b.6. *Percentage change and standard deviation for the posteromedial reach distance (PM) of the Star Excursion Balance Test for each treatment group across the 6 treatment sessions.*

Variables	Treatment group					
	30s		60s		120s	
	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
Session 1	0.90 ± 0.26[bc]	0.84 ± 0.29	**2.10 ± 0.79**[a]	1.55 ± 0.38	2.21 ± 0.54[a]	1.89 ± 0.58
Session 2	0.88 ± 0.45[bc]	1.21 ± 0.38	2.60 ± 0.53[a]	2.00 ± 0.26	2.46 ± 0.62[a]	2.16 ± 0.57
Session 3	0.94 ± 0.61[bc]	1.15 ± 0.21	2.71 ± 0.75[a]	2.54 ± 0.69	2.78 ± 0.20[a]	2.42 ± 0.33
Session 4	0.92 ± 0.61[bc]	1.36 ± 0.33	**2.44 ± 0.40**[a]	1.78 ± 0.93	2.98 ± 0.56[a]	2.59 ± 0.40
Session 5	0.96 ± 0.32[bc]	1.35 ± 0.43	2.12 ± 0.78[a]	1.98 ± 0.37	2.87 ± 0.39[a]	2.49 ± 0.47
Session 6	0.95 ± 0.50[bc]	1.23 ± 0.44	1.81 ± 0.68[ac]	2.04 ± 0.46	2.96 ± 0.41[ab]	2.38 ± 0.24

[a] *significant compared to the 30 second group;* [b] *significant compared to the 60 second group;* [c] *significant compared to the 120 second group; bold font indicates significance when compared to uninjured control.*

The two-way ANOVA for DF-ROM revealed a statistically significant main effect for treatment group ($F_{(1, 90)} = 75.321$, $p < 0.001$, partial $\eta^2 = 0.807$) and measurement time ($F_{(3.493, 314.387)} = 5.952$, $p < 0.001$, partial $\eta^2 = 0.062$). There was also a significant interaction effect between the treatment and time on DF-ROM ($F_{(17.466, 314.387)} = 7.688$, $p < 0.001$, partial $\eta^2 = .299$, $\acute{\epsilon} = 0.699$).

The two-way ANOVA for the WBLT revealed a statistically significant main effect for treatment group ($F_{(1, 90)} = 76.573$, $p < 0.001$, partial $\eta^2 = 0.810$) and measurement time ($F_{(3.408, 306.754)} = 6.084$, $p < 0.001$, partial $\eta^2 = 0.063$). There was also a significant interaction effect between the treatment and time on WBLT ($F_{(17.042, 306.754)} = 6.954$, $p < 0.001$, partial $\eta^2 = 0.279$, $\acute{\epsilon} = 0.682$).

The two-way ANOVA for PG revealed a statistically significant main effect for treatment group ($F_{(1, 90)} = 104.313$, $p < 0.001$, partial $\eta^2 = 0.853$) and measurement time ($F_{(3.995, 359.552)} = 4.206$, $p < 0.01$, partial $\eta^2 = 0.045$). There was also a significant interaction effect between the treatment and time on PG ($F_{(19.975, 359.552)} = 7.420$, $p < 0.001$, partial $\eta^2 = 0.292$, $\acute{\epsilon} = .799$).

The two-way ANOVA for the ANT reach distance revealed a statistically significant main effect for treatment group ($F_{(1, 90)} = 573.836$, $p < 0.001$, partial $\eta^2 = 0.970$) and measurement time ($F_{(3.037, 273.348)} = 23.878$, $p < 0.001$, partial $\eta^2 = 0.210$). There was also a significant interaction effect between the treatment and time on ANT ($F_{(15.186, 273.348)} = 7.872$, $p < 0.001$, partial $\eta^2 = 0.304$, $\acute{\epsilon} = .607$).

The two-way ANOVA for the PL reach distance revealed a statistically significant main effect for treatment group (F (1, 90) = 54.447, $p < 0.001$, partial $\eta^2 = 0.752$) and measurement time (F (3.707, 333.611) = 8.485, $p < 0.001$, partial $\eta^2 = 0.086$). There was also a significant interaction effect between the treatment and time on PL (F (18.534, 333.611) = 3.839, $p < 0.001$, partial $\eta^2 = 0.176$, $\acute{\varepsilon} = .741$).

The two-way ANOVA for PM reach distance revealed a statistically significant main effect for treatment group (F (1, 90) = 54.553, $p < 0.001$, partial $\eta^2 = 0.752$) and measurement time (F (4.186, 376.772) = 22.167, $p < 0.001$, partial $\eta^2 = 0.198$). There was also a significant interaction effect between the treatment and time on PL (F (20.932, 376.772) = 5.839, $p < 0.001$, partial $\eta^2 = 0.245$, $\acute{\varepsilon} = .837$).

4b.3.1. Treatment Session 1

Simple main effects for treatment group revealed statistically significant differences in DF-ROM ($F_{(5, 90)} = 25.001$, $p \leq 0.001$, partial $\eta^2 = .581$), WBLT (F (5, 90) = 23.659, $p \leq 0.001$, partial $\eta^2 = 0.568$), PG (F (5, 90) = 39.975, $p \leq 0.001$, partial $\eta^2 = 0.690$), ANT (F (5, 90) = 199.922, $p \leq 0.001$, partial $\eta^2 = 0.917$), PL (F (5, 90) = 32.830, $p \leq 0.001$, partial $\eta^2 = 0.646$) and PM (F (5, 90) = 22.041, $p \leq 0.001$, partial $\eta^2 = 0.550$) following session 1.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for DF-ROM (9.03 ± 1.77^0, $p \leq 0.001$), WBLT (8.57 ± 1.79cm, $p \leq 0.001$), PG (9.03 ± 1.32^0, $p \leq 0.001$), ANT (1.90 ± 0.13, $p \leq 0.001$), PL (1.06 ± 0.14, $p \leq 0.001$) and PM (1.31 ± 0.18, $p \leq 0.001$). The 60 second treatment group also showed significantly greater

improvement when compared to the 30 second treatment group for ANT (1.00 ± 0.13, $p \le 0.001$), PL (0.75 ± 0.14, $p \le 0.001$) and PM (1.20 ± 0.18, $p \le 0.001$). Significantly greater improvement in the 120 second group when compared to the 60 second group were only observed for the PG (7.08 ± 1.32^0, $p \le 0.001$) and ANT (0.89 ± 0.13, $p \le 0.001$). There were no other statistically significant differences between the intervention groups ($p \ge 0.05$).

For DF-ROM, WBLT, PG and ANT all treatment group showed statistically significant improvements when compared to their uninjured controls ($p \le 0.001$). For PL significant differences when compared to the uninjured control groups were only evident for the 30 second treatment group ($p \le 0.01$), with only the 60 second treatment group showing significant differences when compared to the uninjured control for PM ($p \le 0.05$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \ge 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'very large' effect ($g \ge 1.20$) for PL and a 'moderate' effect ($g \ge 0.50$) for PM. For the 60 second treatment group there was a 'very large' effect ($g \ge 1.20$) for DF-ROM, WBLT and PG, with 'huge' effect ($g \ge 2.00$) for ANT, a 'moderate' effect ($g \ge 0.50$) for PL and a 'large' effect ($g \ge 0.80$) for PM. For the 30 second treatment group there was a 'huge' effect ($g \ge 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'very large' effect ($g \ge 1.20$) for PL and a 'small' effect ($g \ge 0.20$) for PM (Figures 4b.2-7.).

Simple main effects for treatment group revealed statistically significant differences in DF-ROM ($F_{(5, 90)}$ = 46.714, $p \leq 0.001$, partial η^2 = 0.722), WBLT ($F_{(5, 90)}$ = 42.783, $p \leq 0.001$, partial η^2 = 0.704), PG ($F_{(5, 90)}$ = 35.781, $p \leq 0.001$, partial η^2 = 0.665), ANT ($F_{(5, 90)}$ = 295.564, $p \leq 0.001$, partial η^2 = 0.943), PL ($F_{(5, 90)}$ = 16.225, $p \leq 0.001$, partial η^2 = 0.474) and PM ($F_{(5, 90)}$ = 16.225, $p \leq 0.001$, partial η^2 = 0.474) following session 2.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for all dependent variables (DF-ROM = 13.74 ± 1.23^0, $p \leq 0.001$; WBLT = 9.97 ± 1.28cm, $p \leq 0.001$; PG = 9.00 ± 1.29^0, $p \leq 0.001$; ANT = 1.84 ± 0.11, $p \leq 0.001$; PL = 1.26 ± 0.21cm, $p \leq 0.001$; PM = 1.26 ± 0.21cm, $p \leq 0.001$). The 60 second treatment group also showed significantly greater improvement when compared to the 30 second treatment group for all dependent variables (DF-ROM = 3.91 ± 1.23^0, $p \leq 0.001$; WBLT = 3.91 ± 1.28cm, $p \leq 0.001$; PG = 4.31 ± 1.29^0, $p \leq 0.05$; ANT = 0.49 ± 0.11, $p \leq 0.005$; PL = 0.87 ± 0.21cm, $p \leq 0.005$; PM = 0.87 ± 0.21cm, $p \leq 0.005$). Significantly greater improvement in the 120 second group when compared to the 60 second group were observed for the DF-ROM (6.25 ± 1.23^0, $p \leq 0.001$), WBLT (5.92 ± 1.28cm, $p \leq 0.001$), PG (4.69 ± 1.29^0, $p \leq 0.01$), ANT (1.35 ± 0.11, $p \leq 0.001$) but not for PL or PM ($p \geq 0.05$).

For DF-ROM, WBLT and PG the 120 second and 60 second treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$), however no difference was observed between the 30 second treatment group and uninjured controls for these dependent variables ($p \geq 0.05$). For the ANT all

treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$). For PL and PM there were no significant differences between treatment groups and uninjured controls for any treatment duration ($p \geq 0.05$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'negligible' effect ($g \leq 0.01$) for PL and a 'moderate' effect ($g \geq 0.50$) for PM. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with 'very large' effect ($g \geq 1.20$) for both PL and PM. For the 30 second treatment group there was a 'very large' effect ($g \geq 1.20$) for DF-ROM, WBLT and PG, with a huge' effect ($g \geq 2.00$) for ANT, a 'negligible' effect ($g \leq 0.01$) for PL, and a 'moderate negative' effect ($g \geq -0.50$) for PL (Figures 4b.2-7.).

4b.3.3. Treatment Session 3

Simple main effects for treatment group revealed statistically significant differences in DF-ROM ($F_{(5, 90)} = 66.382$, $p \leq 0.001$, partial $\eta^2 = 0.787$), WBLT ($F_{(5, 90)} = 65.219$, $p \leq 0.001$, partial $\eta^2 = 0.784$), PG ($F_{(5, 90)} = 68.573$, $p \leq 0.001$, partial $\eta^2 = 0.792$), ANT ($F_{(5, 90)} = 247.788$, $p \leq 0.001$, partial $\eta^2 = 0.932$), PL ($F_{(5, 90)} = 39.033$, $p \leq 0.001$, partial $\eta^2 = 0.684$) and PM ($F_{(5, 90)} = 39.033$, $p \leq 0.001$, partial $\eta^2 = 0.684$) following session 3.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for all dependent variables (DF-ROM = 9.33 ± 1.03^0, $p \leq 0.001$; WBLT = 9.33 ± 1.04cm, $p \leq 0.001$; PG

= 9.28 ± 1.03^0, $p \leq 0.001$; ANT = 1.95 ± 0.15, $p \leq 0.001$; PL = 1.27 ± 0.14cm, $p \leq 0.001$; PM = 1.27 ± 0.14cm, $p \leq 0.001$). The 60 second treatment group also showed significantly greater improvement when compared to the 30 second treatment group for all dependent variables (DF-ROM = 3.82 ± 1.03^0, $p \leq 0.001$; WBLT = 3.61 ± 1.04cm, $p \leq 0.05$; PG = 4.17 ± 1.03^0, $p \leq 0.005$; ANT = 0.65 ± 0.15, $p \leq 0.005$; PL = 1.00 ± 0.14cm, $p \leq 0.001$; PM = 1.00 ± 0.14cm, $p \leq 0.001$). Significantly greater improvement in the 120 second group when compared to the 60 second group were observed for the DF-ROM (5.50 ± 1.03^0, $p \leq 0.001$), WBLT (5.72 ± 1.04cm, $p \leq 0.001$), PG (5.11 ± 1.03^0, $p \leq 0.001$), ANT (1.29 ± 0.15, $p \leq 0.001$) but not for PL or PM ($p \geq 0.05$).

For DF-ROM, WBLT, PG and ANT all treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$), For PL and PM there were no significant differences between treatment groups and uninjured controls for any treatment duration ($p \geq 0.05$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'moderate' effect ($g \geq 0.50$) for PL and a 'very large' effect ($g \geq 1.20$) for PM. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'small' effect ($g \geq 0.20$) for both PL and PM. For the 30 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT and ANT, with a 'very large' effect ($g \geq 1.20$) for PG, a 'moderate' effect ($g \geq 0.50$) for PL, and a 'moderate negative' effect ($g \geq -0.50$) for PM (Figures 4b.2-7.).

4b.3.4. Treatment Session 4

Simple main effects for treatment group revealed statistically significant differences in DF-ROM ($F_{(5, 90)} = 45.019$, $p \leq 0.001$, partial $\eta^2 = 0.714$), WBLT ($F_{(5, 90)} = 48.413$, $p \leq 0.001$, partial $\eta^2 = 0.729$), PG ($F_{(5, 90)} = 48.019$, $p \leq 0.001$, partial $\eta^2 = 0.727$), ANT ($F_{(5, 90)} = 347.548$, $p \leq 0.001$, partial $\eta^2 = 0.951$), PL ($F_{(5, 90)} = 16.122$, $p \leq 0.001$, partial $\eta^2 = 0.472$) and PM ($F_{(5, 90)} = 16.122$, $p \leq 0.001$, partial $\eta^2 = 0.472$) following session 4.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for ANT (2.62 ± 0.13, $p \leq 0.001$), PL (0.92 ± 0.22cm, $p \leq 0.005$) and PM (0.92 ± 0.22cm, $p \leq 0.005$). The 60 second treatment group also showed significantly greater improvement when compared to the 30 second treatment group for ANT (0.84 ± 0.13, $p \leq 0.001$), PL (1.39 ± 0.22cm, $p \leq 0.001$) and PM (1.39 ± 0.22cm, $p \leq 0.001$). Significantly greater improvement in the 120 second group when compared to the 60 second group were only observed for the ANT (1.77 ± 0.13, $p \leq 0.001$) and not for PL or PM ($p \geq 0.05$). For DF-ROM, WBLT and PG there was no statistically significant difference between any treatment intervention group ($p \geq 0.05$).

For DF-ROM, WBLT, PG and ANT all treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$), For PL and PM the only significant difference between the treatment group and uninjured controls was for the 60 second group ($p \leq 0.005$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'moderate' effect ($g \geq 0.50$) for PL and a 'large' effect ($g \geq 0.80$) for PM. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'very large' effect ($g \geq 1.20$) for PL and a 'large' effect ($g \geq 0.80$) for PM. For the 30 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'small' effect ($g \geq 0.20$) for PL, and a 'large negative' effect ($g \geq -0.80$) for PM (Figures 4b.2-7.).

4b.3.5. Treatment Session 5

Simple main effects for treatment group revealed statistically significant differences in DF-ROM (F (5, 90) = 52.245, p ≤ 0.001, partial η^2 = 0.744), WBLT (F (5, 90) = 55.717, p ≤ 0.001, partial η^2 = 0.756), PG (F (5, 90) = 59.108, p ≤ 0.001, partial η^2 = 0.767), ANT (F (5, 90) = 148.889, p ≤ 0.001, partial η^2 = 0.892), PL (F (5, 90) = 23.365, p ≤ 0.001, partial η^2 = 0.565) and PM (F (5, 90) = 23.365, p ≤ 0.001, partial η^2 = 0.565) following session 5.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for ANT (2.85 ± 0.22, $p \leq 0.001$), PL (1.46 ± 0.18cm, $p \leq 0.001$) and PM (1.46 ± 0.18cm, $p \leq 0.001$). The 60 second treatment group also showed significantly greater improvement when compared to the 30 second treatment group for ANT (0.99 ± 0.22, $p \leq 0.001$), PL (1.21 ± 0.18cm, $p \leq 0.001$) and PM (1.21 ± 0.18cm, $p \leq 0.001$). Significantly greater improvement in the 120 second group when compared to the 60 second group were only observed for the ANT (1.86 ± 0.22, $p \leq 0.001$) and not for PL or PM ($p \geq 0.05$).

For DF-ROM, WBLT and PG there was no statistically significant difference between any treatment intervention group ($p \geq 0.05$).

For DF-ROM, WBLT, PG and ANT all treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$), For PL and PM there was no significant difference between the treatment groups and the uninjured controls for any treatment duration ($p \geq 0.05$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT and PL, with a 'large' effect ($g \geq 0.80$) for PL. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'moderate' effect ($g \geq 0.50$) for PL and a 'small' effect ($g \geq 0.20$) for PM. For the 30 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'small' effect ($g \geq 0.20$) for PL, and a 'large negative' effect ($g \geq -0.80$) for PM (Figures 4b.2-7.).

4b.3.6. Treatment Session 6

Simple main effects for treatment group revealed statistically significant differences in DF-ROM ($F_{(5, 90)} = 48.983$, $p \leq 0.001$, partial $\eta^2 = 0.731$), WBLT ($F_{(5, 90)} = 52.213$, $p \leq 0.001$, partial $\eta^2 = 0.744$), PG ($F_{(5, 90)} = 44.351$, $p \leq 0.001$, partial $\eta^2 = 0.711$), ANT ($F_{(5, 90)} = 127.662$, $p \leq 0.001$, partial $\eta^2 = 0.876$), PL ($F_{(5, 90)} = 20.302$, $p \leq 0.001$, partial $\eta^2 = 0.530$) and PM ($F_{(5, 90)} = 20.302$, $p \leq 0.001$, partial $\eta^2 = 0.530$) following session 6.

The 120 second treatment group showed significantly greater improvement when compared to the 30 second treatment group (mean ± standard error) for ANT (1.79 ± 0.19, $p \leq 0.001$), PL (1.25 ± 0.17cm, $p \leq 0.001$) and PM (1.25 ± 0.17cm, $p \leq 0.001$). The 60 second treatment group also showed significantly greater improvement when compared to the 30 second treatment group for ANT (0.80 ± 0.19, $p \leq 0.001$), PL (0.54 ± 0.17cm, $p \leq 0.05$) and PM (0.54 ± 0.17cm, $p \leq 0.05$). Significantly greater improvement in the 120 second group when compared to the 60 second group were only observed for the ANT (0.99 ± 0.19, $p \leq 0.001$), PL (0.72 ± 0.17cm, $p \leq 0.001$) and PM (0.72 ± 0.17cm, $p \leq 0.001$). For DF-ROM, WBLT and PG there was no statistically significant difference between any treatment intervention group ($p \geq 0.05$).

For DF-ROM, WBLT, PG and ANT all treatment groups showed statistically significant improvements when compared to their uninjured controls ($p \leq 0.001$), For PL and PM there was no significant difference between the treatment groups and the uninjured controls for any treatment duration ($p \geq 0.05$).

Effect size statistics showed that for the 120 seconds treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'moderate' effect ($g \geq 0.50$) for PL and a 'very large' effect ($g \geq 1.20$) for PM. For the 60 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG and ANT, with a 'large negative' effect ($g \geq -0.80$) for PL and a 'moderate negative' effect ($g \geq -0.50$) for PM. For the 30 second treatment group there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT and PG, with a 'very large' effect ($g \geq 1.20$) for ANT, a 'small negative' effect ($g \geq -0.20$) for PM and a 'moderate negative' effect ($g \geq -0.50$) for PM (Figures 4b.2-7.).

Variable	g [95% CI]
Session 1 30 seconds	6.62 [4.86 to 8.38]
Session 1 60 seconds	1.27 [0.51 to 2.03]
Session 1 120 seconds	2.87 [1.88 to 3.86]
Session 2 30 seconds	1.52 [0.74 to 2.31]
Session 2 60 seconds	3.06 [2.04 to 4.08]
Session 2 120 seconds	3.17 [2.13 to 4.21]
Session 3 30 seconds	2.03 [1.18 to 2.88]
Session 3 60 seconds	2.83 [1.85 to 3.81]
Session 3 120 seconds	4.20 [2.96 to 5.45]
Session 4 30 seconds	2.12 [1.25 to 2.98]
Session 4 60 seconds	2.57 [1.63 to 3.50]
Session 4 120 seconds	13.44 [10.07 to 16.80]
Session 5 30 seconds	3.20 [2.15 to 4.25]
Session 5 60 seconds	2.38 [1.47 to 3.28]
Session 5 120 seconds	4.98 [3.58 to 6.38]
Session 6 30 seconds	3.75 [2.60 to 4.91]
Session 6 60 seconds	2.78 [1.81 to 3.75]
Session 6 120 seconds	2.86 [1.88 to 3.85]

g (95% CI)

Figure 4b.2. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for dorsiflexion range of motion (DF-ROM) across the study timeline.*

Variable		g [95% CI)
Session 1 30 seconds		5.75 [4.18 to 7.32]
Session 1 60 seconds		1.21 [0.45 to 1.96]
Session 1 120 seconds		2.90 [1.91 to 3.90]
Session 2 30 seconds		1.47 [0.69 to 2.25]
Session 2 60 seconds		3.06 [2.04 to 4.08]
Session 2 120 seconds		3.08 [2.05 to 4.10]
Session 3 30 seconds		2.11 [1.24 to 2.97]
Session 3 60 seconds		2.73 [1.77 to 3.70]
Session 3 120 seconds		4.17 [2.94 to 5.41]
Session 4 30 seconds		2.23 [1.35 to 3.12]
Session 4 60 seconds		2.61 [1.67 to 3.56]
Session 4 120 seconds		13.44 [10.07 to 16.80]
Session 5 30 seconds		3.31 [2.24 to 4.38]
Session 5 60 seconds		2.47 [1.55 to 3.39]
Session 5 120 seconds		5.05 [3.63 to 6.47]
Session 6 30 seconds		3.67 [2.54 to 4.81]
Session 6 60 seconds		3.03 [2.01 to 4.04]
Session 6 120 seconds		2.94 [1.94 to 3.94]

g (95% CI)

Figure 4b.3. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for the weight-bearing lunge test (WBLT) across the study timeline.*
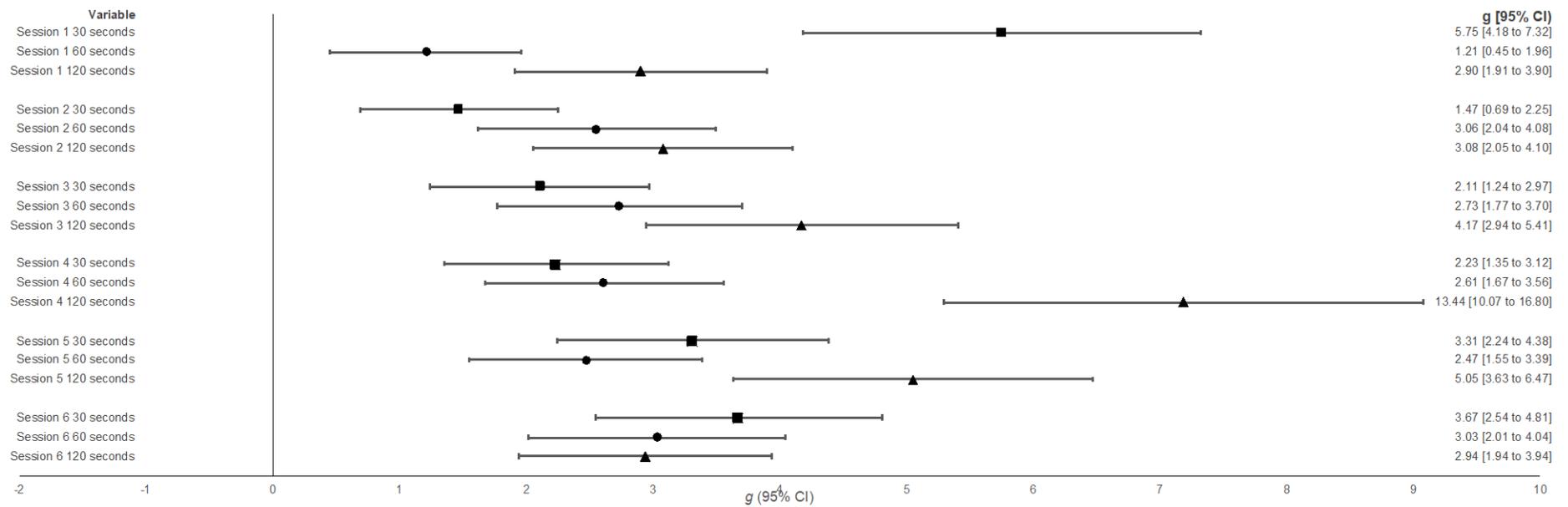
Figure 4b.4. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for posterior glide (PG) across the study timeline.*

Variable	g [95% CI]
Session 1 30 seconds	4.16 [2.93 to 5.40]
Session 1 60 seconds	1.57 [0.77 to 2.36]
Session 1 120 seconds	3.23 [2.18 to 4.29]
Session 2 30 seconds	1.27 [0.51 to 2.03]
Session 2 60 seconds	3.06 [2.04 to 4.08]
Session 2 120 seconds	2.70 [1.74 to 3.66]
Session 3 30 seconds	1.97 [1.13 to 2.82]
Session 3 60 seconds	2.97 [1.97 to 3.98]
Session 3 120 seconds	4.34 [3.07 to 5.61]
Session 4 30 seconds	2.06 [1.20 to 2.92]
Session 4 60 seconds	2.96 [1.96 to 3.97]
Session 4 120 seconds	13.44 [10.07 to 16.80]
Session 5 30 seconds	3.15 [2.11 to 4.19]
Session 5 60 seconds	2.76 [1.80 to 3.73]
Session 5 120 seconds	4.49 [3.19 to 5.79]
Session 6 30 seconds	3.51 [2.41 to 4.62]
Session 6 60 seconds	2.82 [1.84 to 3.80]
Session 6 120 seconds	2.57 [1.63 to 3.50]

g (95% CI)

Figure 4b.5. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for the anterior reach distance (ANT) of the Star Excursion Balance Test across the study timeline.*
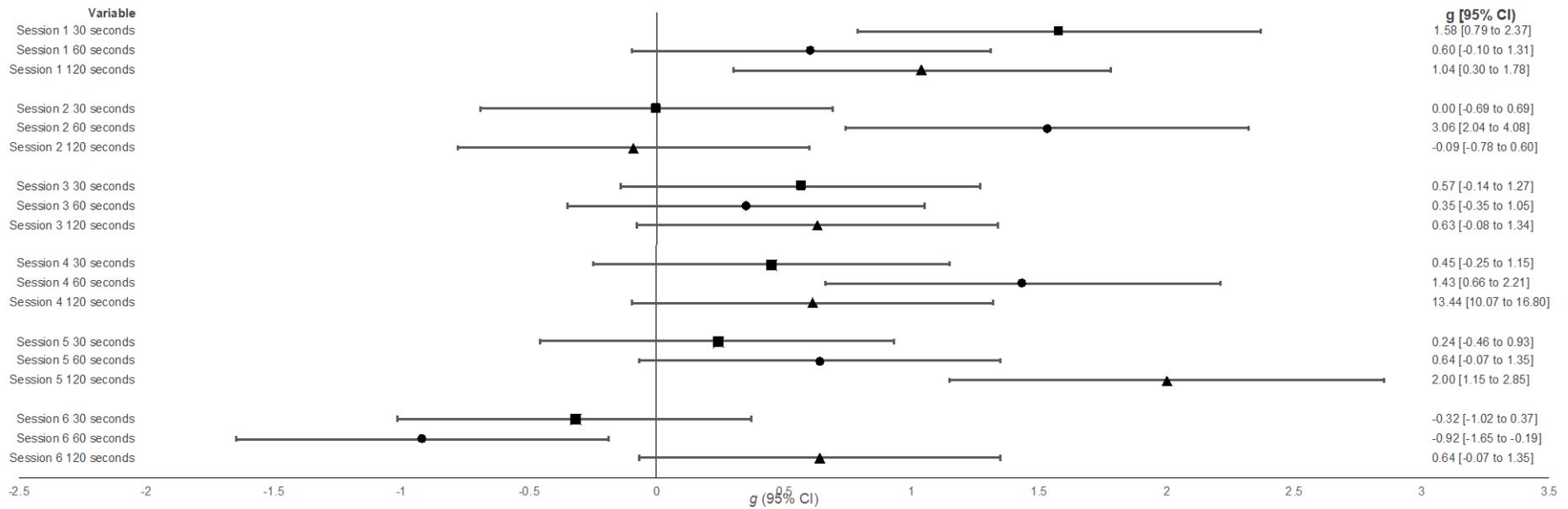
Figure 4b.6. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for the posterolateral reach distance (PL) of the Star Excursion Balance Test across the study timeline.*

Variable		g [95% CI]
Session 1 30 seconds		0.21 [-0.48 to 0.91]
Session 1 60 seconds		0.86 [0.14 to 1.59]
Session 1 120 seconds		0.56 [-0.15 to 1.26]
Session 2 30 seconds		-0.77 [-1.49 to -0.05]
Session 2 60 seconds		3.06 [2.04 to 4.08]
Session 2 120 seconds		0.49 [-0.21 to 1.19]
Session 3 30 seconds		-0.58 [-1.29 to 0.12]
Session 3 60 seconds		0.23 [-0.47 to 0.93]
Session 3 120 seconds		1.29 [0.52 to 2.05]
Session 4 30 seconds		-0.87 [-1.60 to -0.15]
Session 4 60 seconds		0.90 [0.17 to 1.63]
Session 4 120 seconds		13.44 [10.07 to 16.80]
Session 5 30 seconds		-1.00 [-1.74 to -0.27]
Session 5 60 seconds		0.22 [-0.47 to 0.92]
Session 5 120 seconds		0.86 [0.13 to 1.58]
Session 6 30 seconds		-0.58 [-1.29 to 0.13]
Session 6 60 seconds		-0.39 [-1.09 to 0.31]
Session 6 120 seconds		1.68 [0.88 to 2.49]

g (95% CI)

-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5

Figure 4b.7. *Forest plot (g ± 95% CI) of treatment versus uninjured control limb for the posteromedial reach distance (PM) of the Star Excursion Balance Test across the study timeline.*

4b.3.6. Results Summary

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for DF-ROM, WBLT and PG in the 30s, 60s and 120s treatment groups across each of the 6 treatment sessions.

- Significant differences were found between the 120s treatment group and 30s treatment group following session 1 for DF-ROM, WBLT and PG

- Significant differences were found between all treatment groups following session 2 and 3 for DF-ROM, WBLT and PG, with greater treatment durations conferring greater percentage changes.

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for ANT in the 60s and 120s treatment groups across each of the 6 treatment sessions and in the 30s treatment group following sessions 1, 3, 4, 5 and 6.

- Significant differences were found between all treatment groups, for ANT across each of the 6 treatment sessions, with greater treatment durations conferring greater percentage changes.

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for PL following session 1 for the 30s treatment group and session 4 for the 60s treatment group.

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for PM following session 1 and 4 for the 60s treatment group.

- Significant differences were found between the 120s and 30s treatment groups, and the 60s and 30s treatment groups for PL and PM across each of the 6 treatment sessions, with greater treatment durations conferring greater percentage changes.

4b.4. Discussion

The results of this study showed that all treatment durations (30s, 60s and 120s) produced statistically significant improvements across the six treatment sessions for DF-ROM, WB-DFROM, posterior glide, and reach directions of the SEBT ($p < 0.001$). Accessory mobilisations can therefore be deemed to be an effective treatment for inducing acute changes in ankle motion and dynamic postural control in those with CAI across multiple treatment sessions. This technique should be considered during the treatment regimen for individuals with this pathology. Furthermore, this research suggests that the magnitude of change is influenced by treatment duration. The mechanical outcome measures (DF-ROM, WBLT and PG) demonstrate that longer treatment durations confer greater improvements compared to shorter durations for the first three treatment sessions. Grade IV mobilisations work at the end of the available range producing a microfailure of the connective tissue restricting motion (Silvernail *et al.*, 2011). Connective tissue accommodates stress in a manner described by Hooke's law and the stress-strain curve, where a proportional relationship exists between the deformation of an elastic structure and the stress applied to it. During a grade IV mobilisation the tissue moves beyond its elastic limit to the yield point and into the plastic range (Houglum, 2016). This results in a permanent elongation of the tissue due to a failure of the collagen's force-relaxation response when a load is applied, or when the creep response causes deformation to occur too rapidly (Houglum, 2016). This deformation can occur from accumulated stress, potentially explaining the observed increase in mechanical outcome improvements as longer treatment durations are applied. However, the latter three treatment sessions show that whilst improvements can still be elicited from the mobilisation treatments, there were no significant differences between the treatment groups when comparing

DF-ROM, WBLT and PG. This shows that during the initial three treatment sessions, mobilisations of 120 seconds produce significantly greater improvements in arthrokinematic motion which is then significantly reduced as treatment sessions continue.

In a study by Green et al (2001) that focussed on ankle joint mobilisation to improve DF-ROM following acute ankle sprains, improvements were shown with an effect size of 0.45, 0.19, 0.11, 0.37 and 0.09 respectively for sessions 1, 2, 3, 4 and 5 (Terada, Pietrosimone and Gribble, 2013). Within the present study effect sizes for all treatment durations across the six treatment sessions were of a 'very large' magnitude ($\geq$1.20), surmounting the previous results. This may be due to the chronic nature of the participants symptoms in the present study or differences in the mobilisation intervention. Whilst Green et al. did not provide a definitive identification of the grade utilised, due to pain presence the intervention was a small-amplitude oscillation applied at the beginning of range. According to the Maitland concept (Hengeveld and Banks, 2005), this would be defined as a grade I mobilisation which is primarily used to reduce pain and not influence ROM.

Multiple studies highlight the benefit of using grade IV mobilisations over lower grades in order to elicit significant changes in arthrokinematic motion. In two studies by Hoch et al (Hoch, Andreatta, *et al.*, 2012; Hoch *et al.*, 2014), participants were treated six times over a two week period, receiving 4 sets of 2 minutes of Maitland grade III mobilisations and sets of 2 minutes of grade II joint tractions. Upon cessation of the treatment intervention, participants were observed to have increased their WBLT scores by 12.4% with an effect size of >3.0 (Hoch, Andreatta, *et al.*, 2012). Within the

present study the 120 second treatment group showed improvements beyond this value for the first three treatment sessions (15.09%, 14.53% and 14.00% respectively). Effect sizes for the 120 second treatment group were also 'huge' (≥ 2.0) for each of these treatment sessions. For PG there was a significant improvement for all treatment durations, with the exception of the 30 second treatment group in session 2. This was significantly greater in the longer treatment duration groups than shorter ones across the initial three sessions, with effect sizes being seen as very large (≥ 1.20) to huge (≥ 2.0). In the latter Hoch et al study (Hoch *et al.*, 2014) non-significant decrease in PG was observed with an effect size of -0.51.

These findings are surprising as during dorsiflexion the talus must be able to glide posteriorly (Soavi *et al.*, 2000). Restrictions in this movement are often seen within those with CAI due to the propensity of the talus to become subluxed, or malpositioned, through damage to the ligamentous restraint (Wikstrom and Hubbard, 2010). This alters the axis of rotation anteriorly within the coronal plane, and can lead to restrictions in posterior motion and subsequent constraints in DF-ROM (Hubbard and Hertel, 2006). Improvements in DF-ROM can be directly linked to improvements in PG which were observed within the current study, which again may be a related to the lower mobilisation grades used within the other studies. Whilst all three of these arthrokinematic outcome measures have been shown to have excellent reliability coefficients (ICC > 0.75) the similar improvements noted within this study may identify some internal consistency as they could be seen to be measuring the same, or related, constructs. As the WBLT is the most functional of these tests due to its assessment in a weight-bearing position is may be seen as a more meaningful test making the PG test and DF-ROM goniometry redundant.

Whilst grade III and IV mobilisations can work at the end of the available arthrokinematic range, grade IV mobilisations produce a far greater oscillatory frequency and mean force (Silvernail *et al.*, 2011). Greater loads are thus experienced by the connective tissue resulting in greater plastic deformation of the restrictive structures and improvements in the arthrokinematic movement of the treated joint (Green *et al.*, 2001).

Only one previous study has attempted to ascertain the effects of increased mobilisation treatment durations on ankle range of motion. The methodologically similar study by Holland et al (Holland, Campbell and Hutt, 2015) identified that asymptomatic individuals elicited a greater improvement in the WBLT following a single treatment session as the duration of mobilisation increased. This was of the magnitude of 10.9% (120 second group), 7.6% (60 second group) and 5.0% (30 second group), although the authors concluded that none of these were above the minimal detectable change score. Comparing these improvement scores to the current study, the 120 second treatment group showed greater improvements in sessions 1, 2 and 3 (15.09%, 14.53% and 14.00% respectively), with session 4 only being slightly lower at 10.39%. For the 60 second group improvements were above this for treatment session 1 to 5, with session 6 falling marginally below at 6.76%. For the 30 second group, all treatment sessions showed greater levels of improvement than the Holland et al study.

The greater improvement identified can be attributed to the use of symptomatic CAI sufferers, many of whom demonstrated significant reductions in DF-ROM prior to the

commencement of the intervention. At least 10^0 of DF-ROM is needed to walk, descend stairs or kneel (Green, Refshauge and Crosbie, 1999), whilst running requires at least 20^0 (Yamaguchi *et al.*, 2009). CAI suffers often have DF-ROMs below 0^0 (Soucie *et al.*, 2011) due to the propensity of the talus towards anterior subluxation following a LAS resulting in restrictions in posterior noncontractile tissue and anterior ligament laxity (Hoch *et al.*, 2014). This allows for greater changes in ROM to be elicited through the application of anterior-to-posterior joint mobilisations within the CAI population compared to their asymptomatic counterparts.

Within the Holland et al study significant improvements in DF-ROM beyond the minimal detectable change scores were seen for the 30 second (14.2%), 60 second (21.6%) and 120 second groups (32.8%). These values were much higher than reported in the current study where the highest values for the 120 second and 60 second groups being observed following session 1 (15.20% and 9.91%), and following session 5 for the 30 second group (8.43%). The differences may be due to the specific means by which DF-ROM was measured. Research has identified that knee position directly influences DF-ROM, with greater ROM achieved with 90^0 of knee flexion (DiGiovanni *et al.*, 2002), which was a reason for this method being used within the current study. The Holland et al study utilised an extended knee position during DF-ROM measurements which increases the passive tension within the gastrocnemius and general stiffness of the ankle via its effects on the series and elastic components of the muscle-tendon unit (Kovaleski *et al.*, 2008; Krause *et al.*, 2011). As such, this position may have allowed for greater improvements to be elicited as full arthrokinematic range was restricted in the knee extended position. In addition, any

slight flexion of the knee on post-mobilisation testing would result in an artificially augmented improvement in ROM.

Development in the anterior reach direction of the SEBT were significant for all treatment durations, with longer treatments again conferring greater improvements. These improvements can be attributed to their relationship to the WBLT, with research indicating that an estimated 28% of the variance in anterior reach distance can be attributed to this measure (Hoch, Staton and McKeon, 2011b). Following similar mobilisation treatments, Hoch et al (Hoch, Staton, *et al.*, 2012) identified a significant improvement of 2.8% in anterior reach distance on the SEBT following 6 treatment sessions. Within the current study improvements were greater than this for the 120 second treatment group for each of the 6 individual treatment session (range = 3.02 to 4.71%). For the 60 second treatment group this fell marginally below (range = 2.11-2.85%), whilst the 30 second group was considerably lower (range = 1.13 to 1.88%). The effect sizes also identified these improvements to be 'huge' for all groups across the six sessions, with the exception of the 30 second group where a 'very large' effect size was observed following session 6. It is again postulated that these enhanced scores are related to the use of grade IV mobilisation and their ability to provide greater deformation of the connective tissue. However, much of the kinematic predictors of performance on the SEBT can be attributed to proximal joint motion, with hip and knee flexion accounting for 78% of the variance in maximal reach distance (Robinson and Gribble, 2008). As such, improvements in this measure will always be limited if only ankle joint mobility is being improved.

Whilst there were no real notable improvements for posterolateral or posteromedial reach distances when treatment groups were compared against controls, a statistically significant differences for all groups following all six treatment sessions was revealed. Effect size calculations showed a full range of values across the spectrum, including some negative scores. Consequently, no real pattern emerged. It is postulated that mobilisations may be having a bilateral effect on dynamic balance. Motor activity intervention of one limb has been shown to enhance performance within the contralateral untrained limb (Schlenstedt *et al.*, 2017). This 'bilateral transfer' is thought to occur through neural mechanisms, with Carroll et al (Carroll *et al.*, 2006) suggesting two plausible mechanisms. First, unilateral treatment could cause a spill-over effect of neural drive from the active to the inactive hemisphere that induces adaptations in the control system of the contralateral limb. Second, treatment could cause 'bilateral access' in which neuromuscular adaptations in the control system of the treated limb become accessible by the opposite limb. It must also be noted that contralateral effects could also be biased by familiarisation with the testing procedures, although this bias does appear small (Carroll *et al.*, 2006).

4b.4.1. Recommendations for Future Research

The potential limitations of the current study are that only a female collegiate age cohort was used. This may limit the ability of the current study to generalise the results to wider populations as connective tissue exhibits changes in biomechanical properties and cross-sectional area in response to exercise, disuse and aging (Weppler and Magnusson, 2010). Studies have also shown that the tolerance of female ankle ligaments is significantly less than that of males even in the absence of any previous ligamentous injury (Silke, Hertel and Wunderlich, 2011). Whilst this may

increase the risk of LAS and CAI in females it would be expected that the results of mobilisation interventions would be comparable between populations as the purported physiological effects do not appear to be age or gender specific. However, further investigation is needed to confirm this assertion. Further research would also benefit from a focus on the long-term effects of mobilisation beyond the cessation of treatment. As this was not assessed within the current study, conclusions regarding the maintenance of the observed improvements cannot be made. In addition, as treatment durations were limited to a maximum of 120 seconds and as such there can be no identification of whether improvements in outcome measures continue to increase through even longer durations or whether a ceiling effect occurs once a given treatment duration is achieved. Whilst future research could focus on the minutia of mobilisation treatment durations, as the current study already shows significant improvements in function following 120 second treatments, additional research may add little clinical relevance.

4b.5. Conclusion

The current study adds clarity to the use of joint mobilisations treatment and will add to the current clinical practice and rehabilitative strategies for those with CAI. These findings show that higher treatment durations confer greater improvements in arthrokinematic function and dynamic postural control in those with CAI. There is evidence to suggest that 120 second treatment durations produce greater improvements in function in comparison to shorter durations when single sets are being applied within the first week of treatment. By addressing local mechanical impairments and enhancing sensorimotor system function, the joint mobilisation

treatment can positively augment patient oriented and clinician-oriented measures of function.

CHAPTER 5. EFFECTIVENESS OF A HOME-BASED SELF-MOBILISATION AND DYNAMIC POSTURAL CONTROL PROGRAMME FOLLOWIING CLINICAL JOINT MOBILISATION IN FEMALES WITH CHRIONIC ANKLE INSTABILITY

5.1. Introduction

The development of chronic ankle instability has been reported to affect up to 70% of those who experience lateral ankle sprains (Wikstrom *et al.*, 2007). CAI is characterised by residual symptoms which include recurrent bouts of instability, additional sprains, and reduced functional capacity. These symptoms can limit physical activity and activities of daily living for years post injury (Braun, 1999; Konradsen *et al.*, 2002; Hubbard-Turner and Turner, 2015) and have also been reported to decrease health related quality of life (HRQL) (Anandacoomarasamy, 2005; Arnold, Wright and Ross, 2011). Those with CAI also have a greater tendency to develop ankle osteoarthritis compared to those with no history of ankle injury (Valderrabano *et al.*, 2006).

Due to the problems associated with CAI and the high frequency of this pathology, interventions that improve the outcomes for CAI are important for both Therapists and patients. Clinical practice guidelines recommend manual therapy, therapeutic exercises and activities, and sports related activity training to progressively rehabilitate the deficiencies associated with ankle stability and movement coordination impairments (Martin *et al.*, 2013). There is a large body of evidence regarding interventions aimed at reducing the symptoms associated with CAI. Conservative intervention of CAI is accepted as the primary means of managing the condition and preventing reinjury, with research suggesting that 80% of those in the athletic

population who experience LAS and develop CAI recover with effective and structured conservative management (Chan, Ding and Mroczek, 2011). It is well established that the pathology of CAI is complex and cannot be adequately explained through the dichotomy of mechanical and functional instability (Hertel, 2002). CAI presents as a combination of ligament laxity, muscle weakness, postural control deficits and diminished proprioception, as well as altered arthrokinematics and joint structure at the talocrural joint (Denegar, Hertel and Fonseca, 2002; Hertel, 2002; Hopkins *et al.*, 2009). Manual therapy procedures, including passive joint mobilisation and manipulation, mobilisations with movement (MWM), and self-joint mobilisation have all been recommended as methods to improve ankle arthrokinematics and balance (Doherty *et al.*, 2014; Loudon, Reiman and Sylvain, 2014; Cruz-Díaz *et al.*, 2015; Jeon *et al.*, 2015a). Balance and proprioceptive training has also been seen to be beneficial in improving self-reported function, dynamic postural control and static postural control in those with CAI (Hale, Hertel and Olmsted-Kramer, 2007; Mckeon *et al.*, 2008).

Whilst it might appear that the literature has established a broad base of evidence for the use of mobilisation and rehabilitative exercise in the intervention and management of CAI, these two interventions have often been seen as mutually exclusive within the research. Research studies demonstrate that home-based rehabilitation interventions are a safe and viable option for patients with ankle sprains (Bassett and Prapavessis, 2007), which, when given in addition to 'usual care' can be effective at reducing the incidence of recurrent ankle sprains (Hupperets, Verhagen and Van Mechelen, 2009). Whilst Hupperets et al. (2009) identified a positive effect of home-based proprioceptive training, it relied upon athlete self-reporting recurrent sprains, time lost to injury and subsequent cost implications. The lack of objective outcome measures and reliance

on patient reported outcome measures (PROMs) lack the sensitivity to identify residual performance deficits with more performance-based metrics being more efficacious in assessing treatment success (Zuke *et al.*, 2018). In addition, there are no studies which have established the effect of the combination of clinical mobilisation intervention and home-based rehabilitation to improve the deficits observed in those with CAI. Given that female sports participants often have limited access to medical support in comparison to males (Emmonds, Heyward and Jones, 2019), it is also important that conservative intervention is as time and cost effective as possible. Whilst those afflicted with CAI will need to attend a clinician for initial assessment and intervention, the use of home-based rehabilitation exercise reduces health care costs and can achieve the same results as supervised exercise, as long as patients are reliable and compliant (Krischak *et al.*, 2013; Papalia *et al.*, 2013). The findings of the previous studies in Chapters 4a and 4b, show that higher joint mobilisation intervention durations confer greater improvements in arthrokinematic function and dynamic postural control in those with CAI. There is further evidence within Chapters 4a and 4b to suggest that 120 seconds of mobilisation intervention is more effective than shorter treatment durations when single sets are being applied within the first week of intervention. However, research is limited as to the effects that follow-on home-based rehabilitation would have upon these outcomes, and whether they can effectively augment the improvements already elicited by the joint mobilisation intervention. The study of the effects of home-based rehabilitation following joint mobilisation for those with CAI will therefore enhance the intervention of this pathology in a cost and time effective manner.

5.2. Methods

5.2.1. Experimental Design

This investigation employed a randomised parallel group study design. The independent variable was time (week 1, 2, 3, 4), group (intervention and control) and limb (injured, uninjured). The dependent variables were DFROM, WBLT, posterior glide, and normalised reach distances of the Star Excursion Balance Test (SEBT). Participants reported to the research laboratory for an initial testing session which was followed by 3 separate joint mobilisation intervention sessions across a 5-day period with an additional testing session being completed immediately after the final intervention cessation. Following this, participants were required to return to the research laboratory at 7, 14, 21, 28, and 35 days after the final joint mobilisation intervention for further testing to complete the study.

5.2.2. Sample Size

The sample size was calculated using G*Power version 3.1.9 (Faul *et al.*, 2007). The power of the study was set at 95%, with an alpha level of 0.05. The partial eta squared effect size was calculated using data from the previous study. This was achieved through statistical analysis using a mixed model ANOVA of the pre-intervention 1 to post-intervention 3 data independently for each of the six dependent variables being used in the current study. The largest sample size calculated was 48 (Table 5.1). 24 participants would therefore be needed for the study as the contralateral limb would be acting as the control group for each participant.

Table 5.1: *G*Power calculation for each dependent variable using Partial Eta Squared effect sizes.*

Variable	Partial Eta Squared	Sample size	Actual power
DFROM	0.921	28	95.1%
WBLT	0.922	28	95.1%
Posterior Drawer	0.925	28	95.3%
Y-balance Anterior	0.972	28	96.9%
Y-balance Posterolateral	0.795	36	95.8%
Y-balance Posteromedial	0.657	48	95.2%

5.2.3. Participants

A total of 68 female collegiate level team sports players with self-reported CAI were screened for inclusion from the University of Worcester using the internal email system and advertisements posted throughout the University.

Following the completion of the CAIT, FAAM and FAAM-S, 55 female team sports players were randomly allocated to either the intervention or control group, with 48 participants (mean ±SD: age 22.5 ±3.5yrs; height 169.4 ±7.3cm; mass 69.7 ±6.3kg) going on to complete the study (Figure 5.1).
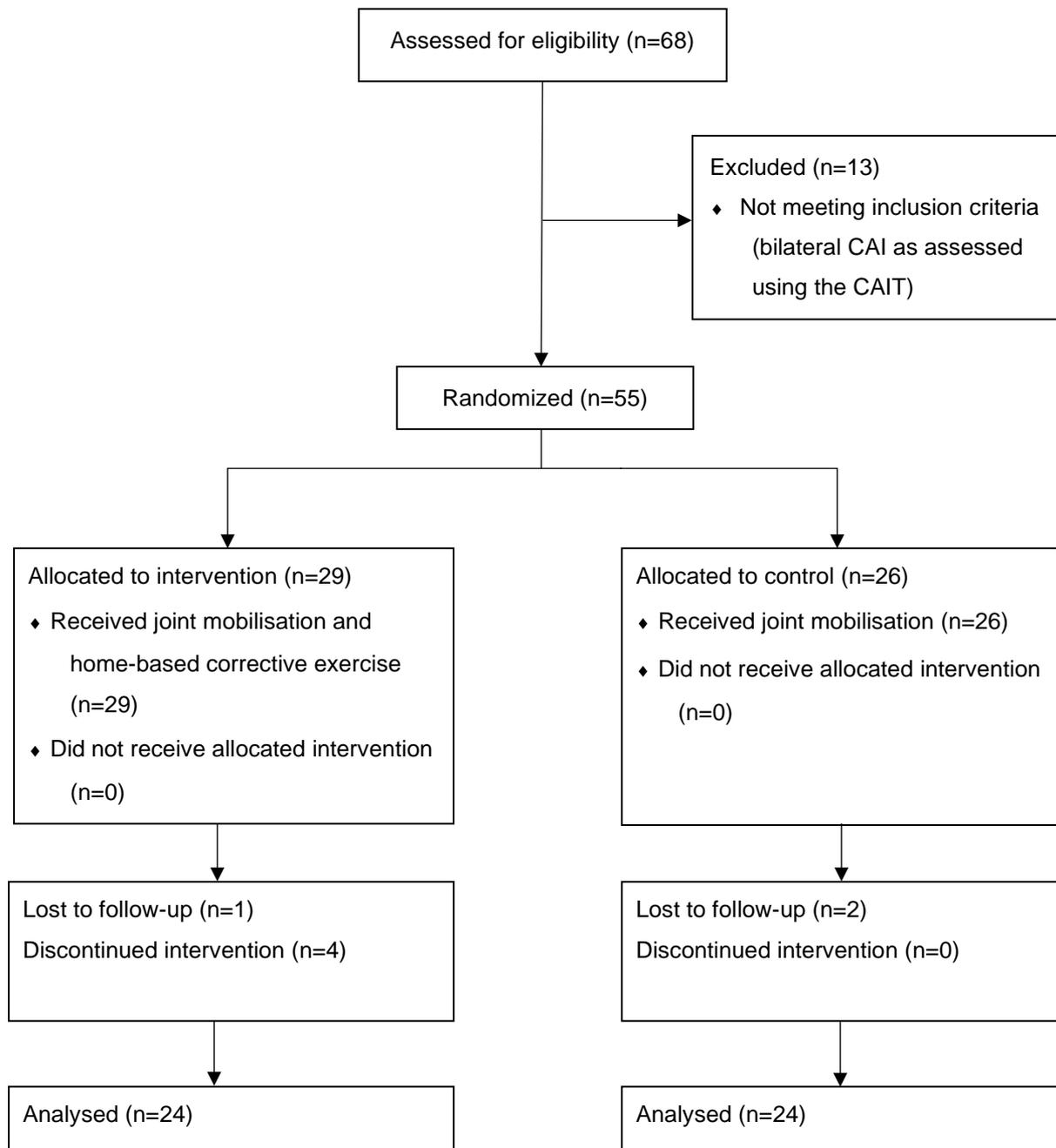
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                    ┌─────────────────────────────┐
                    │ Assessed for eligibility (n=68) │
                    └─────────────────────────────┘
                                 │
                                 │         ┌──────────────────────────────┐
                                 ├────────▶│ Excluded (n=13)               │
                                 │         │  ♦ Not meeting inclusion criteria │
                                 │         │    (bilateral CAI as assessed  │
                                 │         │    using the CAIT)             │
                                 │         └──────────────────────────────┘
                                 ▼
                    ┌─────────────────────┐
                    │  Randomized (n=55)  │
                    └─────────────────────┘
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Figure.5.1. *Flow diagram of participants. Abbreviations: CAI, chronic ankle instability; CAIT, Cumberland Ankle Instability Tool.*

5.2.4. Testing Procedures

After enrolment, each participant had the study explained to them and was given an information sheet giving them written details of the study (Appendix 5). Following the study explanation, participants were required to complete a health and consent form (Appendix 6) in order for written consent to be gained. Participants were then randomly

Figure.5.1. *Flow diagram of participants. Abbreviations: CAI, chronic ankle instability; CAIT, Cumberland Ankle Instability Tool.*

The flow diagram contains:
- Assessed for eligibility (n=68)
- Excluded (n=13): ♦ Not meeting inclusion criteria (bilateral CAI as assessed using the CAIT)
- Randomized (n=55)
- Allocated to intervention (n=29): ♦ Received joint mobilisation and home-based corrective exercise (n=29); ♦ Did not receive allocated intervention (n=0)
- Allocated to control (n=26): ♦ Received joint mobilisation (n=26); ♦ Did not receive allocated intervention (n=0)
- Lost to follow-up (n=1); Discontinued intervention (n=4)
- Lost to follow-up (n=2); Discontinued intervention (n=0)
- Analysed (n=24)
- Analysed (n=24)

5.2.4. Testing Procedures

After enrolment, each participant had the study explained to them and was given an information sheet giving them written details of the study (Appendix 5). Following the study explanation, participants were required to complete a health and consent form (Appendix 6) in order for written consent to be gained. Participants were then randomly

allocated to balanced intervention groups (n=24) of intervention or control using a computer-generated simple random allocation sequence (Appendix 9). Participants and the researcher were blinded from the group allocation until after the first pre-intervention tests were completed. All participants (intervention and control) completed their first testing session prior to receiving 120s of the joint mobilisation intervention (pre-intervention testing 1). Participants were then required to return 48 and 72 hours afterwards to receive a further joint mobilisation intervention. Following the third (72 hours) intervention participants underwent a 2nd testing session (post-intervention testing 1). Upon completion of the third intervention and testing session, the intervention group were given the home-based rehabilitation exercises to be completed over the following 4 weeks. Each exercise was demonstrated in its entirety and participants were observed completing the exercises to ensure that they were being performed correctly. The intervention group was instructed to complete the rehabilitation exercises once daily (Appendix 10). The control group were instructed to maintain normal physical activity and activities of daily living, but to complete no specific ankle rehabilitation exercises. All participants were required to return to the clinic for follow up testing sessions following the final joint mobilisation intervention session after 7 days (week 1), 14 days (week 2), 21 days (week 3), and 28 days (week 4). Adherence to the home-based rehabilitation programme was ascertained verbally from each participant upon attendance at the testing sessions. Any participant not adhering fully to the required daily exercises was removed from the study. An additional follow-up session was scheduled for 35 days (week 5) in order for participants to complete the self-reported function questionnaires (CAIT, FAAM and FAAM-S) (Figure 5.2).
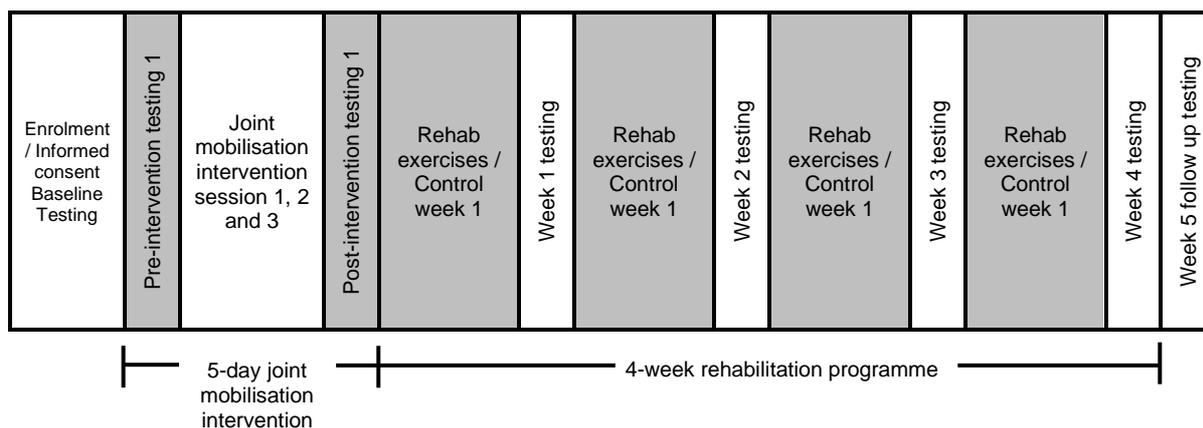
Figure 5.2. *Study timeline representing the three joint mobilisation intervention and testing sessions and 4-week rehabilitation programme with week 5 follow up.*

5.2.5. Ankle Self-Mobilisation Using a Strap

Participants were instructed to complete the self-mobilisation technique once a day for the duration of the study following a standardised procedure (Jeon *et al.*, 2015b). While lunging the participant performed the ankle self-mobilisation with the foot elevated on a step using a nonelastic strap that was 30cm in length. The height and width of the step was set at 20cm, to allow participants to utilise a standard stair step. The injured ankle was placed on the step with the uninjured foot placed on the ground in the lunge position and backward force applied by pulling on the strap. The front of the strap was placed around the anterior aspect of the talus just inferior to the medial and lateral malleoli. The back of the strap was placed around the medial region of the rear foot on the ground (Figure 5.3). The step was used to control the pulling-force angle of the strap in the posterior-inferior direction in order to mimic that of a therapist applied joint mobilisation. The participant was required to perform the self-mobilisation with the strap pulled taut in the initial position. The knee of the injured limb was subsequently moved forward along a straight line to effect a lunge whilst the strap provided the anteroposterior force to the talus. The end position was defined as being the point at which the heel of the participants injured foot could no longer maintain contact with

the step. This end position was then maintained for 20 seconds before the participant returned to the initial position. The self-mobilisation intervention was performed 15 times, with 10 seconds rest between each repetition.
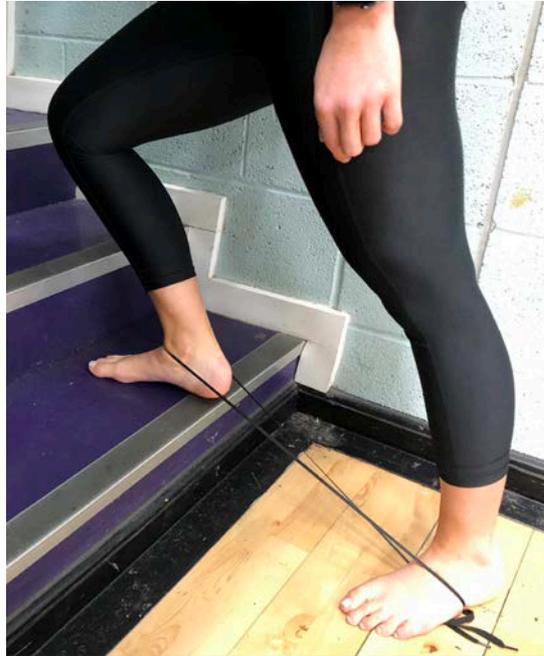
Figure 5.3. *Ankle self-mobilisation using a strap*

5.2.6. Rehabilitation Intervention

The rehabilitation exercise consisted of participants completing the anterior, posteromedial and posterolateral directions of the SEBT. Participants were each given instructions detailing the specific directions of the SEBT and the exercise protocol (Chapter 3, Figure 3.4). This allowed participants to complete the SEBT with correct foot alignment and negated the need for participants to set up a full SEBT each time they completed the exercise intervention. Participants positioned their injured limb with equal halves of the length and width of the foot in each quadrant of the SEBT. Participants then performed maximal reaches in the three directions with the uninvolved limb followed by a single light toe touch on the tape measure. Participants were required to complete 15 repetitions in each direction. A repetition was not

counted if the participants' hands did not remain on the hips, stance foot position was not maintained, the heel lost contact with the floor, or balance was lost.

5.2.7. Statistical Analysis

The percentage improvement for each dependent variable was calculated within each testing session and used for all data analysis due to its clinical relevance and immediate accessibility to clinicians (Vickers, 2001). Mixed model ANOVAs ($p \leq 0.05$) were used to examine the differences in dependent variables separately. The independent variable for each analysis was time (pre-post mobilisation, week 1, 2, 3, 4), group (intervention, control) and limb (injured, uninjured). Post hoc comparisons were completed using Tukey's HSD in the presence of a group effect. Effect sizes (ES) were calculated between injured limb and control, and groups using a bias-corrected hedge's *g* with 95% confidence intervals. ES was interpreted as negligible (0-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19) very large (1.2-1.99) and huge ($\geq$2.0) (Sawilowsky, 2009).

Mixed model ANOVAs ($p \leq 0.05$) were used to examine the differences in CAIT, FAAM and FAAM-S dependent variables separately from baseline to week 5 follow up. Percentage improvements in these metrics were not calculated prior to analysis due to the FAAM and FAAM-S already being presented as percentage scores. The independent variable for each analysis was time (baseline, 1-week follow up), group (intervention, control) and limb (injured, uninjured). Mauchly's sphericity test was conducted on all ANOVA measures with the Greenhouse-Geisser adjustment included for all significant outputs.

5.3. Results

5.3a. Mobilisation Intervention

All data from the dependent variables were inspected for outliers via visual checking of the box-plots, with values greater than 1.5 box-lengths being considered outliers. As the identified outliers were not a result of data entry error or measurement error they were not rejected as invalid and were hence included in the statistical analysis.

The data was non-normally distributed for the WBLT and ANT reach distance data as assessed by Shapiro-Wilk ($p \geq .05$). All other data was normally distributed. The assumption of homogeneity of variance, as assessed by Levene's test, was violated for all variables ($p \leq .05$). In order to address the violations of homogeneity of variance, a one-way Welch ANOVA was conducted.

Mean ± standard deviation for each measure are listed in Table 5a.1.

Table 5a.1. *Percentage change and standard deviation for dorsiflexion range of motion (DF-ROM), weight bearing lunge test (WBLT) posterior glide (PG), and anterior (Ant), posteromedial (PM) and posterolateral (PL) directions of the Star Excursion Balance Test (SEBT) across the 5-day joint mobilisation intervention prior to the home-based rehabilitation intervention.*

	Intervention group			
Variables	**Intervention**		**Control**	
	Injured	**Uninjured**	**Injured**	**Uninjured**
DF-ROM	**45.20 ± 10.17**	-0.02 ± 0.81	**43.81 ± 9.47**	0.45 ± 2.00
WBLT	**46.27 ± 8.11**	0.17 ± 0.83	**43.98 ± 5.09**	0.14 ± 0.85
PG	**47.41 ± 8.49**	0.23 ± 0.94	**43.96 ± 7.69**	0.23 ± 0.94
SEBT-Ant	**12.81 ± 4.09**	0.05 ± 0.30	**12.04 ± 3.02**	-0.07 ± 0.40
SEBT-PL	**8.48 ± 2.32**	0.02 ± 0.49	**8.81 ± 2.10**	0.05 ± 0.45
SEBT-PM	**7.43 ± 2.46**	0.24 ± 0.36	**7.99 ± 2.56**	0.27 ± 0.45

bold font indicates significance when compared to uninjured limb

The percentage improvements were statistically significantly different for all groups for DF-ROM (Welch's $F_{(3, 41.950)}$ = 314.998, $p \leq 0.001$), WBLT (Welch's $F_{(3, 46.333)}$ = 813.047, $p \leq 0.001$), PG (Welch's $F_{(3, 46.244)}$ = 485.273, $p \leq 0.001$), ANT (Welch's $F_{(3, 45.543)}$ = 197.984, $p \leq 0.001$), PL (Welch's $F_{(3, 46.739)}$ = 228.743, $p \leq 0.001$) and PM (Welch's $F_{(3, 46.024)}$ = 134.163, $p \leq 0.001$).

Games-Howell post hoc analysis revealed that there was a statistically significant improvement in the intervention group ankle receiving mobilisation than the uninjured one for DF-ROM, WBLT, PG, ANT, PL and PM ($p \leq 0.001$). This was also evident for the control group ankle receiving mobilisation and the uninjured one for DF-ROM, WBLT, PG, ANT, PL and PM ($p \leq 0.001$). There was no significant difference between the intervention and control groups that received mobilisation ($p \geq 0.05$), or the uninjured ankles that did not ($p \geq 0.05$).

Effect size statistics showed that for both the intervention group and the control group receiving mobilisation there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT, PL and PM (Figure 5a.1.).

Variable		g [95% CI]
DF-ROM Intervention		6.17 [4.81 to 7.52]
DF-ROM Control		6.23 [4.86 to 7.60]
WBLT Intervention		7.87 [6.19 to 9.54]
WBLT Control		11.82 [9.39 to 14.25]
PG Intervention		7.68 [6.05 to 9.32]
PG Control		7.85 [6.18 to 9.52]
SEBT ANT Intervention		4.33 [3.29 to 5.36]
SEBT ANT Control		5.53 [4.29 to 6.77]
SEBT PL Intervention		4.96 [3.82 to 6.11]
SEBT PL Control		5.80 [4.51 to 7.09]
SEBT PM Intervention		4.02 [3.04 to 5.01]
SEBT PM Control		4.13 [3.13 to 5.13]

g (95% CI)

Figure 5a.1. *Forest plot (g ± 95% CI) of intervention versus control group for dorsiflexion range of motion (DF-ROM), weight bearing lunge test (WBLT), posterior glide (PG), and anterior (ANT), posteromedial (PL) and posterolateral (PM) directions of the Star Excursion Balance Test (SEBT) across the 5-day joint mobilisation intervention prior to the home-based rehabilitation intervention.*

5.3b. Rehabilitation Intervention

All data from the dependent variables were inspected for outliers via visual checking of the box-plots, with values greater than 1.5 box-lengths being considered outliers. As the identified outliers were not a result of data entry error or measurement error they were not rejected as invalid and were hence included in the statistical analysis.

Following checks for normality and homogeneity of variance, all dependent variable data had elements that were found to be non-normally distributed and the assumption of homogeneity of variance was violated, as assessed by Shapiro-Wilk and Levene's test respectively ($p \leq .05$). As non-normality of this data does not affect Type I error rate substantially and the ANOVA is deemed fairly 'robust' to deviations from normality, the ANOVA was used for all subsequent analysis.

Mean percentage increase ± standard deviation for the dependent variables are listed in Tables 5b.1-6.

Table 5b.1. *Percentage change and standard deviation for dorsiflexion range of motion (DF-ROM) for intervention and control groups across the 4-week home-based exercise intervention.*

Variables	Intervention group			
	Intervention		Control	
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	**17.58 ± 7.78[b]**	0.03 ± 0.62	**-11.23 ± 1.76[a]**	-0.31 ± 0.99
Week 2 (week 1 to week 2)	**9.07 ± 3.56[b]**	-0.16 ± 0.63	**-3.94 ± 2.03[a]**	0.08 ± 0.61
Week 3 (week 2 to week 3)	**3.02 ± 1.12[b]**	0.36 ± 0.67	0.68 ± 1.52[a]	0.05 ± 0.75
Week 4 (week 3 to week 4)	**2.02 ± 1.45[b]**	-0.03 ± 0.70	0.45 ± 1.19[a]	0.06 ± 0.52
Post-Mobilisation to Week 4	**34.99 ± 12.65[b]**	0.19 ± 0.90	**-14.04 ± 2.84[a]**	-0.15 ± 1.53

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5b.2. *Percentage change and standard deviation for the weight-bearing lunge test (WBLT) for intervention and control groups across the 4-week home based exercise programme.*

Variables	Intervention group			
	Intervention		Control	
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	**18.06 ± 5.90[b]**	0.01 ± 1.01	**-10.39 ± 1.84[a]**	-0.20 ± 0.71
Week 2 (week 1 to week 2)	**9.04 ± 3.13[b]**	0.02 ± 0.77	**-3.55 ± 1.46[a]**	0.02 ± 0.66
Week 3 (week 2 to week 3)	**3.65 ± 1.63[b]**	0.14 ± 0.62	-0.14 ± 1.70[a]	-0.08 ± 0.61
Week 4 (week 3 to week 4)	**2.75 ± 1.80[b]**	0.04 ± 0.76	-0.71 ± 1.73[a]	0.10 ± 0.52
Post-Mobilisation to Week 4	**37.24 ± 10.78[b]**	0.19 ± 0.90	-14.31 ± 2.65[a]	-0.16 ± 0.83

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5b.3. *Percentage change and standard deviation for posterior glide (PG) for intervention and control groups across the 4-week home based exercise programme.*

| Variables | Intervention group | | | |
| | Intervention | | Control | |
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	**17.58 ± 7.69[b]**	0.01 ± 0.57	**-9.05 ± 2.59[a]**	-0.12 ± 0.70
Week 2 (week 1 to week 2)	**9.41 ± 3.74[b]**	0.00 ± 0.36	**-3.45 ± 1.81[a]**	0.09 ± 0.60
Week 3 (week 2 to week 3)	**3.01 ± 1.31[b]**	0.00 ± 0.51	-0.58 ± 2.38[a]	-0.01 ± 0.39
Week 4 (week 3 to week 4)	**1.94 ± 1.47[b]**	0.15 ± 0.60	0.28 ± 2.44[a]	-0.15 ± 0.68
Pre-Mobilisation to Week 4	**33.36 ± 13.37[b]**	0.16 ± 0.82	**-12.48 ± 3.70[a]**	-0.18 ± 1.05

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5b.4. *Percentage change and standard deviation for the anterior reach distance (ANT) for intervention and control groups across the 4-week home based exercise programme.*

| Variables | Intervention group | | | |
| | Intervention | | Control | |
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	**6.38 ± 2.08[b]**	-0.01 ± 0.34	**-6.06 ± 1.74[a]**	-0.01 ± 0.15
Week 2 (week 1 to week 2)	**3.50 ± 1.30[b]**	0.02 ± 0.27	-0.01 ± 0.21[a]	0.03 ± 0.13
Week 3 (week 2 to week 3)	**2.99 ± 0.93[b]**	0.06 ± 0.26	0.11 ± 0.54[a]	0.00 ± 0.17
Week 4 (week 3 to week 4)	**0.70 ± 0.85**	-0.38 ± 1.82	0.75 ± 1.41	-0.04 ± 0.21
Pre-Mobilisation to Week 4	**14.21 ± 4.06[b]**	-0.32 ± 1.84	**-5.96 ± 1.76[a]**	0.02 ± 0.22

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5b.5. *Percentage change and standard deviation for the posterolateral reach distance (PL) for intervention and control groups across the 4-week home based exercise programme.*

Variables	Intervention group			
	Intervention		Control	
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	1.32 ± 1.03^b	0.51 ± 0.47	-0.51 ± 2.00^a	-0.00 ± 0.09
Week 2 (week 1 to week 2)	**3.71 ± 2.42^b**	0.66 ± 0.52	0.10 ± 0.33^a	0.01 ± 0.11
Week 3 (week 2 to week 3)	**5.20 ± 2.22^b**	1.13 ± 0.85	-0.05 ± 0.85^a	-0.10 ± 0.50
Week 4 (week 3 to week 4)	**1.45 ± 0.97^b**	0.58 ± 0.40	0.01 ± 0.86^a	0.04 ± 0.51
Pre-Intervention to Week 4	**12.19 ± 5.29^b**	2.91 ± 1.38	-0.47 ± 1.90^a	-0.06 ± 0.38

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5b.6. *Percentage change and standard deviation for the posteromedial reach distance (PM) for intervention and control groups across the 4-week home based exercise programme.*

Variables	Intervention group			
	Intervention		Control	
	Injured	Uninjured	Injured	Uninjured
Week 1 (post-mobilisation to week 1)	**5.61 ± 1.70^b**	0.25 ± 0.39	-0.18 ± 0.93^a	-0.06 ± 0.11
Week 2 (week 1 to week 2)	**4.70 ± 1.70^b**	0.61 ± 0.39	-0.33 ± 0.68^a	-0.10 ± 0.16
Week 3 (week 2 to week 3)	1.58 ± 0.69^b	1.64 ± 1.03	-0.10 ± 0.51^a	0.08 ± 0.24
Week 4 (week 3 to week 4)	0.86 ± 0.57^b	0.53 ± 0.47	0.13 ± 0.44^a	0.07 ± 0.37
Pre-Intervention to Week 4	**13.31 ± 4.36^b**	3.06 ± 1.36	-0.47 ± 1.85^a	-0.02 ± 0.28

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

5.3b.1. Statistical Analysis

The two-way ANOVA for DF-ROM revealed a statistically significant main effect for intervention group ($F_{(1, 92)} = 276.441$, $p < 0.001$, partial $\eta^2 = 0.813$), although the main effect for measurement time was not significant ($F_{(1.435, 132.055)} = 2.816$, $p = 0.080$, partial $\eta^2 = 0.030$). There was also a significant interaction effect between the intervention and time on DF-ROM ($F_{(4.306, 132.055)} = 132.917$, $p < 0.001$, partial $\eta^2 = 0.813$).

The two-way ANOVA for WBLT revealed a statistically significant main effect for intervention group ($F_{(3, 92)} = 441.130$, $p \leq 0.001$, partial $\eta^2 = 0.935$), and measurement time ($F_{(2.185, 201.047)} = 8.841$, $p \leq 0.001$, partial $\eta^2 = 0.088$). There was also a significant interaction effect between the intervention group and time on WBLT ($F_{(6.556, 201.047)} = 155.456$, $p \leq 0.001$, partial $\eta^2 = 0.835$).

The two-way ANOVA for PG revealed a statistically significant main effect for intervention group ($F_{(3, 92)} = 238.779$, $p \leq 0.001$, partial $\eta^2 = 0.886$), and measurement time ($F_{(1.853, 170.442)} = 9.97$, $p \leq 0.001$, partial $\eta^2 = 0.098$). There was also a significant interaction effect between the intervention group and time on PG ($F_{(5.558, 170.442)} = 99.961$, $p \leq 0.001$, partial $\eta^2 = 0.765$).

The two-way ANOVA for ANT revealed a statistically significant main effect for intervention group ($F_{(3, 92)} = 303.663$, $p \leq 0.001$, partial $\eta^2 = 0.908$), and measurement time ($F_{(1.876, 172.615)} = 15.801$, $p \leq 0.001$, partial $\eta^2 = 0.147$). There was also a significant interaction effect between the intervention group and time on ANT ($F_{(5.629, 172.615)} = 125.704$, $p \leq 0.001$, partial $\eta^2 = 0.804$).

The two-way ANOVA for PL revealed a statistically significant main effect for intervention group (F (3, 92) = 101.858, $p \leq 0.001$, partial η^2 = 0.769), and measurement time (F (2.714, 249.707) = 28.045, $p \leq 0.001$, partial η^2 = 0.234). There was also a significant interaction effect between the intervention group and time on PL reach distance (F (8.143, 249.707) = 18.369, $p \leq 0.001$, partial η^2 = 0.375).

The two-way ANOVA for PM revealed a statistically significant main effect for intervention group (F (3, 92) = 170.154, $p \leq 0.001$, partial η^2 = 0.847), and measurement time (F (2.279, 209.638) = 48.146, $p \leq 0.001$, partial η^2 = 0.344). There was also a significant interaction effect between the intervention group and time on PM reach distance (F (6.836, 209.638) = 98.417, $p \leq 0.001$, partial η^2 = 0.762).

5.3b.2. Rehabilitation Week 1

Main effects for intervention group revealed statistically significant differences in DF-ROM (F $_{(3, 92)}$ = 209.589, p $\leq$ 0.001, partial η^2 = 0.872), WBLT (F $_{(3, 92)}$ = 338.457, p $\leq$ 0.001, partial η^2 = 0.917), PG (F $_{(3, 92)}$ = 178.958, p $\leq$ 0.001, partial η^2 = 0.854), ANT (F $_{(3, 92)}$ = 618.988, p $\leq$ 0.001, partial η^2 = 0.915), PL (F $_{(3, 92)}$ = 11.016, p $\leq$ 0.001, partial η^2 = 0.264) and PM (F $_{(3, 92)}$ = 192.895, p $\leq$ 0.001, partial η^2 = 0.863).

Improvements were significantly greater in the intervention group injured ankle compared to the intervention group uninjured ankle for DF-ROM, WBLT, PG, ANT and PM ($p \leq 0.001$), but was not evident for PL ($p \geq 0.05$). A significant difference between the control group injured ankle and the control group uninjured ankle was evident for DF-ROM, WBLT, PG and ANT ($p \leq 0.001$), but no differences were observed for PL or PM ($p \geq 0.05$). There was a significant difference between the injured ankles of the intervention group and the control group for DF-ROM, WBLT, PG, ANT, PL and PM

($p \leq 0.001$). There was no significant difference between the uninjured ankles for the intervention group compared to the control group for any dependent variable ($p \geq 0.05$).

Effect size statistics showed that for the intervention group injured ankle there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT, PL and PM. For the control group injured ankle there was a 'huge negative' effect ($g \geq -2.00$) for DF-ROM, WBLT, PG and ANT, with a 'small negative' effect ($g \geq -0.20$) for PL and PM (Figure 5b.1-6.).

5.3b.3. Rehabilitation Week 2

Simple main effects for intervention group revealed statistically significant differences in DF-ROM ($F_{(3, 92)} = 166.827$, $p \leq 0.001$, partial $\eta^2 = 0.845$), WBLT ($F_{(3, 92)} = 213.700$, $p \leq 0.001$, partial $\eta^2 = 0.875$), PG ($F_{(3, 92)} = 164.464$, $p \leq 0.001$, partial $\eta^2 = 0.843$), ANT ($F_{(3, 92)} = 160.194$, $p \leq 0.001$, partial $\eta^2 = 0.839$), PL ($F_{(3, 92)} = 47.002$, $p \leq 0.001$, partial $\eta^2 = 0.605$) and PM ($F_{(3, 92)} = 150.507$, $p \leq 0.001$, partial $\eta^2 = 0.831$).

Improvements were significantly greater in the intervention group injured ankle compared to the intervention group uninjured ankle for DF-ROM, WBLT, PG, ANT, PL and PM ($p \leq 0.001$). A significant difference between the control group injured ankle and the control group uninjured ankle was also evident for DF-ROM, WBLT, PG and PM ($p \leq 0.001$), but no differences were observed for ANT or PL ($p \geq 0.05$). There was a significant difference between the injured ankles of the intervention group and the control group for all dependent variables ($p \leq 0.001$). There was no significant difference between the uninjured ankles for the intervention group compared to the control group ($p \geq 0.05$), with the exception of the PM reach distance ($p \leq 0.05$).

Effect size statistics showed that for the intervention group injured ankle there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT, PL and PM. For the control group injured ankle there was a 'huge negative' effect ($g \geq -2.00$) for DF-ROM, WBLT and PG, with a 'small negative' effect ($g \geq -0.20$) for ANT, PL and PM (Figure 5b.1-6.).

5.3b.4. Rehabilitation Week 3

Simple main effects for intervention group revealed statistically significant differences in DF-ROM ($F_{(3, 92)}$ = 38.45, $p \leq 0.001$, partial η^2 = 0.556), WBLT ($F_{(3, 92)}$ = 51.644, $p \leq 0.001$, partial η^2 = 0.627), PG ($F_{(3, 92)}$ = 32.448, $p \leq 0.001$, partial η^2 = 0.514), ANT ($F_{(3, 92)}$ = 166.347, $p \leq 0.001$, partial η^2 = 0.844), PL ($F_{(3, 92)}$ = 91.158, $p \leq 0.001$, partial η^2 = 0.748) and PM ($F_{(3, 92)}$ = 45.177, $p \leq 0.001$, partial η^2 = 0.596).

Improvements were significantly greater in the intervention group injured ankle compared to the intervention group uninjured ankle for DF-ROM, WBLT, PG, ANT and PL ($p \leq 0.001$), but not PM ($p \geq 0.05$). A significant difference between the control group injured ankle and the control group uninjured ankle was also evident for DF-ROM, WBLT, PG and ANT ($p \leq 0.001$), but no differences were observed for PL or PM ($p \geq 0.05$). There was a significant difference between the injured ankles of the intervention group and the control group for DF-ROM, PL and PM ($p \leq 0.001$), but not for WBLT, PG, ANT ($p \leq 0.05$). There was no significant difference between the uninjured ankles for the intervention group compared to the control group for all dependent variables ($p \geq 0.05$), with the exception of the PM reach distance ($p \leq 0.05$).

Effect size statistics showed that for the intervention group injured ankle there was a 'huge' effect ($g \geq 2.00$) for DF-ROM, WBLT, PG, ANT, PL and PM. For the control

group injured ankle there was a 'moderate' effect ($g \geq 0.50$) for DF-ROM, a 'negligible negative' effect for WBLT ($g \geq -0.05$), a 'small negative' effect ($g \geq -0.20$) for PG, a 'small negative' effect ($g \geq -0.20$) for ANT, a 'negligible' effect ($g \geq 0.01$) for PL and PM (Figure 5b.1-6.).

5.3b.5. Rehabilitation Week 4

Simple main effects for intervention group revealed statistically significant differences in DF-ROM (F $_{(3, 92)}$ = 20.21, p ≤ 0.001, partial η^2 = 0.397), WBLT (F $_{(3, 92)}$ = 31.226, p ≤ 0.001, partial η^2 = 0.505), PG (F $_{(3, 92)}$ = 9.448, p ≤ 0.001, partial η^2 = .236), ANT (F $_{(3, 92)}$ = 4.891, p ≤ 0.001, partial η^2 = 0.138), PL (F $_{(3, 92)}$ = 20.807, p ≤ 0.001, partial η^2 = 0.404) and PM (F $_{(3, 92)}$ = 15.170, p ≤ 0.001, partial η^2 = 0.331).

Improvements were significantly greater in the intervention group injured ankle compared to the intervention group uninjured ankle for DF-ROM, WBLT, PG, ANT and PL ($p \leq 0.001$), but not PM ($p \geq 0.05$). No significant difference was observed between the control group injured ankle and the control group uninjured ankle for any dependent variable ($p \geq 0.05$). There was a significant difference between the injured ankles of the intervention group and the control group for DF-ROM, WBLT, PG, PL and PM ($p \leq 0.001$), but not for ANT ($p \leq 0.05$). There was no significant difference between the uninjured ankles for the intervention group compared to the control group for all dependent variables ($p \geq 0.05$), with the exception of the PM reach distance ($p \leq 0.05$).

Effect size statistics showed that for the intervention group injured ankle there was a 'very large' effect ($g \geq 1.20$) for DF-ROM, WBLT and PG, a 'moderate' effect ($g \geq 0.50$)

for ANT and PM, and a 'large' effect ($g \geq 0.80$) for PL. For the control group injured ankle there was a 'small' effect ($g \geq 0.20$) for DF-ROM, and PG, a 'moderate negative' effect for WBLT ($g \geq -0.50$), a 'moderate' effect ($g \geq 0.50$) for ANT, and a 'negligible' effect for PL and PM ($g \geq 0.01$) (Figure 5b.1-6.).
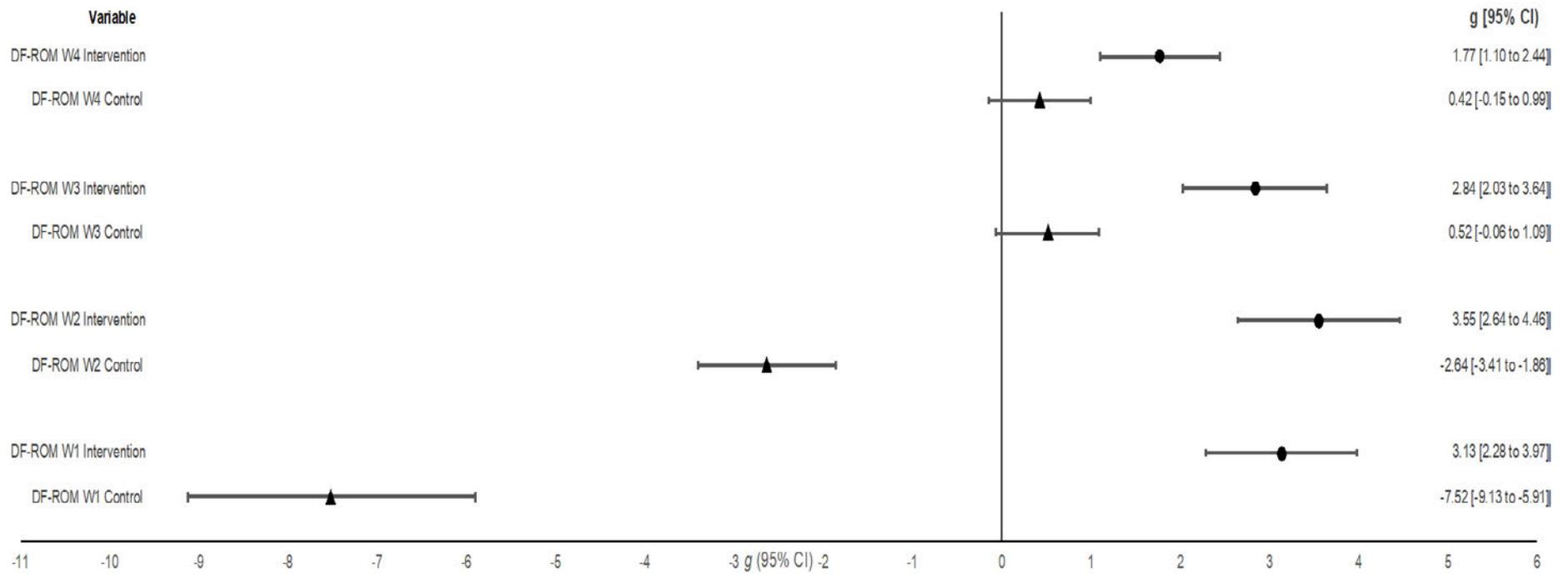
Figure 5b.1. *Forest plot (g ± 95% CI) of intervention versus control for dorsiflexion range of motion (DF-ROM) across the 4-week home based exercise programme.*
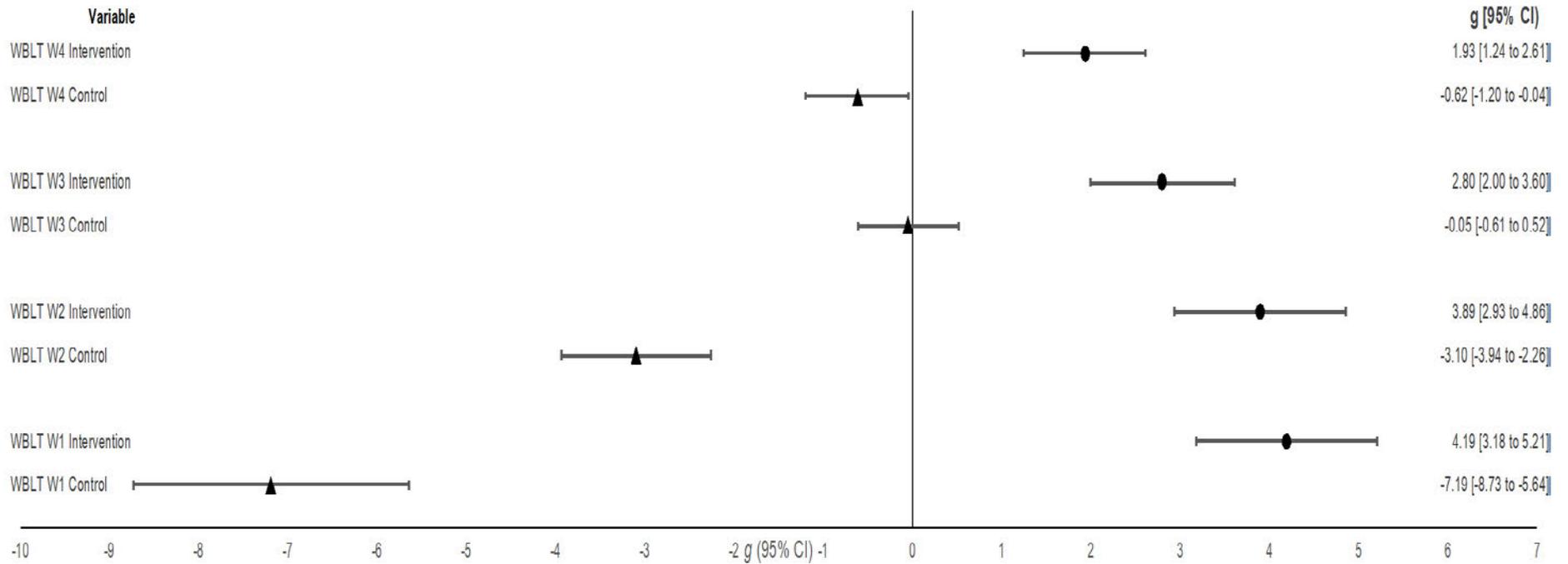
Figure 5b.2. *Forest plot (g ± 95% CI) of intervention versus control for weight-bearing lunge test (WBLT) across the 4-week home based exercise programme.*
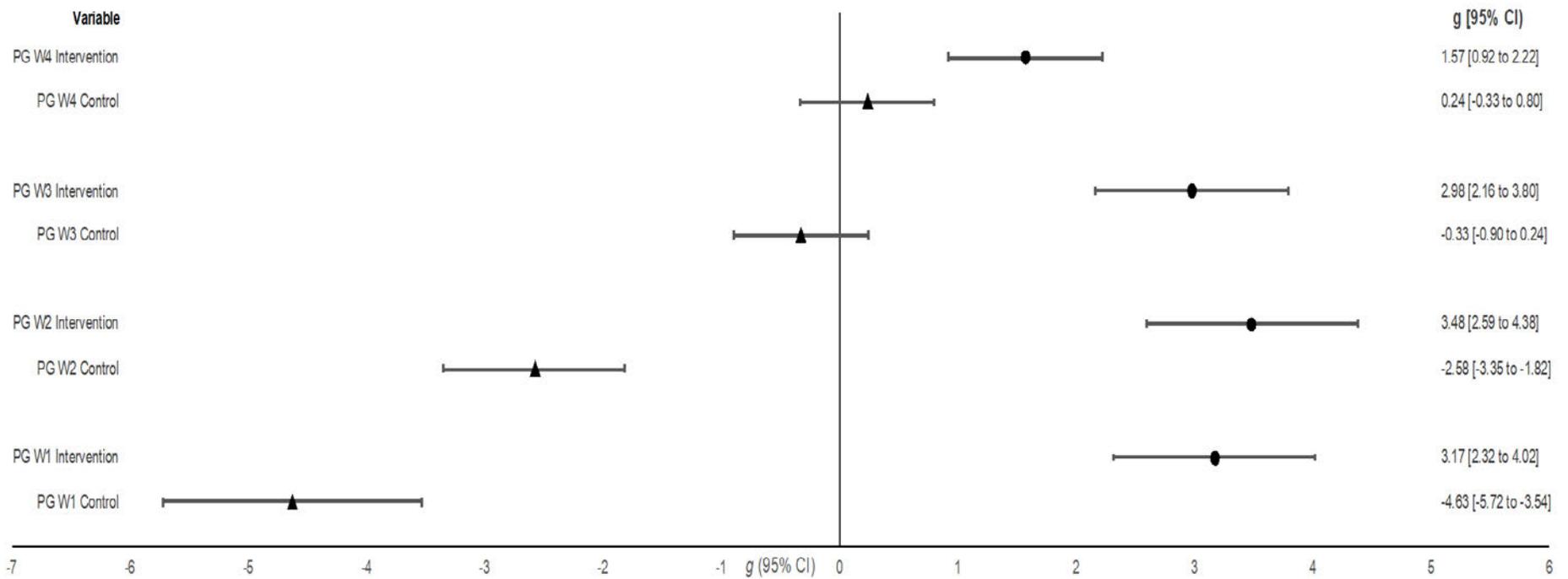
Figure 5b.3. *Forest plot (g ± 95% CI) of intervention versus control for posterior glide (PG) across the 4-week home based exercise programme.*
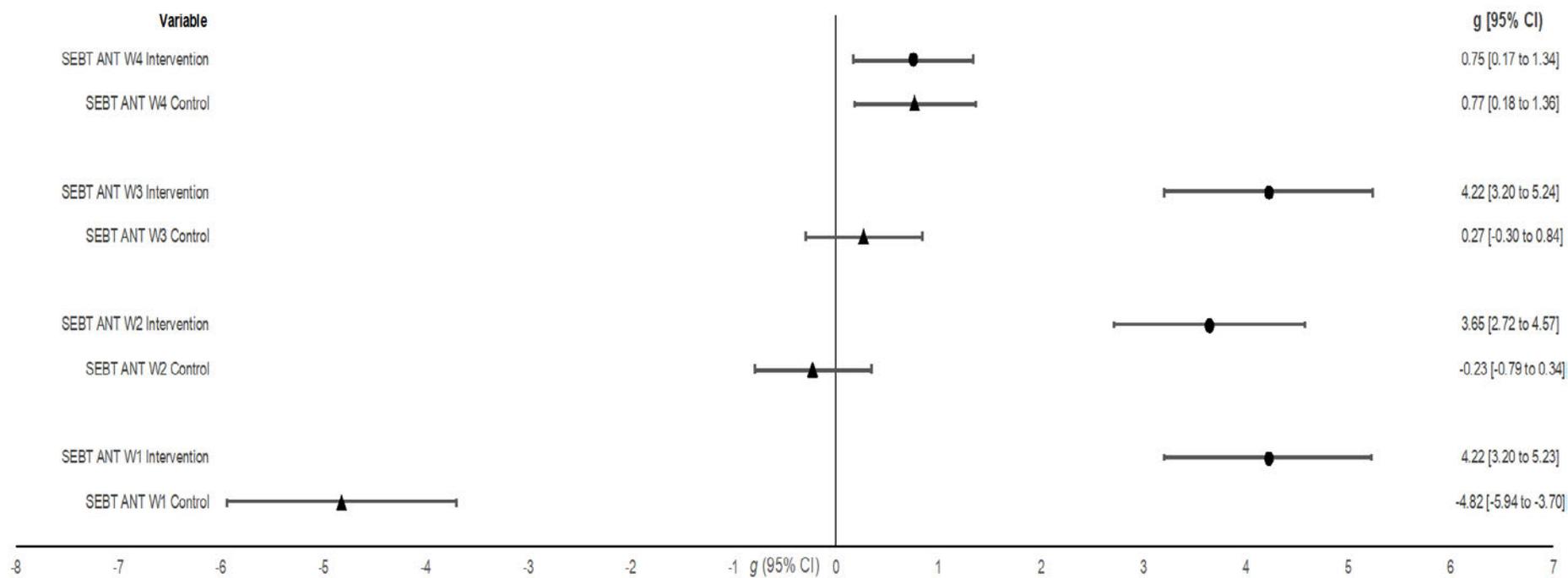
Figure 5b.4. *Forest plot (g ± 95% CI) of intervention versus control for the anterior reach distance (ANT) across the 4-week home based exercise programme.*
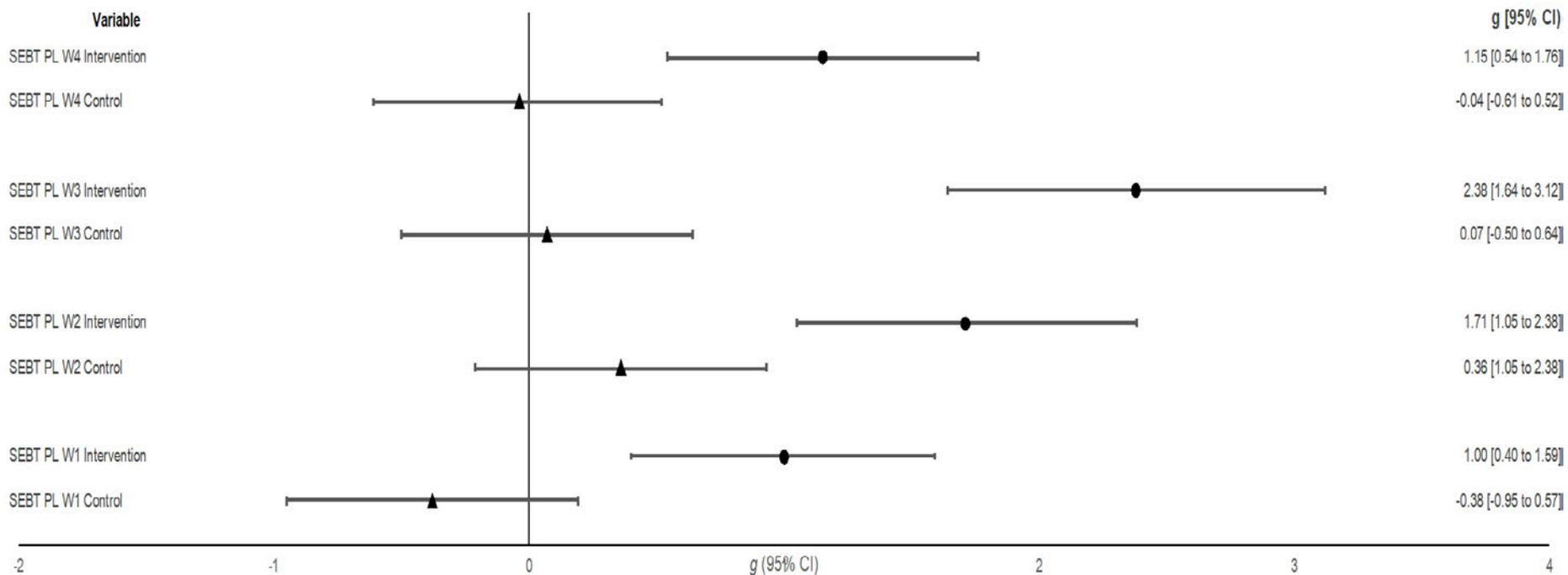
Figure 5b.5. *Forest plot (g ± 95% CI) of intervention versus control for the posterolateral reach distance (PL) across the 4-week home based exercise programme.*
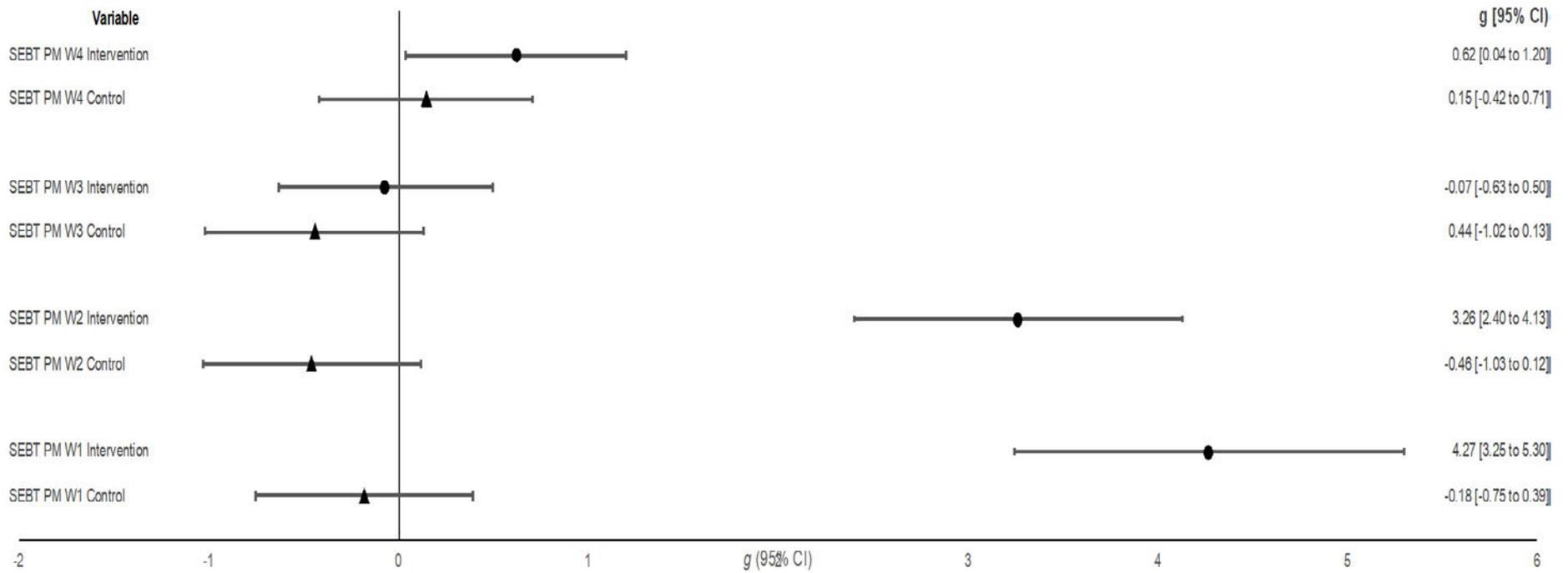
Figure 5b.6. *Forest plot (g ± 95% CI) of intervention versus control for the posteromedial reach distance (PM) across the 4-week home based exercise programme.*

5.3c. Self-Reported Function

There were no outliers in the CAIT, FAAM-ADL or FAAM-Sport data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box.

The data for the CAIT, FAAM-ADL and FAAM-Sport was non-normally distributed ($p \leq .05$) as assessed by Shapiro-Wilk test. The assumption of homogeneity of variance was violated for the CAIT and FAAM-ADL ($p \leq .05$) but not the FAAM-Sport ($p \geq .05$). As non-normality of this data does not affect Type I error rate substantially and the ANOVA is deemed fairly 'robust' to deviations from normality, the ANOVA was used for all subsequent analysis.

Mean ± standard deviation for the CAIT, FAAM-ADL and FAAM-Sport scores from baseline to follow-up and the differences are listed in Tables 5c.1 and 5c.2.

Table 5c.1. *Mean score and standard error for the Cumberland Ankle Instability Tool (CAIT) for intervention and control groups from baseline to follow-up.*

Variables		Intervention group			
		Intervention		Control	
		Injured	Uninjured	Injured	Uninjured
CAIT	Baseline	12.33 ± 0.78	27.71 ± 0.40	12.04 ± 0.71	27.54 ± 0.36
	Follow-up	15.92 ± 0.81[b]	27.83 ± 0.39	12.79 ± 0.74[a]	27.67 ± 0.35
	Difference	**3.58 ± 0.12** [b]	0.12 ± 0.09	**0.75 ± 0.14**[a]	0.13 ± 0.11

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significance when compared to uninjured limb.*

Table 5c.2. *Mean score and standard error for the Foot and Ankle Ability Measure Activities of Daily Living (FAAM-ADL) and Sport (FAAM-S) subscales for intervention groups from baseline to follow-up.*

Variables		Intervention group	
		Intervention	Control
FAAM-ADL	Baseline	68.96 ± 1.73	66.67 ± 2.09
	Follow-up	82.71 ± 1.31[b]	69.17 ± 2.03[a]
	Difference	**13.75 ± 1.21**[b]	**2.50 ± 0.74**[a]
FAAM-S	Baseline	48.33 ± 2.06	47.71 ± 2.33
	Follow-up	65.42 ± 2.02[b]	50.83 ± 2.25[a]
	Difference	**17.08 ± 1.47**[b]	**3.13 ± 0.89**[a]

[a] *significant compared to the injured intervention group;* [b] *significant compared to the injured control group; bold font indicates significant change from baseline to follow-up.*

The two-way ANOVA for the CAIT revealed a statistically significant main effect for intervention group ($F_{(3, 92)}$ = 196.389, $p < 0.001$, partial η^2 = 0.865) and measurement time ($F_{(1, 92)}$ = 391.972, $p < 0.001$, partial η^2 = 0.810). There was also a significant interaction effect between the intervention and time on CAIT scores ($F_{(3, 92)}$ = 203.566, $p < 0.001$, partial η^2 = 0.869).

The two-way ANOVA for the FAAM-ADL revealed a statistically significant main effect for intervention group ($F_{(1, 46)}$ = 10.314, $p < 0.005$, partial η^2 = 0.183) and measurement time ($F_{(1, 46)}$ = 131.022, $p < 0.001$, partial η^2 = 0.740). There was also a significant interaction effect between the intervention and time on FAAM-ADL scores ($F_{(1, 46)}$ = 62.798, $p < 0.001$, partial η^2 = 0.577).

The two-way ANOVA for the FAAM-Sport revealed a statistically significant main effect for intervention group ($F_{(1, 46)}$ = 6.689, $p < 0.05$, partial η^2 = 0.127) and measurement time ($F_{(1, 46)}$ = 137.751, $p < 0.001$, partial η^2 = 0.750). There was also a significant interaction effect between the intervention and time on FAAM-S scores ($F_{(1, 46)}$ = 65.721, $p < 0.001$, partial η^2 = 0.588).

Main effects for intervention group revealed a statistically significant difference in CAIT scores pre-intervention, ($F_{(3, 92)}$ = 226.316, $p \leq 0.001$, partial η^2 = 0.881). The CAIT scores were significantly different for the intervention group and control group when compared to the uninjured side ($p \leq 0.001$), although there were no other statistically significant differences between the injured ankles ($p \geq 0.05$) or the uninjured ankles ($p \geq 0.05$) for the intervention group when compared to the control group.

Prior to the first intervention session there were no statistically significant differences in FAAM-ADL scores ($F_{(1, 46)} = 0.719$, $p = 0.401$, partial $\eta^2 = 0.000$) or FAAM-S scores ($F_{(1, 46)} = 0.040$, $p = 0.842$, partial $\eta^2 = 0.000$).

Following the rehabilitation intervention there was a statistically significance difference in CAIT scores ($F_{(3, 92)} = 167.823$, $p \leq 0.001$, partial $\eta^2 = 0.845$). The CAIT scores were significantly different for the intervention group and control group when compared to the uninjured side ($p \leq 0.001$). There was also a statistically significant difference between the injured intervention group and the injured control group ($p \leq 0.001$), although there were no statistically significant differences between the uninjured ankles ($p \geq 0.05$). Following the rehabilitation intervention there was a statistically significant difference in FAAM-ADL scores ($F_{(1, 46)} = 31.316$, $p \leq 0.001$, partial $\eta^2 = 0.405$) or FAAM-S scores ($F_{(1, 46)} = 23.343$, $p \leq 0.001$, partial $\eta^2 = 0.337$) between the intervention and control groups.

There was a statistically significant effect of time (baseline to follow-up) for the injured intervention group for the CAIT ($F_{(1, 23)} = 904.830$, $p \leq 0.001$, partial $\eta^2 = 0.975$), FAAM-ADL ($F_{(1, 23)} = 128.446$, $p \leq 0.001$, partial $\eta^2 = 0.848$) and FAAM-S ($F_{(1, 23)} = 134.714$, $p \leq 0.001$, partial $\eta^2 = 0.854$). This was also evident for the injured control group (CAIT - $F_{(1, 23)} = 29.571$, $p \leq 0.001$, partial $\eta^2 = 0.563$; FAAM-ADL - $F_{(1, 23)} = 11.500$, $p \leq 0.005$, partial $\eta^2 = 0.333$; FAAM-S - $F_{(1, 23)} = 12.234$, $p \leq 0.005$, partial $\eta^2 = 0.347$). For the CAIT there was no significant effect of time for either uninjured ankle ($p \geq 0.05$).

For the CAIT, effect size statistics showed that there was a 'huge' effect for the injured intervention group ($g = 6.54$), whilst a 'small' effect size was evident for the injured control group ($g = 0.19$) (Figure 5c.1.).
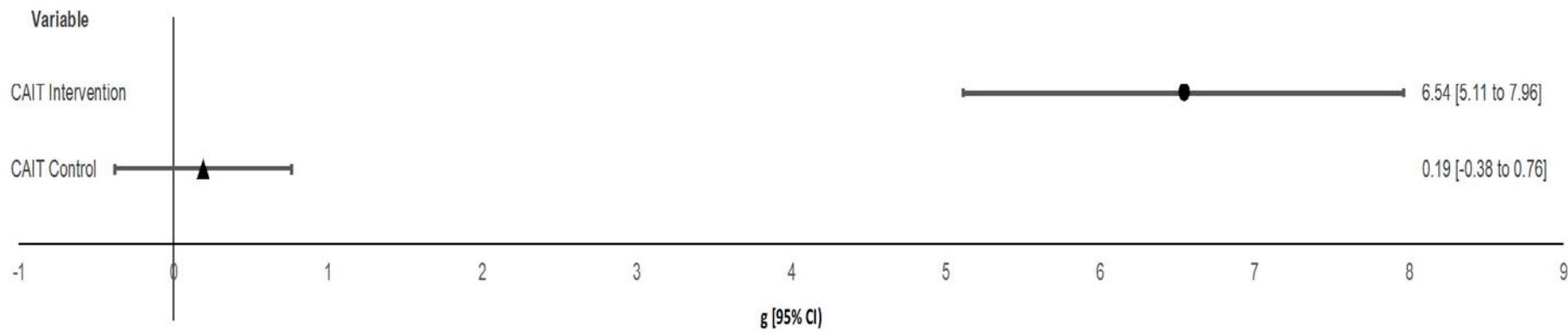
Figure 5c.1. *Forest plot (g ± 95% CI) of intervention versus control for the CAIT from baseline to follow-up.*

5.3d. Results Summary

- Mean percentage change for the injured limb was significant when compared to the uninjured limb for all measures for both the intervention and control groups following the 5-day joint mobilisation treatment.

- Within the intervention group, mean percentage change for the injured limb was significantly greater when compared to the uninjured limb for DF-ROM, WBLT, PG and ANT across each of the 4 rehabilitation weeks.

- Within the control group, mean percentage change for the injured limb was significantly less when compared to the uninjured limb for DF-ROM, WBLT and PG across rehabilitation weeks 1 and 2. This was true for ANT across rehabilitation week 1.

- Significant differences were found between the intervention and control groups for DF-ROM, WBLT, PG, PL and PM across each of the 4 rehabilitation weeks. This was true for ANT across rehabilitation weeks 1, 2 and 3.

- Within the intervention group mean percentage change for the injured limb was significantly greater when compared to the uninjured limb for PL across rehabilitation weeks 2, 3 and 4, and for PM across rehabilitation weeks 1 and 2.

- Within the control group there were no significant differences in PL or PM between the injured and uninjured limb across any of the 4 rehabilitation weeks.

- Mean score changes for the CAIT, FAAM-ADL and FAAM-S were significant from baseline to follow-up for intervention and control group.

- Mean scores changes for CAIT, FAAM-ADL and FAAM-S were significantly greater in the intervention group compared to the control.

5.4. Discussion

5.4a. Mobilisation Intervention

The observed improvements in outcome measures following the joint mobilisation intervention again demonstrates that this can significantly improve arthrokinematic motion and dynamic postural control, with comparable changes to DF-ROM, WBLT and PG occurring in a similar manner to that observed in Chapters 4a and 4b The 'huge' effect sizes elicited in the injured limb for both intervention and control groups shows that three sessions of 120 seconds of grade IV anterior-to-posterior talar joint mobilisations is an effective means to improve function in those with CAI prior to commencing a home-based rehabilitation programme. This provides further validation for the study findings from Chapter 4a and 4b and highlights that 120 second treatment durations are more effective than shorter treatment durations when single sets are being applied within the first week of treatment. The uninjured limb for the intervention and control group showed no statistically significant improvements in function following intervention, meaning that the contralateral limb could be used as an appropriate 'paired' control limb. The contralateral limb is often used in clinical and anthropological studies due to the implicit assumption that no significant differences exist between bilateral limbs and that the amount of unintended variation between intervention and control groups is reduced (Mustafy, Londono and Villemure, 2018). However, these results differ somewhat in comparison to the previous studies in Chapter 4a and 4b. The uninjured control limbs within these studies showed some improvement following intervention in both PL and PM reach distances. Explanations for this variance is difficult, but two prevalent theories may go some way to explaining the improvements previously observed that are not evident here. Whilst utilising the uninjured contralateral limb as a control represents an apposite means to 'pair' limbs, it does not

necessarily represent a normal control. Any abnormality or effect evident in the treated limb (in this case the one with CAI), may have an indirect effect on the contralateral limb. Indeed the literature does show that intervention of one limb can create changes in the contralateral limb in a variety of different tissues, including bone, ligament, cartilage and muscle (Frank *et al.*, 1994). This could provide a potential explanation for the improvement in PL and PM in the previous studies, but as no other outcome measure showed improvements in the uninjured control limb, this hypothesis may not hold true. A more convincing hypothesis would be that a learning effect had occurred within the studies of Chapter 4a and 4b. The methodology of the previous studies had participants completing the SEBT prior to and immediately after six sessions of joint mobilisation intervention over a 2-week period. This equates to a total of 12 separate testing sessions. Furthermore, these sessions were on average only 48 hours apart meaning that there was a greater chance that neuromuscular adaptations may have occurred through a learning effect (Robbins *et al.*, 2017). Within the current study, these testing sessions were only conducted prior to the first mobilisation intervention session, and then following the third intervention application which was 94 hours later. This may have diminished the possibility of a learning effect and explain the lack of improvement in PL and PM for the uninjured control limb within this study.

5.4b. Rehabilitation Intervention

5.4b.1. Arthrokinematics

The study findings highlight that significant improvements in arthrokinematic function (DF-ROM, WBLT and PG) can be achieved with the application of a simple home-based rehabilitation exercise regime when preceded by talocrural joint mobilisation intervention. Results also suggest that the improvements achieved with the prior joint

mobilisation intervention are not maintained if no continued rehabilitation is performed, and that there is a propensity for some of these improvements to be lost if no further treatment targeting arthrokinematic function is delivered.

The improvements in arthrokinematic function followed a similar pattern for each of the three outcome measures for all four groups across the 4-weeks of testing. The comparable improvements in DF-ROM and WBLT are unsurprising as these tests are both highly reliable methods of assessing the same objective measure (Venturini *et al.*, 2007; Powden, Hoch and Hoch, 2015b), whereas the congruent improvements in PG and these dorsiflexion measures are a result of posterior talar glide being an accessory motion component that is integral to ankle dorsiflexion (Vicenzino *et al.*, 2006b). Consequently, the use of these three measures in conjunction may not be warranted and allows for the identification of some potential test redundancy. Although the PG test provides a reliable estimate of posterior talar glide (ICC = 0.88-0.99) (Denegar, Hertel and Fonseca, 2002; Vicenzino *et al.*, 2006a) it may be criticised due to its subjectivity in terms of the clinician's ability to assess the capsular end feel. Similarly, whilst the DF-ROM goniometry shows excellent intra-clinician and inter-clinician reliability coefficients (>0.75) (Krause *et al.*, 2011) there are a number of variables that can affect the measure including foot pronation, tibial rotation and knee positioning (Tiberio, Bohannon and Zito, 1989; Dawe and Davis, 2011). As a result, the functional nature of the WBLT makes it a more meaningful test particularly for the later stages of rehabilitation when the client can effectively weight bare, whereas goniometry measures should be restricted to the periods before this is possible. The injured intervention group demonstrated a statistically greater improvement than their uninjured control limb at all time points, whilst the injured control group showed a

significantly negative improvement when compared to their uninjured limb within the first 2 weeks. For the intervention group, improvements of around 18% in DF-ROM, WBLT and PG were identified following the first week of rehabilitation exercises, with an associated 'huge' effect size. This was comparable to the additional three mobilisation treatment sessions (4, 5 and 6) completed during the second week of treatment in study 4b, which showed improvements of around 10% for session 4 and 5, and 5.5% for session 6. The effects of the home-based exercises then showed a marked reduction in effectiveness over the following three weeks with approximate values of 9%, 3% and 2% for weeks 2, 3 and 4 respectively. The reduction in the effect of the home-based rehabilitation is unsurprising as it would be expected that there is a 'biological ceiling effect' for the magnitude of adaptation that can be obtained if exercises are not progressed and that improvement in function becomes reduced as we near the limits of function. Effective exercise progression can significantly enhance clinical outcomes and is therefore needed to ensure advancement towards the rehabilitative goal (Blanchard and Glasgow, 2014). Whilst the exercises used within this study were progressed in terms of the maximal distance the participant could lunge or reach, this was not clinically effective beyond the second week of adherence. As such, additional exercises may be needed to further augment the improvements elicited by the current home-based exercise intervention but must be underpinned by sound clinical reasoning through the combination of scientific and professional theory (Jones, Jensen and Edwards, 2008). Jeon et al. (2015) also identified a significant improvement in arthrokinematic function following stretching exercises performed 5 times per week for 3 weeks. The authors utilised a similar self-mobilisation technique using a strap as the current study but concluded a 51.98% and 13.5% increase in DF-ROM and WBLT respectively with corresponding effect sizes of 1.36 (very large) and

0.85 (large). The variation in these two figures is surprising as both measures are designed to measure dorsiflexion range of motion in either a non-weight bearing or weight bearing position. Consequently, it could be expected that improvements in one measure would translate to similar improvements in the other, if the intervention has addressed an arthrokinematic restriction that was limiting function.

Within the current study the cumulative increase in these two measures were comparable at 34.99% and 37.24%, with notably 'huge' effect sizes. The majority of this improvement occurring within the first two weeks demonstrating that the extended time period in the Jeon et al. (2015) study may not be warranted and may result in diminished returns. As the changes in DF-ROM and WBLT corresponded to similar improvements in PG (33.36%) it could be concluded that these improvements are a direct result of changes to arthrokinematic function and in particular the restored accessory motion of the talus. However, a full conclusion as to this would require imaging investigation to determine whether the theorised anterior positional fault had been altered (Wikstrom and Hubbard, 2010).

The improvements in arthrokinematic motion following the self-mobilisation protocol can be attributed to the combined alterations in the accessory joint movement and stretching of the gastrocsoleus complex. The gastrocsoleus complex has an influence on dorsiflexion due its antagonistic function, with the gastrocnemius tightness being a common cause of impaired dorsiflexion due to its biarticular nature (Baumbach *et al.*, 2014). The procedure for the self-mobilisation technique involved the participant adopting a weight-bearing lung position with the test foot elevated. During the required lunge motion, the participants body weight was shifted forwards over the stance foot

producing a stretching force to the gastrocnemius and soleus. When stretching exercises such as this are repeated it leads to an increase in DF-ROM because of changes in the architecture of the gastrocnemius muscle-tendon unit and displacement of the myotendinous junction (Nakamura *et al.*, 2011; Kang *et al.*, 2015). Throughout the self-mobilisation movement the strap also induced a posterior talar glide and minimised any unwanted anterior talar displacement resulting in the reestablishment of normal ankle-joint mechanics (Jeon *et al.*, 2015b). It has been demonstrated that the incorporation of talar joint mobilisation and gastrocnemius stretching results in greater improvements in DF-ROM and PG compared with stretching alone (Kang *et al.*, 2015). In the study by Kang et al (2015), 24 male participants completed a comparable exercise intervention which was performed for 10 repetitions held for 30 seconds each. Results showed that there was a 28.59% improvement in PG following this intervention which is markedly higher than the greatest improvement of 17.58% elicited in week 1 of the current study. Although the current study adopted a shorter (20 second) static hold in the end of range position, it would be expected that the application of daily rehabilitation exercise would result in a larger improvement in outcome measures. However, as the current participants had already undergone a period of clinical joint mobilisation intervention, the magnitude of improvement available may have been limited due to a ceiling effect. Following the initial joint mobilisations treatment there was a 45.20% improvement in DF-ROM which when combined with the home-based exercise intervention shows an overall improvement of over 60%, well beyond that of the Kang et al (2015) study.

The control group showed a significant decrease in DF-ROM, WBLT and PG in the injured limb during week 1 (-11.23%, -10.39% and -9.05%) and week 2 (-3.94%, -

3.55% and -3.45%) of the home-based exercise intervention. The decrease in arthrokinematic function following cessation of the mobilisation intervention may be due to biological tissue conforming to the theory of viscoelastic behaviour (Houglum, 2016). This is a combination of elastic and viscous actions meaning that any applied stress results in an instantaneous elastic strain with a subsequent time-dependent viscous strain. The presence of crimping within normal collagen bundles in conjunction with the variability in bundle alignment means that subunits are loaded asynchronously (Threlkeld, 1992). As such, it is possible that whilst plastic deformation is occurring, it is only the bundles that are most closely aligned to the direction of load that are experiencing the full stress and undergoing permanent changes in length. Additional bundle and fibres may be loaded elastically so that when the mobilisation force that is deforming the tissue is removed, there is an elastic recoil and these tissues return to their previous resting length (Magee, Zachazewski and Quillen, 2007). A new length of the tissue is established but this reflects the balance between the elastic recoil of the intact collagen and the plastically deformed (broken) fibres (Threlkeld, 1992). Within biological tissue this elastic recoil may not be instantaneous and may reflect non-permanent creep deformation as water is redistributed from the tissue to the anatomical space surrounding it (Nordin, Lorenz and Campello, 2001). This holds true for the current study as the reduction in the arthrokinematic measures over the first two-weeks is well below the improvement elicited following the mobilisation intervention. This means that whilst there was a reduction in function during the first 2-weeks of the home-based rehabilitation for the injured limb of the control group, that an improvement beyond the baseline measures has still occurred due to the initial mobilisation intervention.

5.4b.2. Dynamic Postural Control

The result indicate that dynamic postural control can be improved in those with CAI through the application of home-based rehabilitation exercise. It is also evident that improvements in the three reach distances of the SEBT (ANT, PL and PM) differ with respect to their magnitude and the time frame through which they occur. The anterior reach distance demonstrated significant improvements for the injured intervention group when compared to their uninjured side which was evident across all 4-weeks of the exercise programme. Similar to the measures of arthrokinematic function, these improvements diminished as the weeks progressed potentially due to the ceiling effect as participants neared limits of function which approached that of the non-injured limb. Further explanation for the decline can be attributed to the relationship that the anterior reach distance has to the WBLT. When calculated the improvements in ANT in this study represent 35.3% (week 1), 38.7% (week 2), 81.9% (week 3) and 25.5% (week) of the observed improvements in the WBLT. Whilst there is some inconsistency within these figures, there is some similarity for weeks 1, 2 and 4 with previous research which suggests that an estimated 28% of the variance in ANT can be attributed to changes in performance on the WBLT (Hoch, Staton and McKeon, 2011b). This may also explain the observed decrease in performance for the injured control group in week 1, which can be related to the significant reduction in the WBLT at the same time point.

The PL reach distance showed statistically significant improvements for the injured intervention group for week 2, 3 and 4, with the largest values achieved in week 3. This was in contrast to the PM reach distance where significant improvements were only evident in the first 2 weeks, peaking in week 1. Due to the plasticity of the adult

sensorimotor system it is unsurprising that improvements such as this were observed. Research highlight that grey and white brain matter rapidly adapt in response to balance training programmes and can show detectable structural changes in as few as two training sessions (Taubert *et al.*, 2010). An explanation for the delayed improvement in PL reach distance may be due to the structural plasticity of the sensorimotor system appearing to respond more favourably to balance training accomplished over an extended period of time (Taubert *et al.*, 2010). Interestingly, there is good evidence to suggest that sensorimotor adaptation consists of two processes; one that shows a strong adaptive response to initial training that is then maintained afterwards, and one that shows little or no adaptive response to the initial training but which responds strongly following the cessation of the training (Smith, Ghazizadeh and Shadmehr, 2006). This may link to the assertion that it is the number of times that a movement is practiced, as opposed to the amount of time that has passed, that determines the level of adaptation (Huang and Shadmehr, 2007). The differences in the movement patterns and muscle activation between the PL and PM reach directions may also explain the differences in when improvement occurred. Research suggests that the knee flexion angle needed for successful performance is significantly lower in the PL reach direction than the PM (Earl and Hertel, 2001). For muscle activation, those with CAI show significantly delayed gluteal muscle activation onset times during PM reach and less EMG activity in the Gluteus Maximus during PL reach than healthy individuals (Jaber *et al.*, 2018). The PL reach distance is particularly challenging as the pelvis must be maintained in a level position over the stance leg. In order to successfully perform the movement, the trunk must be shifted anteriorly as the individual reaches backwards in order to maintain their centre of mass over the base of support. This produces flexion of the trunk and an associated flexion

moment at the hip. Increased activation of the gluteus maximus is then needed to counteract the sagittal plane flexion of the hip and trunk. Those with CAI show reduced gluteus maximus activation which is not sufficient to counteract the sagittal plane movement or control the internal rotation of the femur during the PL reach direction. Consequently, there is an overcompensation to maintain the body's centre of mass within the base of support and leads to higher levels of postural sway (Jaber *et al.*, 2018). The rotation movement associated with the PL reach direction is often a common mechanism for lower extremity injuries and may explain why this movement pattern took longer to improve than the other reach directions (Webster and Gribble, 2013).

Comparison to extant literature is difficult due to the paucity of mythologically similar studies. However, some comparison can be drawn to Mckeon *et al.* (2008) who identified a 10.98% and 12.99% improvement in PM and PL reach distances respectively following a 4 week supervise balanced training programme, whilst no change was observed in the ANT direction. The current study identified slightly different improvements in PM and PL of 13.31% and 12.19%, and an improvement in ANT of 14.29%. The difference in PM and PL may be due to the frequency of the training programme as the McKeon et al study had participants completing only 3 sessions per week, which is in contrast to the daily exercise requirements of the current study. Additionally, the training programme in the previous study emphasised balance activities designed to challenge recovery of single-limb balance following perturbation and hence did not directly replicate the movements associated with the SEBT outcome measure. This may also explain the lack of improvement in the ANT direction as no exercise attempted to advance the DF-ROM of participants which has

been shown to directly influence the performance of this reach direction (Hoch, Staton and McKeon, 2011b).

5.4b.3. Self-Reported Function

The results of the study show that measures of self-reported function can be improved following mobilisation intervention and that this improvement is magnified if it is followed by adherence to a home-based rehabilitation programme. Effect sizes indicated that improvements in the CAIT were 'huge' for the injured intervention group and the improvement of 3.58 points is higher than the previously identified minimal clinically important difference in this score of ≥3 points, which should be used as the minimum threshold to indicate detectable and clinically meaningful improvement following treatment in those with CAI (Wright, Linens and Cain, 2017). Whilst there were identifiable improvements for the injured control group (0.75 points), the small effect size showed that these were minimal, and well below the improvement score of 3.06 identified following 120 second of mobilisation in Chapter 4a. This suggests that the participants within this study have the impression that the improvements in function diminished when intervention and/or rehabilitation did not continue. The CAIT has been identified as a sensitive means by which to identify improvements in function for individuals with CAI (Powden, Hoch and Hoch, 2017). Whilst this measure is primarily used as a diagnostic tool to identify the pathology, the relevance of the questionnaire items to the activity limitations of those with CAI make this an appropriate outcome measure to use clinically with this population (Gribble *et al.*, 2014).

The improvements in both the FAAM-ADL AND FAAM-S were statistically significant for both the intervention (FAAM-ADL = 13.75; FAAM-S = 17.08) and control group

(FAAM-ADL = 2.50; FAAM-S = 3.13). However, only the improvements identified in the intervention group were beyond the minimal clinically important difference that has been previously identified of 8 points and 9 point for the ADL and Sports subscales respectively (Martin *et al.*, 2005). The improvement in the FAAM-S is particularly important as this subscale addresses the limitations of athletes with CAI. Research implies that athletes with CAI have greater limitations with sports activities than ADLs and the FAAM-S can be used to more clearly elucidate these limitations (Carcia, Martin and Drouin, 2008). This was clearly evident within the current study as scores on the ADL subscale were noticeably greater than those on the Sport subscale.

Improvements in the CAIT, FAAM-ADL and FAAM-S indicates that the adopted rehabilitation strategy can effectively improve the health-related quality of life of those with CAI. Previously published research has identified good quality patient orientated evidence to support this, with evidence from a 2017 systematic review and meta-analysis of 15 studies suggesting that a combination of manual therapy and balance training interventions can be used to improve patient-oriented outcomes (Powden, Hoch and Hoch, 2017). Although there appears to be a link between the performance-based and patient-reported measures within the current study, it is important that these are not seen as interchangeable as they assess different aspects of function. Indeed, performance-based measures tend to assess physiological factors whilst patient-reported measures are far more likely to capture perceptions and beliefs regarding the patients current condition (Bean *et al.*, 2011).

5.4b.4. Recommendations for Future Research

The study relied on participants adherence to the home-base rehabilitation programme, which was ascertained verbally prior to each individual testing session. Whilst all participants included within the data analysis reported full adherence, research estimates that non-adherence to home exercise can be as high as 50% (Argent, Daly and Caulfield, 2018). As the participants within the current study were from a physically active athletic population it could be postulated that their adherence levels would be high. However, participants may have been over-reporting their adherence in order to continue with the study. If this were to have occurred any results collected may not give a true and valid assessment of the effects of the intervention. Research also suggests that deceptive participants are older, predominantly male, and place an emphasis on income from trial participation (Devine *et al.*, 2013, 2015). As the programme was designed to take no more than 12 minutes to complete daily, had no financial remuneration and demographic was younger females, it was hoped that the reported adherence levels were an accurate depiction of what the participants actually did with no fabrication. Future research may therefore need to include a more detailed method of monitoring adherence, be it through electronic means, or observed practice. The repeated use of the SEBT as a measurement tool and rehabilitation exercise may have limited the ability to detect a true improvement in dynamic postural control. The completion of these movements throughout the rehabilitation programme may have resulted in a learning or practice effect taking place, by which performance scores were improved as a function of performing the task repeatedly. In addition, balance training can lead to highly specific task specific adaptations with limited transfer to even qualitatively similar tasks (Green and Bavelier, 2008; Giboin, Gruber and Kramer, 2015). As such the improvements in dynamic postural control as

assessed by the SEBT may not be evident in additional dynamic postural control tasks. Although the performance of each exercise task included inherent progressive overload in terms of how far the participant could lunge or reach with each repetition, the intervention was not progressed in any other way. This may have produced the 'ceiling effect' that was noted over the 4-weeks. Whilst progression is a key component of an effective rehabilitation programme, this must be selected based upon sound clinical reasoning and individual athlete development. As such, the current rehabilitation exercise intervention provides an answer as to when this should look to occur for those with CAI. However, research that identifies appropriate 'cut-off' scores for each test by which a performance threshold is established would allow for appropriate progression to be made in the absence of clinician involvement.

5.5. Conclusion

The findings of this study show that the application of joint mobilisations in the first week of intervention, followed by a home-based rehabilitation programme can enhance the mechanical, functional, and self-reported function of those with CAI. The improvements that occur following joint mobilisations in arthrokinematic function are lost if additional rehabilitation is not implemented. The combination of joint mobilisation intervention and home-based rehabilitation programmes should form a part of the initial intervention regime for those with CAI. Specifically, an effective protocol for these interventions is the application of three, 120 second joint mobilisations within the first week of intervention, followed by 2 weeks of daily rehabilitation exercise that includes ankle self-mobilisation and targets dynamic postural control, with improvements assessed through both performance and patient-reported outcome measures.

CHAPTER 6. THE DISSEMINATION OF CAI INTERVENTION BASED RESEARCH TO THE PRACTITIONER: A CURRENT OVERVIEW OF THE PERCEPTIONS OF PRACTITIONERS AND RESEARCHERS

6.1. Introduction

Sports and physical activity related injuries present a significant health problem for those who experience them (Verhagen, Bolling and Finch, 2015). Lateral ankle sprains (LAS) are the most prevalent musculoskeletal injuries in sport and in the physically active (Gribble *et al.*, 2016a). More than half of those who sustain a LAS do not seek medical treatment and therefore do not receive adequate or effective rehabilitation (Mckay *et al.*, 2001). Following these initial injuries individuals may develop long term problems, with up to 70% reporting recurrent bouts of instability, additional ankle sprains and reduced functional capacity (Wikstrom *et al.*, 2007). These issues form the foundation of CAI which must be understood by the clinician if effective treatment and rehabilitation is to be prescribed. Indeed, clinical research into CAI is essential to improving the care of those individuals who present with this pathology in order to develop clear and effective treatment protocols. However, the impact of injury treatment and prevention programmes are a function of both the programme and its implementation (Donaldson *et al.*, 2017).

There is evidence that healthcare performance can be improved by the engagement of clinicians with contemporary research evidence (Boaz *et al.*, 2015). However, the implementation of current research is challenging. Within healthcare research, the time between research evidence being produced and its dissemination and use in practice takes on average 17 years (Slote Morris, Wooding and Grant, 2011). The

effective dissemination of healthcare research is therefore important to reduce the research-to-practice time gap and maximise the impact of the treatment intervention. The RE-AIM framework (Reach, Effectiveness, Adoption, Implementation and Maintenance) was proposed as a means by which to encourage the documentation of research in a way that is accessible to practitioners in order to affect their practice (Glasgow, Vogt and Boles, 1999). However, merely producing research in this manner is often not sufficient to affect clinical practice as treatment programmes have little impact if they are not widely used. The key functions of effective knowledge dissemination for practitioners must ensure that the research is relevant, accessible and credible (Contandriopoulos *et al.*, 2010). Injury research which is not associated with the practical realities of adoption, implementation and maintenance, and which does not attempt to affect current practice will not prevent or improve health (Hanson *et al.*, 2014). In order for effective interventions to be disseminated and utilised, three areas of expertise must be integrated 1) research, 2) context and 3) practice (Figure 6.1). All three are integral to the effective implementation of evidence-based interventions and ensure that they are practical and relevant to the real world of sports injury management.

Figure 6.1. *Integrating expertise to ensure effective utilisation of evidence-based interventions in real world practice (Hanson et al., 2014).*

Knowledge transfer and knowledge gain has become increasingly prevalent within the scientific literature and has become an important topic within the field of sports injury (Provvidenza *et al.*, 2013). Due to the prevalence of CAI within the sports and physically active community it is important to communicate information that optimises the treatment and management of this pathology and is heightened by the theory of knowledge transfer. Knowledge transfer was initially understood as a unidirectional flow of information from the producers of knowledge to the knowledge user. A more contemporary understanding views knowledge transfer as an ongoing relationship that is characterised by exchanges between producers and users whereby the process of knowledge development influences the substance of the knowledge developed (Jacobson, 2007). The evaluation of the effectiveness of knowledge transfer strategies

generally falls into one of two categories. The first focuses on the implementation process in order to identify whether knowledge was implemented according to plan and to identify any factors that facilitated or impeded this implementation. The second assesses the effectiveness of the knowledge transfer strategy in terms of its capacity to yield the intended effects (Gervais *et al.*, 2016).

Knowledge transfer theories should play a role in the development of research agendas by suggesting areas for research. Indeed, there should be a reciprocal relationship between theory and knowledge transfer practice and research (Jacobson, 2007). Whilst the pathology of CAI has been widely researched there is little evidence of dissemination to practitioners, beyond the distribution of peer-reviewed journal articles to the research community. Even those clinicians who search for and read scientific literature find locating relevant resources challenging due to the rapidly growing number of journals and published articles (Ru, Wang and Yao, 2017).

Constructivist social epistemology views knowledge and its transfer as a social construct (Jacobson, 2007). This defines knowledge in terms of whether it is accepted and when and how it is applied within specific contexts, and not merely as to whether it is true or false. Consequently, this theory provides an appropriate model for the dissemination of injury prevention practices, and in particular the use of these within real-world clinical contexts (Peters, 2000). The implementation of the principles of knowledge transfer theory is therefore important when developing educational strategies and in order to determine the success of such strategies (Provvidenza *et al.*, 2013). Whilst the current research within this thesis has been designed around the treatment of a widespread and significant pathology, it must also be accessible to

practitioners. Consequently, the research can only be deemed effective if it influences real world practice.

Many clinical practitioners have a prevalence for formal learning methods which has led to the extensive provision of conferences and workshops in order to extend and maintain practitioner knowledge and ability (French and Dowds, 2008; Gunn and Goding, 2009; Chipchase, Johnston and Long, 2012). Participation in active CPD approaches such as workshops, have been shown to improve knowledge and practice behaviours to a greater extent than passive methods (Menon *et al.*, 2009). Whilst workshops have been seen to be an effective means of improving practice behaviours, those attending CPD programs who receive ongoing education and follow-up sessions appear to demonstrate the most success (Mansouri and Lockyer, 2007; Menon *et al.*, 2009). However, the delivery of ongoing educational contact and follow-up is rarely feasible, with the time and cost implications prohibiting their frequent use (Chipchase, Cavaleri and Jull, 2016). Short-course CPD is a time and resource efficient way to disseminate research and influence practice and has been shown to positively affect self-efficacy within attendees (Makopoulou *et al.*, 2019).

An investigation into the dissemination and intended adoption of the intervention programmes detailed within this thesis is warranted in order to improve evidence-based practice (EBP) and to reduce the gap between research and practice. The findings from the studies in Chapters 4a, 4b and 5 give a clear indication as to the effective use of joint mobilisation and home-based rehabilitation to treat CAI and provide a clear framework for treatment within the first 3 weeks. Therefore, the aim of this study was to analyse the effectiveness of a single short-course CAI workshop

presenting the research findings and recommendations from the current thesis in order

to develop practitioner's knowledge and influence their intended future practice.

6.2. Methods

6.2.1. Experimental Design

This investigation employed a quasi-experimental pre-post repeated measures study design intended to measure the impact of the workshop upon participants knowledge gain and intended future practice. Participants completed pre and post workshop questionnaires designed to evaluate the impact of the workshop on current practice.

6.2.2. Participants

A total of 102 manual therapy practitioners and graduating manual therapy students (mean ±SD: age 25.1 ±5.9yrs, years of practice 3.1 ±3.2yrs range 1-16 years) attended the workshops and completed the pre and post workshop questionnaires. Of these participants, 49 were qualified and practicing (graduate practitioners) (age 28.4 ±6.4yrs, years of practice 5.3 ±3.4yrs), and 53 (age 22.0 ±3.2yrs, years of practice 1.0 ±0.0yrs) were due to graduate (graduates) and be eligible to begin practicing imminently. Participants were contacted through social media, email and word of mouth and attended either a face-to-face or virtual workshop. Inclusion criteria consisted of a qualification and/or certification at level 6 or higher that permits the use of manual therapy treatments under insured conditions, experience of using manual therapy techniques in a clinical setting and experience of working as a manual therapy practitioner within sport. Exclusion criteria pertained to failure to show evidence of the inclusion criteria.

6.2.3. Testing Procedures

Upon attendance at the workshop, the purpose of the study was explained to the participants and consent obtained (Appendix 11 and 12). For the live workshops this

was conducted in person and for the virtual workshops a verbal commentary was given. Participants were then required to compete the pre-workshop questionnaire, with the option to provide a false name for anonymity (as long as the same name was used also for the post-workshop questionnaire to allow for comparison). All participants were asked to include one year of treatment experience as part of their undergraduate/postgraduate degree programmes into their years of practice calculation. Within these courses there is a requirement to conduct and record a significant number of practicing hours in order to be eligible for graduation. This allows individuals to gain knowledge and understanding throughout this time and was hence the reason for including this into their calculation of experience. The pre-workshop questionnaire was designed to determine the participants current knowledge and treatment regarding chronic ankle instability and their attitude towards their future practice (Appendix 13). Following the workshop participants were asked to complete the post-workshop questionnaire identifying the potential impact of the workshop on their knowledge, understanding and future practice (Appendix 14).

6.2.4. Questionnaire

The pre and post workshop questionnaires were designed to evaluate the current knowledge base of participants and the impact that the workshop would have upon their clinical practice. Paper based questionnaires were given to participants for the live workshops, whereas a link to a Google forms version of the questionnaire was given to those attending the virtual workshops. Both versions contained the same questionnaire items. The pre-workshop questionnaire (Appendix 13) consisted of background questions to ascertain the participants current level of practice and experience, and questions relating to their current knowledge of CAI, it's treatment

and how their practice may benefit from attendance at the workshop. The post-workshop questionnaire (Appendix 14) consisted of questions which required the participants to identify the impact that the workshop had upon their knowledge and the effect it would have upon their future practice. The questions primarily asked participants to indicate their level of agreement for each statement before and after the workshop using a five-point Likert-type scale, with some additional multiple-choice questions.

6.2.5. CAI Workshop

The CAI workshop was designed by the author of this thesis and consisted primarily of a PowerPoint presentation (Appendix 15) with demonstrations (live workshops) or videos (virtual workshops) and supplementary materials (Appendix 16). Participants attended either a face-to-face workshop or a virtual one that was delivered by the thesis author. The workshops were approximately 30 minutes in duration with slight time variations based on the means of delivery and the audience. The primary aims of the workshops were to educate the participants on CAI and provide them with research informed treatment protocols that could be effectively utilised within their practice. The workshop outlined three main areas: (1) the epidemiology and pathology of CAI; (2) the results and clinical implications of the research studies within this thesis and (3) specific guidance to facilitate the implementation of the identified treatment protocols. The workshop was underpinned with academic literature and practical demonstrations/videos where appropriate. Participant questions were also welcomed and responded to based on the results of the studies and the experience of the author within the process of this research. No additional information was provided following the termination of the workshop.

6.2.6. Statistical Analysis

Basic descriptive and frequency distributions were carried out on all outcome variables and presented as count and percentage scores. The internal consistency of the items used to assess practitioner's knowledge of ankle sprains (3 items), the perceived benefit to their practice (3 items), and the extent to which they would use the information provided in the future (3 items) were examined by calculating Cronbach's alpha. Differences between question responses from Graduate Practitioners (GP) and Graduates (G) were examined using the Mann-Whitney U test. The Wilcoxon signed-rank test was performed on all paired questionnaire data to identify if there was a significant subjective improvement in knowledge following the workshop. This was conducted for each group individually (Graduate Practitioners and Graduates) where a statistically significant difference in responses was identified following the Mann-Whitney U test. All other tests were performed with the sample as a combined group of practitioners (P). All statistical analyses were performed with a significance level of $p \leq 0.05$.

6.3 Results

There were 20 different main sports identified that the practitioners worked in with the most frequent being football (22.6%) followed by Rugby (14.7%) and Netball (12.8%) (Table 6.1). Of the 102 practitioners sampled, 49 were currently practicing as Graduate Practitioners whilst 53 were in the process of graduating. These 53 practitioners all had 1 year of experience (51.96%) practicing through their clinical placement experience within their course. Of the remaining practitioners 18.63% had 2-3 years' experience, 12.75% had 4-5 years, 10.78% had 6-10 years and 5.88% had more than 10 years' experience. Frequency of practice ranged from less than 5 hours per week (1.96%) to greater than 35 hours (10.78%), with 57.84% involved in 5 to 15 hours of practice and 14.71% practicing for 15 to 25 and 25 to 35 hours per week (Table 6.2).

Table 6.1. *Main sport of those practitioners attending the workshop*

American Football	Athletics	Badminton	Basketball	Cheerleading
2 (1.96%)	7 (6.86%)	3 (2.94%)	5 (4.90%)	3 (2.94%)
Combat Sports	**Climbing**	**Cricket**	**Equestrian**	**Fitness**
4 (3.92%)	1 (0.98%)	5 (4.90%)	1 (0.98%)	7 (6.86%)
Football	**Golf**	**Gymnastics**	**Hockey**	**Ice Hockey**
23 (22.55%)	1 (0.98%)	1 (0.98%)	3 (2.94%)	2 (1.96%)
Netball	**Rugby**	**Swimming**	**Tennis**	**Other**
13 (12.75%)	15 (14.71%)	2 (1.96%)	3 (2.94%)	1 (0.98%)

The Mann-Whitney U tests identified differences in median scores for Graduate Practitioners and Graduates for a number of questionnaire items. For pre-workshop question 1 (Ankle sprain injuries can have a high likelihood of recurrence, $U = 1596.5$, $z = 2.262$, $p = 0.024$), 97.96% of the GP group agreed or strongly agreed in comparison to 88.68% of Graduates. This was in contrast to question 3 (Ankle sprain injuries can lead to long term problems in ankle function, $U = 958$, $z = -2.440$, $p = 0.015$) where 83.02% of the G group agreed or strongly agreed and just 73.47% from

the GP group. For post-workshop question 13 (My confidence to deliver a CAI treatment programme BEFORE the workshop was, $U = 1763.5$, $z = 3.268$, $p = 0.001$), 46.94% of the GP group identified high or very high confidence whilst no Graduate identified very high confidence and only 5.66% high confidence. These questions were therefore analysed as separate groups. All other question responses showed no statistically significant differences between Graduate Practitioners or Graduates ($p \geq 0.05$).

Table 6.2. *Descriptive questions from pre-workshop questionnaire*

Question	Possible answers (No. and percentage)				
	Yes		**No**		
Are you currently practicing?	49 (48.04%)		53 (51.96%)		
	1 year	**2-3 years**	**4-5 years**	**6-10 years**	**10+ years**
How long have you been practicing?	53 (51.96%)	19 (18.63%)	13 (12.75%)	11 (10.78%)	6 (5.88%)
	<5 hours	**5-15 hours**	**15-25 hours**	**25-35 hours**	**>35 hours**
How frequently are you practicing?	2 (1.96%)	59 (57.84%)	15 (14.71%)	15 (14.71%)	11 (10.78%)

Cronbach's alpha revealed an acceptable level of internal consistency (≥ 0.70) for the related questionnaire items regarding the practitioner's pre-workshop knowledge of ankle sprains (Q1-3 = 0.793) and the perceived benefit that a greater understanding of CAI would have to their practice (Q6-8 = 0.816). There was also acceptable internal consistency for the post-workshop questionnaire items identifying the extent to which the presented information would be used by practitioners within their future practice (Q18-20 = 0.741).

6.3.1. Pre-Workshop Questionnaire

Table 6.3. reports that the majority of practitioners agreed (GP = 32.65%; G = 43.40%) or strongly agreed (GP = 65.31%; G = 45.28%) that ankle sprains have a high likelihood of recurrence. There was a similar pattern for the assertion that ankle sprains can have a negative impact on performance/quality of life (agree = 53.92%; strongly agree = 29.41%) and that these injuries can lead to long term problems in ankle function (agree, GP = 51.02%, G = 35.85%; strongly agree, GP = 22.45%, G = 47.17%). 49.02% of practitioners agree or strongly agreed that CAI could be treated with mobilisations, with 46.08% being unsure. More practitioners believed that CAI could be treated with exercise (agree = 37.25%; strongly agree = 35.29%), with fewer being unsure (21.57%) of the effectiveness of this treatment method. The majority of practitioners agreed or strongly agreed that their practice would benefit from a greater understanding of CAI (93.13%), a greater understanding of the use of mobilisations and exercise to treat CAI (89.21%), and specific protocols to improve ankle function for CAI (94.11%).

6.3.2. Post-Workshop Questionnaire

Following the workshop 11.76% stated that they had attended to improve their practical skills, 15.69% to help reduce injuries, and the majority (72.55%) to improve their knowledge and awareness. All practitioners believed (100%) that there is a need for training to develop confidence in treating CAI, that the workshop provided the knowledge to use mobilisations and exercise approaches for CAI, and that the presented information would be useful within their treatment sessions (Table 6.4).

Table 6.3. *Likert scale questions from pre-workshop questionnaire*

Question		Possible answers (No. and percentage)				
Ankle Sprains:	*Group*	**Strongly disagree**	**Disagree**	**Unsure**	**Agree**	**Strongly agree**
1. Have a high likelihood of recurrence	GP	0 (0.00%)	0 (0.00%)	1 (2.04%)	16 (32.65%)	32 (65.31%)
	G	1 (1.89%)	2 (3.77%)	3 (5.66%)	23 (43.40%)	24 (45.28%)
2. Can have a negative impact on performance / quality of life		3 (2.94%)	3 (2.94%)	11 (10.78%)	55 (53.92%)	30 (29.41%)
3. Can lead to long term problems in ankle function	GP	0 (0.00%)	7 (14.29%)	6 (12.24%)	25 (51.02%)	11 (22.45%)
	G	1 (1.89%)	2 (3.77%)	6 (11.32%)	19 (35.85%)	25 (47.17%)

Question	Possible answers (No. and percentage)				
Treatment:	**Strongly disagree**	**Disagree**	**Unsure**	**Agree**	**Strongly agree**
4. It is possible to treat chronic ankle instability with mobilisations	1 (0.98%)	4 (3.92%)	47 (46.08%)	42 (41.18%)	8 (7.84%)
5. It is possible to treat chronic ankle instability with exercise	2 (1.96%)	4 (3.92%)	22 (21.57%)	38 (37.25%)	36 (35.29%)
I think my practice would benefit from:	**Strongly disagree**	**Disagree**	**Unsure**	**Agree**	**Strongly agree**
5. A greater understanding of chronic ankle instability and its effects on function	0 (0.00%)	1 (0.98%)	6 (5.88%)	32 (31.37%)	63 (61.76%)
6. A greater understanding of the use of mobilisations and exercise to treat ankle instability	0 (0.00%)	3 (2.94%)	8 (7.84%)	35 (34.31%)	56 (54.90%)
7. Specific mobilisation and exercise protocols to improve ankle function in those with chronic ankle instability	0 (0.00%)	0 (0.00%)	6 (5.88%)	34 (33.33%)	62 (60.78%)

Table 6.4. *Descriptive questions from post-workshop questionnaire*

Question	Possible answers (No. and percentage)		
	I wanted to improve my practical skills	**I wanted to help reduce injuries**	**I wanted to improve my knowledge and awareness**
Why did you attend the workshop?	12 (11.76%)	16 (15.69%)	74 (72.55%)
	Yes	**No**	**Don't know**
15. Do you think there is a need for training to help people feel more confident about treating CAI?	102 (100%)	0	0
16. Overall, do you think the workshop provided you with the knowledge to use mobilisations and exercise approaches for CAI?	102 (100%)	0	0
17. Do you think you will use the presented information in your sessions?	102 (100%)	0	0

Practitioners all showed high (16.67%) or very high (83.33%) levels of satisfaction following the workshop (Table 6.5). The workshop elicited a statistically significant median increase from before the workshop to after the workshop in participants knowledge of CAI issues ($z = 8.990$, $p \leq 0.001$), knowledge of mobilisation treatment for CAI ($z = 8.973$, $p \leq 0.001$) and knowledge of exercise treatment for CAI ($z = 9.017$, $p \leq 0.001$). Whilst practitioner confidence to deliver CAI treatment programmes was different between the Graduate Practitioner and Graduate groups before the workshop ($U = 1763.5$, $z = 3.268$, $p = 0.001$), there were no differences in this metric following the workshop ($p \leq 0.001$). Both Graduate Practitioners ($z = 5.863$, $p \leq 0.001$) and Graduate groups ($z = 6.598$, $p \leq 0.001$) showed enhanced levels of confidence following the workshop. Subsequently, nearly all of the practitioners stated that it was likely or very likely that their future treatment of CAI would take note of the research findings (99.02%) and follow the recommendations of the study (100%). Similarly, 98.04% agreed or strongly agreed that they would use the information from the workshop in all of their sessions and be able to adapt it to suit their needs, whilst 100% thought the information would be useful in the long term.

Table 6.5. *Likert scale questions from post-workshop questionnaire*

Question	Possible answers (No. and percentage)				
	Very low	**Low**	**Moderate**	**High**	**Very high**
4. Overall, my satisfaction with the workshop is	0 (0.00%)	0 (0.00%)	0 (0.00%)	17 (16.67%)	85 (83.33%)
How would you rate your knowledge of CAI?	**Very poor**	**Poor**	**Okay**	**Good**	**Very good**
5. My knowledge of CAI issues before the workshop was	2 (1.96%)	30 (29.41%)	65 (63.73%)	5 (4.90%)	0 (0.00%)
6. My knowledge CAI issues after the workshop is	0 (0.00%)	0 (0.00%)	0 (0.00%)	35 (34.31%)	67 (65.69%)
How would you rate your knowledge of mobilisation to treat CAI?	**Very poor**	**Poor**	**Okay**	**Good**	**Very good**
7. My knowledge of mobilisation treatment for CAI before the workshop was	2 (1.96%)	27 (26.47%)	63 (61.76%)	10 (9.80%)	0 (0.00%)
8. My knowledge of mobilisation treatment for CAI after the workshop is	0 (0.00%)	0 (0.00%)	0 (0.00%)	30 (29.41%)	72 (70.59%)
How would you rate your knowledge of exercise to treat CAI?	**Very poor**	**Poor**	**Okay**	**Good**	**Very good**
9. My knowledge of exercise treatment for CAI before the workshop was	2 (1.96%)	25 (24.51%)	58 (56.86%)	17 (16.67%)	0 (0.00%)
10. My knowledge of exercise treatment for CAI after the workshop is	0 (0.00%)	0 (0.00%)	0 (0.00%)	29 (28.43%)	73 (71.57%)
Following the workshop, how likely are you to implement the research findings into your own practice?	**Very unlikely**	**Unlikely**	**Unsure**	**Likely**	**Very likely**

	Group					
11. My future treatment of CAI will take note of the research findings		0 (0.00%)	0 (0.00%)	1 (0.98%)	48 (47.06%)	53 (51.96%)
12. My future treatment will follow the recommendations of the research study		0 (0.00%)	0 (0.00%)	0 (0.00%)	28 (27.45%	74 (72.55%)

How would you rate your confidence to deliver a CAI treatment programme following the workshop?	Group	Very low	Low	Moderate	High	Very high
13. My confidence to deliver a CAI treatment programme before the workshop was	GP	3 (6.12%)	12 (24.49%)	11 (11.45%	22 (44.90%)	1 (2.04%)
	G	6 (11.32%)	15 (28.30%)	29 (54.72%)	3 (5.66%)	0 (0.00%)
14. My confidence to deliver a CAI treatment programme after the workshop is	GP	0 (0.00%)	0 (0.00%)	4 (8.16%)	11 (22.45%)	39 (79.59%)
	G	0 (0.00%)	0 (0.00%)	2 (3.77%)	17 (32.08%)	33 (62.26%)

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
To what extent do you think you:					
18. Will use the information in all of my sessions for those with CAI	0 (0.00%)	0 (0.00%)	2 (1.96%)	46 (45.10%)	54 (52.94%)
19. Will be able to adapt the information to suit my needs	0 (0.00%)	0 (0.00%)	2 (1.96%)	30 (29.41%)	70 (68.63%)
20. The information will be useful in the long term	0 (0.00%)	0 (0.00%)	0 (0.00%)	17 (16.67%)	85 (83.33%

6.4. Discussion

The findings of the current research indicate that manual therapy practitioners understand that ankle sprains have a high likelihood of recurrence as well as having a negative impact on performance and leading to long term functional problems. This is explained as any practitioner who attends to musculoskeletal injuries within an active population would have likely experienced a high prevalence of ankle sprain presentation due to this injury type accounting for nearly a quarter of all sports related injuries (Fong *et al.*, 2007; Gribble *et al.*, 2016a). However, there was a significant difference between the Graduate Practitioners and Graduates in relation to the extent to which they believed that ankle sprains would reoccur (65.31% versus 45.28%). This difference may be due to the personal experiences of the practitioners. These injuries have the highest recurrence rate of any musculoskeletal injury (Anandacoomarasamy, 2005), and there is strong evidence to suggest that athletes have twice the risk of recurrent sprain within 1 year of the initial injury (Petersen *et al.*, 2013). Therefore, Graduate Practitioners with greater practicing experience would have observed more injuries and seen evidence of more repeated LAS than Graduates with less experience.

Interestingly, more of the Graduates (47.17%) than the Graduate Practitioners (22.45%) strongly agreed that ankle sprains could lead to long term problems with ankle function, with an additional 14.29% of the Graduate Practitioner group actually disagreeing with this statement. Persistent symptoms are a common outcome following ankle inversion injuries (Anandacoomarasamy, 2005) and can include deficits in range of motion (Denegar and Miller, 2002), balance and proprioception (Hertel, 2002), gait (Delahunt, Monaghan and Caulfield, 2006a), landing biomechanics

(Mason-Mackay, Whatman and Reid, 2017) and strength (Kaminski and Hartsell, 2002). Although these symptoms may reduce athletic performance, athletes may be able to adopt altered movement patterns to compensate for these issues and still maintain their level of activity. Athletes with a history of LAS have been shown to utilise more multi-joint and multi-muscle strategies during landing activities (Lin, Lin and Lee, 2019) and different motor control strategies (Kim *et al.*, 2019). Consequently, many of the Graduate Practitioners may believe that once an athlete has returned to competition that they are symptom free. This may be exacerbated by practitioners experiencing pressure to make return to play decisions on athletes that benefits the short-term interests of the team but could be detrimental to the athlete in the long term (Testoni *et al.*, 2013). Consequently, the Graduate Practitioners within this study may have been viewing LAS as a short term condition based on their experience of the duration between injury and return to sport, without a true appreciation of the more long term consequences such as reduced physical activity across the lifespan and increased risk for the development of ankle osteoarthritis (Beynnon, Murphy and Alosa, 2002). The evidence base has identified that primary research forms the basis of sports injury management plans in only 14% of Achilles tendinopathy cases and 24% of patella femoral pain syndrome (PFPS) cases, whilst personal experience accounts for 59% of management plans in Achilles tendinopathy cases and 44% in PFPS (Murray *et al.*, 2005). Although personal experience is important within injury management, this must be informed by research evidence and literature, and not be based on unsubstantiated methods or self-proclaimed expert opinion. It is therefore important that practitioners involved in the treatment and rehabilitation of LAS and CAI understand the long-term consequences of these pathologies and are not merely concerned with returning the athlete to sport within the shortest time period. Following

injury, pressure is often placed upon medical staff by both management (managers, coaches etc) and athletes in order to clear them for return to play (RTP) (Ekstrand *et al.*, 2019). Practitioners are then often forced to make RTP decisions that are influenced by these third parties and are not reliant on the evidence base, practical judgement or pre-existing RTP protocols (Menta and D'Angelo, 2016). An understanding of the weight that these decisions have upon an athlete's health and career is therefore essential. In the case of CAI an appreciation of the need for continued management following RTP is also needed due to the significant long-term health implications associated with this pathology.

In terms of treatment, the majority of practitioners agreed that CAI could be treated with exercise (72.54%), less than half (49.02%) believed that this was possible with mobilisations. This is surprising as it is well documented within systematic reviews which show evidence that mobilisations are an effective way to reduce mechanical and functional deficits associated with CAI (Doherty *et al.*, 2017; Vallandingham, Gaven and Powden, 2019). Specifically, improvements in DF-ROM of 4.1% (Silva *et al.*, 2017) 4.4% (Landrum *et al.*, 2008) and 4.9% (Hoch, Andreatta, *et al.*, 2012) have been observed following the application of talocrural joint mobilisations. Whilst the effect of ankle joint mobilisations on functional deficits are more contentious, improvements have also been clearly observed in static postural control (Hoch and McKeon, 2011a) and performance in the SEBT (Hoch *et al.*, 2014; Cruz-Díaz *et al.*, 2015). Due to the peer-reviewed publication of research into the various interventions that can be used to treat CAI, it is tempting to assume that this information has been disseminated effectively to practitioners. However, if this were to be true then there should have been a notable decrease in the prevalence and severity of the CAI

pathology within the active population, and an associated increase in the response of Graduates and Graduate Practitioners to this question item. Consequently, there appears to have been failure in either the dissemination of research, its adoption, or the relevance of the research to practice (Finch, 2011). The RE-AIM framework was developed partially as a response to the lack of real-world application of research which was traditionally conducted under optimal efficacy conditions and offers a comprehensive approach for evaluating the impact of health care interventions (Jilcott *et al.*, 2007; Gaglio, Shoup and Glasgow, 2013). The framework includes an evaluation of an interventions reach, effectiveness, adoption, implementation and maintenance. Whilst peer-reviewed research publications often have considerable reach, and clearly demonstrate effectiveness, the way in which they are presented produces a gap between knowledge and practice. Research that is not associated with the practicalities of adoption, implementation and maintenance will not prevent injuries or improve patient outcomes and leads to questions regarding the purpose of the research beyond that of mere scholarly activity (Hanson *et al.*, 2014).

Whilst there was some variance in the reasons for attending the workshop, the majority did so in order to improve their knowledge and awareness (72.55%). This was mirrored in the practitioner's assertion that they would benefit from a greater understanding of CAI (93.13% agree or strongly agree) and mobilisations and exercise to treat ankle instability (89.21% agree or strongly agree). This translated into an agreement that specific protocols of mobilisation and exercises for CAI would be beneficial to their practice (94.11%). Continuing professional development (CPD) is the enhancement and extension of knowledge and expertise and includes a range of learning activities which develop and maintain a health practitioners capacity to practice safely,

effectively and legally within their evolving scope of practice (Filipe *et al.*, 2014). As such, CPD is the longest phase of professional education and is essential for the provision of health care which is evidence based (Davis *et al.*, 2003). CPD is also a mandatory requirement to maintain professional registration, so the demand for appropriate learning activities such as those provided by the CAI workshop is high. The use of research evidence within clinical practice requires the practitioner to regularly consult the literature in order to update their knowledge, which is a time-consuming task for busy practitioners. A well designed CPD workshop can be used to effectively disseminate knowledge in a time-friendly manner to these practitioners and has been shown to improve knowledge and guideline-consistent behaviours (Menon *et al.*, 2009). Active approaches such as this also tend to elicit greater improvements in practice behaviour than passive approaches such as reading (Menon *et al.*, 2009). Whilst knowledge gain is beneficial, the effectiveness of knowledge transfer need to be evaluated with regards to the RE-AIM framework. This requires an assessment as to whether the presented knowledge has been implemented as required, whether the adopted strategy has yielded the intended results, and whether the new practice behaviour has been maintained (Kortteisto *et al.*, 2010; Gervais *et al.*, 2016).

The workshop effectively improved practitioners' knowledge of CAI, and mobilisation treatment and exercise protocols for this pathology ($p \leq 0.001$). Consequently, the majority of practitioners stated that they were likely or very likely to take note of the research findings (99.02%) and all stated that they would follow the recommendations of the workshop (100%). The adoption of any treatment interventions by practitioners is essential if a significant health care impact is to be made (Finch and Donaldson, 2010). Whilst actual adoption was not measured in the current study, theories of

human behaviour have shown that within non-clinical populations the most immediate predictor of behaviour is intention (Webb and Sheeran, 2006). Similarly, implementation research has identified that there exists a predictable relationship between intentions of health care professionals and their subsequent behaviour (Eccles *et al.*, 2006). Although the relationship between intention and behaviour is not perfect, it is reliable, and shows how the intention to adopt a healthcare intervention directly effects the actual implementation of the strategy. This can be explained by the theory of planned behaviour (TPB) which indicates that it is an individual's attitude towards a behaviour and their perceived behavioural control which influence their intentions. Research confirms that the TPB provides a suitable theoretical framework that links intention to implementation within professional healthcare practice and facilitates the RE-AIM frameworks evaluation of research implementation (Kortteisto *et al.*, 2010). However, whilst both the Graduate Practitioner and Graduate groups identified an improvement in their confidence to deliver CAI treatment programmes following the workshop ($p ≤ 0.001$), there was a statistically significant difference between the groups rating of their own confidence before the workshop ($U = 1763.5$, $z = 3.268$, $p ≤ 0.001$) with GP being more confident. Confidence is not an innate fixed characteristic and is generally seen to be acquired and improved over time and is developed through experiences (Jones and Sheppard, 2012). As such, the Graduate group may see themselves as being less confident due to the limited experiences they have had and time that they have been practicing for. The role of health profession education is to develop the knowledge and skill of the practitioner in order to enable independent and competent practice (Jones and Sheppard, 2012). Whilst undergraduate degree programmes are producing graduates who have achieved the requisite level of academic and clinical knowledge, their confidence and self-efficacy

in specific situations can only be developed through activity and experience. The ability of these programmes to provide quality clinical education opportunities is essential for developing students' clinical skills and self-efficacy, as in addition to self-efficacy being related to knowledge, it has also been related to the successful performance of health care clinical skills (Opacic, 2003). Research suggests that the magnitude of domain-specific efficacy developed by Athletic Training students is similar between undergraduate and masters courses (Pfeifer *et al.*, 2019). Whilst this highlights consistency between such programmes, it indicated that there is scope for improvement. Recommendations point to the need for imaginal experiences to be integrated into clinical degree courses. Imaging mastery experiences such as this may help to make up for a lack of hands on opportunities within clinical settings and go some way to improving students ability to handle the cognitive and physical arousal associated with clinical decision making (Pfeifer *et al.*, 2019). Previous studies have reported that students possess higher levels of confidence and lower levels of performance related anxiety when these methods are adopted (Monsma *et al.*, 2011).

Subsequently, all practitioners (Graduate Practitioners and Graduates) believed that there is a need for more training to help people feel more confident about treating CAI. This follows the concept of self-efficacy, which is an element of confidence that is task and situation specific (Bandura, 1977), and is important to ensure successful outcomes for patients. Indeed, practitioners with higher self-reported confidence appear to be associated with higher patient-reported alliance to health care interventions (Brunner *et al.*, 2019). The development of practitioner confidence and self-efficacy in treating CAI may help to reduce the incidence of a fear-avoidance mechanism which may be employed by practitioners in order to protect their

professional confidence and self-esteem which can become threatened when dealing with conditions outside of their clinical comfort zone (Synnott *et al.*, 2015). Self-efficacy play an important role in the volitional phase of behavioural planning and is a powerful predictor of intention (Garcia and Mann, 2003). There may therefore be a similar link within the current study between the improvement in the participants confidence and their intention to adopt the recommendations of the workshop. Whilst there is a clear link between the intention and future behaviour of healthcare professionals (Eccles *et al.*, 2006), there is some research which suggests that high levels of behavioural determinants do not translate to effective implementation of injury prevention programmes (IPPs) (Frank, Register-Mihalik and Padua, 2015). However, much of this research has been conducted on non-healthcare professionals and hence their attitudes towards preventative practice may not be comparable as they are not required to be educated on the use of efficacious IPPs as part of their profession (Norcross *et al.*, 2016). The effective implementation of new healthcare interventions is influenced by barriers and facilitators to practice, which impact on the ultimate success of the strategy. Research has highlighted a number of potential barriers and facilitators to implementing injury prevention programmes which relate to both the content and nature of the actual prevention programme, as well as the delivery methods and support provided by athletes, management and support staff (McCall *et al.*, 2015; O'Brien, Young and Finch, 2017). Although many of the practitioners who attended the workshops will be solely responsible for the injury management of their athletes/clients, within a multi-disciplinary team there is the potential for conflicting views and ideas (O'Brien *et al.*, 2019). Where necessary, the identification of these staff related factors will be necessary to ensure the intervention strategies and injury treatment is following the research recommendations and is adopted, implemented

and maintained as a practice behaviour. The time commitment needed to implement an intervention strategy has also been cited as a barrier to implementation (Dix *et al.*, 2020). In a survey of soccer coaches, 87% were less likely to be compliant with an IPP if they thought it to be time-consuming (Soligard *et al.*, 2010). The presented injury treatment intervention within the workshop was a time-effective treatment method, involving minimal athlete contact time and home-based exercise which should mitigate the time-consuming barrier to implementation and enhance maintenance over time.

Based on the post-workshop questionnaire the delivered information was seen by all practitioners to be effective in providing them with the knowledge to use exercise and mobilisations in the treatment of CAI and that they would use this information in future treatment sessions. Whilst this is a gratifying outcome from the workshop, research into the efficacy of workshop based learning has consistently demonstrated that although structured CPD improves the knowledge and practice of clinicians, it has minimal effect on patient outcomes (Mansouri and Lockyer, 2007; O'Neil and Addrizzo-Harris, 2009). This may be a consequence of traditional CPD courses presenting information in an abstract sense which does not correlate with the practical application of the learned techniques and protocols (Chipchase, Johnston and Long, 2012). Furthermore, the implementation of injury treatment strategies often fail because the intervention is either too complex or does not adequately address the practitioners own behaviours in relation to the delivery of treatment (Stame, 2010). The attended workshop and the included CAI research were designed in such a way to ensure that the recommendations and treatment protocols were simple to follow. Whilst the design of this research study does not allow for an analysis of the practitioners' future application of the research findings, there was an agreement by

nearly all practitioners that the information provided would be used in all of their treatment session (98.04%) and that they could adapt this to suit their needs (98.04%). There was also complete agreement (100%) that there would be long-term use of the information in their treatment of those with CAI. Within the RE-AIM framework, the concept of maintenance refers to the sustained delivery and effectiveness of the intervention (Shaw *et al.*, 2019). Although the current study did not longitudinally assess whether the presented information and intervention were preserved as a new practice behaviour, the agreement of all practitioners as to the long-term use of these methods goes some way to predicting practice maintenance. Research suggests that when compliance to an injury prevention or treatment programme is high, there is a significant reduction in injury and time loss for athletes (Silvers-Granelli *et al.*, 2018). Unfortunately, the adoption rates and implementation of evidence based injury prevention strategies are often low, even within the highest levels of sport (Bahr, Thorborg and Ekstrand, 2015). In addition, there are often major reporting gaps regarding the implementation and maintenance of these programmes within the research (O'Brien and Finch, 2014) and only 1% of sports injury prevention publications focus on programme implementation and maintenance (Klügl *et al.*, 2010).

6.4.1. Recommendations for Future Research

The study focussed on the participants knowledge, confidence and intention to adopt at the time points directly before and after the workshop. As such, there could be no definitive analysis of the practitioner's actual future application of the research findings as the current study was limited to only being able to describe the practitioners intended behaviour. Whilst changes in knowledge, confidence and intention to adopt

are often demonstrated following clinical workshops such as this, changes to clinical actions in the long term are often less forthcoming. Future research should therefore focus on follow-up questionnaires to identify whether the intention of practitioners to adopt the presented strategies and advice were put into clinical practice, whilst also exploring any barriers and facilitators to implementation. CPD events are generally only attended by those practitioners who have an interest in the topic being discussed and who feel that they would benefit from being in attendance. Consequently, the results of the study may have some sampling bias as to the effectiveness and use of the presented research findings, as those practitioners in attendance may have been more susceptible and may not be representative of the profession as a whole. Pre and post information regarding the practitioner's knowledge before and after the workshop was taken during the post-workshop questionnaire. Conducting a standard before and after analysis of the practitioner's knowledge may have led to evidence of unconscious incompetence where participants were unaware of their lack of knowledge in a subject. This is problematic during Likert scale questions and may have left minimal scope for the practitioners to evaluate any changes in knowledge following the workshop. By presenting the questions assessing this knowledge during the post-workshop questionnaire, it allowed the practitioners to identify whether any clear changes in their knowledge of CAI and the use of mobilisations and exercise to treat the condition had occurred. This helped to ensure a level of conscious competence where the practitioners became aware of what they did or did not know.

6.5 Conclusion

Traditional sports medicine approaches which are based purely on epidemiological methods are unlikely to be practically applicable to practitioners, and new procedures

for reporting research are needed. A paradigm shift is therefore required by sports injury researchers to consider the real-world implementation of the injury interventions being researched and to develop partnerships between the researchers and practitioners delivering the treatments. The use of CPD workshops is an ideal means by which to disseminate research in an accessible manner, particularly with the rise of social media and video conferencing software. These active approaches to CPD have been seen to be more effective than passive methods and should be adopted in order to effectively disseminate research knowledge in order to influence practice. Within the current study a clear improvement in practitioner knowledge and understanding of CAI and treatment methods was evident following the CPD workshop. These findings also identify that the current knowledge base of sports injury practitioners regarding the CAI pathology may be limited. This is worrying for such a prevalent condition and highlights further the need for CPD events to enhance practitioner knowledge. Following the CPD workshop the practitioner's behavioural intention to use the information provided was clear and shows that intended clinical practice can be enhanced through the use of workshop-based research dissemination. However, follow up studies that can identify whether long-term changes to practice have occurred and assess the effect on patient outcomes are needed but were beyond the scope of the current study.

7.1. Summary

This chapter summarises the major overarching findings of the preceding studies comprising the thesis and considers their collective clinical and research implications. The objectives of this thesis were to provide a comprehensive examination of the effect of varying treatment durations of a Maitland anterior-to-posterior talar mobilisation in those with CAI and to identify an effective and efficient clinical method for improving the associated outcome measures, and to disseminate this information to practitioners. These objectives were achieved through i) an examination of the effect of varying treatment durations during a 2-week talocrural joint mobilisation intervention on measures of DF-ROM, posterior talar laxity, dynamic postural control and self-reported function; ii) an exploratory study to identify the extent to which improvements in outcome measures are sustained for a 4-week period following mobilisation treatment and the effect that a specific ankle exercise regime can have on these measures during the same time frame; iii) the collated information was disseminated to practitioners to identify the impact that this research would have upon their clinical practice using the RE-AIM framework. To summarise the findings, the hypotheses from Chapter 1 are revisited:

Hypothesis for Aim 1: Following the 2-week talocrural joint mobilisation intervention, participants receiving longer treatment durations will demonstrate greater improvements in clinical and self-reported measures of function.

Finding: It was confirmed that joint mobilisation treatment can significantly improve arthrokinematic motion, dynamic postural control and self-reported function when

delivered over a 2-week period. Increased treatment durations were shown to confer the greatest improvements in outcome measures over this timeframe. However, only the 120s treatment group demonstrated statistically significant improvements in all dynamic postural control measures over the 2-week period. Further investigation identified that the improvements in arthrokinematic function (DF-ROM, WBLT and PG) and performance on the anterior reach direction of the SEBT were most evident within the first 3 treatment sessions (week 1), indicating that 120 second treatment durations are more effective than shorter treatment durations when single sets are being delivered within the first week of treatment. Other findings show that significant improvement in posterolateral and posteromedial reach distances were greater as the mobilisation treatment duration increased but were not notably different from the improvements shown in the control limbs. It was postulated that a potential cross-over effect could plausibly explain these results, and that mobilisations may have a bilateral effect on dynamic balance.

__Hypothesis for Aim 2:__ Joint mobilisations will result in a sustained improvement in DF-ROM, laxity, dynamic postural control, and self-reported function following treatment cessation, and the application of a specific home-based ankle exercise programme will augment these improvements further.

Finding: The findings showed that the improvements that occurred following the joint mobilisation intervention were not maintained following treatment cessation, and that there is a propensity for some of these improvements to be lost if no further treatment targeting arthrokinematic function is delivered. However, improvements in dorsiflexion (DF-ROM and WBLT), laxity (PG), dynamic postural control (SEBT), and self-reported

function (CAIT and FAAM) were augmented by the inclusion and adherence to a home-based ankle exercise programme.

Hypothesis for Aim 3: The use of longer talocrural joint mobilisation treatment durations and the inclusion of ankle specific home-exercise programmes will result in the greatest improvement in clinical and self-reported measures of function in those with CAI.

Finding: It was confirmed that the application of joint mobilisations in the first week of intervention, followed by a home-based rehabilitation programme can enhance the mechanical, functional, and self-reported function of those with CAI. Additional findings showed that the magnitude of improvement in arthrokinematic function was greatest during the first 2-weeks of rehabilitative treatment. This was also evident for the anterior and posteromedial reach direction of the SEBT, whilst the posterolateral reach distance peaked following week 3.

Hypothesis for Aim 4: The dissemination of the research will result in the development of practitioner's knowledge, and intention to adopt and implement the recommendations of the study within their own future clinical practice.

Finding: The hypothesis was confirmed as a clear improvement in practitioner knowledge and understanding of CAI and treatment methods was evident following the CPD workshop. Furthermore, following the CPD workshop the practitioner's behavioural intention to use the information provided was clear and showed that their intended clinical practice was enhanced through the use of the workshop-based research dissemination method.

7.2. Synthesis and Application of Results

The first two studies of this thesis (Chapter 4a and 4b) enhanced the current knowledge on the effect that mobilisation treatment durations have upon individuals with CAI using both clinician and patient-oriented measures. The results of these studies showed that the duration of mobilisation treatment has a direct influence on the magnitude of improvements observed. Specifically, individuals with CAI who received six, 120s grade IV AP talocrural joint mobilisation, delivered over a 2-week period showed significantly greater improvements in dorsiflexion (DF-ROM and WBLT), PG, dynamic balance and self-reported function than those receiving shorter durations (60s and 30s) of treatment. These improvements were most evident within the mechanical measures of function, as whilst there was a cumulative improvement in dynamic postural control in the posterolateral and posteromedial reach directions, this was not statistically different from the improvement observed in the control limb following each individual treatment session. Consequently, there is evidence to suggest that ankle joint mobilisations may have a bilateral effect on dynamic balance. Results from Chapter 5 may point to a more convincing hypothesis whereby a learning effect had occurred, although further investigation would be needed to confirm or refute this supposition. Furthermore, the magnitude of improvement in function was most substantial in the first treatment week. These results identify that joint mobilisations are an effective treatment method to improve functional deficits associated with CAI, and that 120s of treatment is and effective and efficient means of improving these when delivered as single sets in the first week of treatment. Comparison to methodologically similar research (Hoch, Andreatta, *et al.*, 2012; Gilbreath *et al.*, 2014; Cruz-Díaz *et al.*, 2015; McKeon and Wikstrom, 2016) also suggests that grade IV mobilisations are advantageous to grade III mobilisations due

to their ability to produce a greater oscillatory frequency and mean force (Silvernail *et al.*, 2011) and that these should be selected for the treatment of those with CAI when improvements in arthrokinematic function are the objective. These studies also provide patient-oriented evidence that joint mobilisation treatment can provide improvements to the health-related quality of life (HRQL) of those with CAI, and that patient reported outcome measures can be effectively utilised to determine the subjective outcome of CAI treatment interventions (Powden, Hoch and Hoch, 2017).

Chapter 5 further identified that the application of three treatments of 120s of Grade IV AP talocrural joint mobilisation administered over a 5-day period, can improve arthrokinematic function and dynamic postural control. Interestingly, these improvements are not maintained upon cessation if no further treatment is provided, and that there is a propensity for some of these improvements to be lost if no further treatment targeting arthrokinematic function is delivered. However, there are still notable improvements beyond baseline measures. This suggests that although mobilisations are an effective treatment method for CAI, they may not 'fix' the underlying physiological disorder completely but are a means to allow for the progression of rehabilitation to occur. Within this study the participants were all actively involved in sports competition/training. Whilst this may show that the participants were coping with their CAI, they did not fall within the research classification of CAI copers. Individuals classified as copers do not experience subsequent injuries, residual symptoms or functional disability (Wikstrom and Brown, 2014). Consequently, the objective of the rehabilitation was to provide a suitable treatment regimen that could be completed whilst still competing/training, and that could improve the participants

functional capacity through an increase in DF-ROM and dynamic postural control, reducing the risk of injury and improving the long-term sequalae of CAI.

The adherence to a specific home-based rehabilitation intervention that targets restrictions in arthrokinematic function and dynamic postural control was seen to elicit significant improvements in function when preceded by a talocrural joint mobilisation intervention. The improvements in arthrokinematic function were evident throughout the 4-week rehabilitation intervention, however a marked reduction in the level of improvement was evident, with the greatest improvements occurring within the first two weeks. The self-mobilisation of the ankle using a nonelastic strap is therefore an effective means of improving arthrokinematic function in those with CAI. This method follows the MWM technique whereby the application of a combined posterior-inferior talar glide and active dorsiflexion movement can minimise anterior talar displacement and restore normal joint kinematics and improve DF-ROM (Vicenzino *et al.*, 2006b; Jeon *et al.*, 2015b). These outcomes are important for sports participants, as reductions in DF-ROM cause changes in gait patterns and landing biomechanics, which can dispose individuals to additional pathologies such as medial tibial traction periostitis, metatarsalgia, Achilles tendinopathy, plantar fasciopathy and strain of the gastrocnemius (Young *et al.*, 2013). The long-term effects of alterations in the arthrokinematics of the talocrural joint can also lead to post-traumatic osteoarthritis (PTOA) (Valderrabano *et al.*, 2006). Evidence suggests that cartilage regeneration most reliably occurs in a mechanically unloaded, well aligned limb (Kanamiya *et al.*, 2002; Felson and Kim, 2007), and that adherence to a specific rehabilitation protocol focussing on neuromuscular control may prevent or reverse PTOA (Carbone and Rodeo, 2017)

The improvement in dynamic postural control was also evident following the home-based rehabilitation programme. Postural control deficits have been clearly identified in individuals with a history of ankle sprain (McKeon and Hertel, 2008; Arnold *et al.*, 2009), which have been postulated to be secondary to a combination of impaired neuromuscular control and proprioception (Hertel, 2002). Poor neuromuscular control, such as the inability to balance (Plisky *et al.*, 2006) or control the body during dynamic actions (Gribble and Robinson, 2009), increases the risk of lower extremity injury, particularly at the ankle. As such, interventions which improve these components will improve sports performance (Zech *et al.*, 2010) and reduce injuries (Hübscher *et al.*, 2010; Schiftan, Ross and Hahne, 2015). However, the magnitude of improvement in dynamic postural control and the time frame through which they occur differed within this study with respect to the anterior, posterolateral and posteromedial reach directions of the SEBT. Similar to the arthrokinematic function measures, improvement in the ANT was most notable during the first two weeks of adherence. Conversely the PL reach direction took until week two to show any improvements with the largest increases observed in week three, which contrasted with the PM reach direction peaking in week two, with no other significant improvements beyond this time point. These findings indicate that sensorimotor function may take longer to adapt than arthrokinematic function. This is linked to the assertion that the level of adaptation of the sensorimotor system is determined by the number of times that a movement is practiced (Huang and Shadmehr, 2007). As it was only the PL reach direction that showed peak improvements beyond the second weak of the home-based rehabilitation intervention it was concluded that two weeks of adherence was the most efficient and effective duration to improve both arthrokinematic and sensorimotor

function in those with CAI when preceded by joint mobilisation treatment that consists of 120s of treatment delivered as single sets in the first week of treatment.

The changes in DF-ROM and WBLT identified in Chapters 4a, 4b and 5 corresponded to similar improvements in PG. It could be concluded that these improvements are a direct result of a restoration of the normal arthrokinematic function of the talocrural joint through a correction of the anterior positional fault of the talus and its accessory motion (Vicenzino *et al.*, 2006b). Whilst this can be postulated as a research informed theory, a full investigation using anatomical imaging would be necessary to prove this assertion. However, the comparable improvements in these measures may have identified some test redundancy. Although both goniometry measurement of DF-ROM and the PG test are seen as highly reliable (Denegar, Hertel and Fonseca, 2002; Vicenzino *et al.*, 2006b; Krause *et al.*, 2011) the ability of the clinician to subjectively assess capsular end feel and the lack of consistency in ROM brought about by changes in lower limb positioning allows for criticism of these methods. Consequently, the WBLT may be seen as a more functional and meaningful test particular for those who can effectively weight-bare and should be recommended as the primary choice for clinicians wishing to measure DF-ROM

The studies from Chapters 4a, 4b and 5 utilised the contralateral limb as a paired control. This is an accepted method within many clinical and anthropological studies due to the implicit assumption that no significant differences exist between bilateral limbs which reduces the amount of unintended variation between intervention and control groups (Mustafy, Londono and Villemure, 2018). Although improvements in dynamic postural control were observed for the contralateral limb in studies 4a and 4b,

the most likely explanation was that a learning effect had taken place, as such changes were not observed in study 5. Consequently, whilst literature does show that changes in different tissues, including bone, ligament, cartilage and muscle of the contralateral limb can created by an intervention (Frank *et al.*, 1994), this thesis supports the use of the untreated or uninjured contralateral limb as an appropriate paired control.

The studies from Chapters 4a, 4b and 5 utilised patient, clinician and laboratory-oriented measures (PCL model) to examine local and global impairments in arthrokinematic and sensorimotor function, as well as capturing the level of function for individuals within their environment. By applying these components, it allowed for the evaluation of the laboratory methods used and their appropriateness for evaluating treatment, the effectiveness of the interventions at a clinical level, and the patient's perception of the intervention effects. The convergence of these individual segments can aid in the classification of new research evidence (McKeon *et al.*, 2011). The integration of the PCL model into the current thesis has therefore provided a more comprehensive view of the clinical evidence, allowing for the effective dissemination of the research findings to practitioners.

The final study within this thesis (Chapter 6) utilised the RE-AIM framework to disseminate the research findings to practitioners within a CPD workshop. Analysis showed that the current knowledge base of practitioners regarding CAI and treatment methods may be lower than expected, but that both elements were enhanced following the CPD workshop. As LAS and the CAI are one of the most prevalent conditions within an active population (Doherty *et al.*, 2014; Wikstrom *et al.*, 2007), it is important that practitioners have an appropriate knowledge base regarding these pathologies.

The CPD workshop delivered as part of the current thesis also resulted in a signifciant effect upon the practitioners intention to use the recommended treatment identified in chapters 4a, 4b and 5. Each of these findings suggest that CPD workshops are an appropriate means for research dissemination, and that knowledge, understanding and the intention to adopt an intervention can be enhanced through this method. This will hopefully add evidence for the paradigm shift which is needed within sports injury research in order to consider the real-world implementation of injury interventions. This should also help to reduce the research-to-practice time gap and maximise the impact of the treatment intervention on future practice.

7.3. Future Directions

The studies described within the thesis raise a number of questions that could be addressed in future research in order to aid our understanding of CAI and treatment intervention. The studies in chapters 4a, 4b and 5 showed a clear link between improvements in DF-ROM and the measures of posterior talar glide (PG). Whilst it can be assumed that this was a result of a restoration of normal arthrokinematic function of the talocrural joint this requires further investigation. Following injury to the ATFL, the talus can become anteriorly malpositioned, which has been proven using unstressed radiographic imaging (Wikstrom and Hubbard, 2010) and is directly linked to the observed reductions in posterior talar glide and DF-ROM (Cosby and Hertel, 2011). It is postulated that AP talar joint mobilisations may address the talar positional fault and restore DF-ROM. However, this assertion may only be proved through imaging and is a recommended area of study that will provide important information as to the mechanisms by which joint mobilisation work and affect function.

The indication of the presence of the CAI pathology within the participants was based upon their subjective history and a score of less than 24 on the CAIT. Whilst this adheres to the standard inclusion criteria endorsed by the International Ankle Consortium (IAC) (Gribble *et al.*, 2014), it gives no indication as to the specific functional problems that the individual has. Consequently, the division of CAI sufferers into subgroups with similar clinical characteristics may be better linked to treatment outcomes. One or more of these CAI subgroups may respond more favourably than others. An example of this would be that mobilisations would have a greater effect on those with more substantial reductions in DF-ROM or those with an anteriorly positioned talus by addressing the positional fault or increasing the posterior talar glide. Those suffering from more FAI may respond more to dynamic balance exercises. The investigation of CAI subgroups and how these can be defined and identified would therefore be the first step in providing more efficacious treatments and intervention.

The longitudinal effects of joint mobilisation and rehabilitation is another area requiring investigation. Whilst it was clearly shown that positive effects were elicited from these treatments, the contribution of these to the prevention or reduction of recurrent ankle injury is warranted. In addition, the studies herein identified improvements in PROM that were above the MCID with regards to the CAIT and both subscales of the FAAM. However, few participants reached the scores needed to be deemed symptom free and no longer falling within the heterogenous condition of chronic ankle instability as defined by the IAC. Further studies may therefore be able to identify appropriate rehabilitation progression in order to continue to develop the participants functional

capacity so that they can become redefined as either copers or asymptomatic in nature.

The RE-AIM framework provided key guidance for the design of the CPD workshop and dissemination of the research to practitioners. However, only the practitioner's intention to adopt was identified and as such conclusions as to the impact of the workshop on actual practice could not be made. Future investigation into the actual adoption of research informed practice by practitioners and the maintenance of these techniques in the long-term is needed to provide an understanding of the interventions real-world impact.

7.4. Conclusion

Multiple treatments sessions of Maitland Grade IV anterior to posterior talar glide joint mobilisations can significantly improve arthrokinematic function, dynamic postural control, and self-reported function in those with chronic ankle instability. Longer treatment durations are recommended when single sets are applied within the first week of treatment. These improvements are not maintained following treatment cessation, although function is kept above baseline levels. However, the inclusion of a home-based rehabilitative exercise programme focussing on dynamic postural control and self-applied ankle mobilisation and stretching can further augment these improvements. The results therefore advocate that 120s of joint mobilisation treatment is applied in the first week of treatment, followed by an at home rehabilitative exercise programme for the proceeding 2-weeks. Further findings of the thesis show that CPD workshops are an effective way to present research information to improve the knowledge, understanding and intention to adopt new treatment strategies within

healthcare professionals. These methods should be adopted by researchers in order to disseminate research knowledge to influence practice. The use of CPD workshops is an effective means to achieve this and reduces the time between the production of research evidence and its dissemination and use in practice.

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APPENDIX 1.

Inclusion and Exclusion Criteria.

Adapted from the standard inclusion criteria endorsed, as a minimum, by the International Ankle Consortium for enrolling patients that fall within the heterogeneous condition of chronic ankle instability in controlled research (Gribble *et al.*, 2014)

Inclusion criteria

1. A history of at least 1 significant ankle sprain

   The initial sprain must have occurred at least 12 months prior to study enrolment

   Associated with inflammatory symptoms (pain, swelling, etc)

   Created at least 1 interrupted day of desired physical activity

   The most recent injury occurred more than 3 months prior to study enrolment.

   > An "ankle sprain" is defined as "An acute traumatic injury to the lateral ligament complex of the ankle joint as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot. This usually results in some initial deficits of function and disability."

2. A history of the previously injured ankle joint "giving way" and/or recurrent sprain and/or "feelings of instability."

   > "Giving way" is defined as "The regular occurrence of uncontrolled and unpredictable episodes of excessive inversion of the rear foot (usually experienced during initial contact during walking or running), which do not result in an acute lateral ankle sprain."

   Specifically, participants should report at least 2 episodes of giving way in the 6 months prior to study enrolment

   > A "recurrent sprain" is defined as "two or more sprains to the same ankle".
   >
   > "Feeling of ankle joint instability" is defined as "The situation whereby during activities of daily living (ADL) and sporting activities the participant feels that the ankle joint is unstable and is usually associated with the fear of sustaining an acute ligament sprain."

   Specifically, self-reported ankle instability is confirmed with the Cumberland Ankle Instability Tool (CAIT) where a score of less than 24 out of a possible 30 is used to indicate the presence of the condition

3. The Foot and Ankle Ability Measure (FAAM) is utilised as a general self-reported foot and ankle function questionnaire to describe the level of disability of the cohort. A score of <90% and <80% on the Activities of Daily Living (ADL) scale and Sport (ADL-S) scale was required respectively.

Exclusion criteria

1. A history of previous surgeries to the musculoskeletal structures (ie, bones, joint structures, nerves) in either limb of the lower extremity. It is understood and accepted in clinical and research practice that surgery to repair insufficient joint structures is designed to restore structural integrity but creates residual changes in the central and peripheral portions of the nervous system. Even with appropriate rehabilitation and follow-up management, there are concomitant neuromuscular and structural alterations after surgery that would confound the ability to isolate the effects of chronic ankle instability.

2. A history of a fracture in either limb of the lower extremity requiring realignment. Similar to the first exclusion criterion, significant compromise to skeletal tissue will threaten the internal validity of the selection of study populations with isolated chronic ankle instability.

3. Acute injury to musculoskeletal structures of other joints of the lower extremity in the previous 3 months, which impacted joint integrity and function (ie, sprains, fractures) resulting in at least 1 interrupted day of desired physical activity

Cumberland Ankle Instability Tool (CAIT)

This form will be used to categorize your ankle instability. It consists of 9 questions, each with multiple answers. Please choose only ONE response to each question that BEST describes your ankle. This should occur in regards to EACH ankle. Please be honest and truthful in all of your responses. Thank you for your participation.

	LEFT	RIGHT	Score
1. I have pain in my ankle			
Never	☐	☐	5
During sport	☐	☐	4
Running on uneven surfaces	☐	☐	3
Running on level surfaces	☐	☐	2
Walking on uneven surfaces	☐	☐	1
Walking on even surfaces	☐	☐	0
2. My ankle feels UNSTABLE			
Never	☐	☐	4
Sometimes during sport (not every time)	☐	☐	3
Frequently during sport (every time)	☐	☐	2
Sometimes during daily activity	☐	☐	1
Frequently during daily activity	☐	☐	0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never	☐	☐	3
Sometimes when running	☐	☐	2
Often when running	☐	☐	1
When walking	☐	☐	0
4. When going down stairs, my ankle feels UNSTABLE			
Never	☐	☐	3
If I go fast	☐	☐	2
Occasionally	☐	☐	1
Always	☐	☐	0
5. My ankle feels UNSTABLE when standing on ONE leg			
Never	☐	☐	2
On the ball of my foot	☐	☐	1
With my foot flat	☐	☐	0

6. My ankle feels UNSTABLE when

Never	☐	☐	3
I hop from side to side	☐	☐	2
I hop on the spot	☐	☐	1
When I jump	☐	☐	0

7. My ankle feels UNSTABLE when

Never	☐	☐	4
I run on uneven surfaces	☐	☐	3
I jog on uneven surfaces	☐	☐	2
I walk on uneven surfaces	☐	☐	1
I walk on a flat surface	☐	☐	0

8. TYPICALLY, when I start to roll over (or 'twist') on my ankle, I can stop it

Immediately	☐	☐	3
Often	☐	☐	2
Sometimes	☐	☐	1
Never	☐	☐	0
I have never rolled over on my ankle	☐	☐	3

9. After a TYPICAL incident of my ankle rolling over, my ankle returns to 'normal'

Almost immediately	☐	☐	3
Less than one day	☐	☐	2
1-2 days	☐	☐	1
More than 2 days	☐	☐	0
I have never rolled over on my ankle	☐	☐	3

<u>Foot and Ankle Ability Measure (FAAM)</u>
Activities of Daily Living Subscale

Please answer **<u>every question</u>** with **<u>one response</u>** 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 "Not Applicable" (N/A).

	No difficulty	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Standing	☐	☐	☐	☐	☐	☐
Walking on even ground	☐	☐	☐	☐	☐	☐
Walking on even ground without shoes	☐	☐	☐	☐	☐	☐
Walking up hills	☐	☐	☐	☐	☐	☐
Walking down hills	☐	☐	☐	☐	☐	☐
Going up stairs	☐	☐	☐	☐	☐	☐
Going down stairs	☐	☐	☐	☐	☐	☐
Walking on uneven ground	☐	☐	☐	☐	☐	☐
Stepping up and down curbs	☐	☐	☐	☐	☐	☐
Squatting	☐	☐	☐	☐	☐	☐
Coming up on your toes	☐	☐	☐	☐	☐	☐
Walking initially	☐	☐	☐	☐	☐	☐
Walking 5 minutes or less	☐	☐	☐	☐	☐	☐
Walking approximately 10 minutes	☐	☐	☐	☐	☐	☐
Walking 15 minutes or greater	☐	☐	☐	☐	☐	☐

Foot and Ankle Ability Measure (FAAM)
Activities of Daily Living Subscale

Because of your foot and ankle how much difficulty do you have with:

	No difficulty	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Home responsibilities	☐	☐	☐	☐	☐	☐
Activities of daily living	☐	☐	☐	☐	☐	☐
Personal care	☐	☐	☐	☐	☐	☐
Light to moderate work (standing, walking)	☐	☐	☐	☐	☐	☐
Heavy work (push/pulling, climbing, carrying)	☐	☐	☐	☐	☐	☐
Recreational activities	☐	☐	☐	☐	☐	☐

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities.

__ __ . 0 %

Foot and Ankle Ability Measure (FAAM)
Sports Subscale

Because of your foot and ankle how much difficulty do you have with:

	No difficulty	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Running	☐	☐	☐	☐	☐	☐
Jumping	☐	☐	☐	☐	☐	☐
Landing	☐	☐	☐	☐	☐	☐
Starting and stopping quickly	☐	☐	☐	☐	☐	☐
Cutting/lateral movements	☐	☐	☐	☐	☐	☐
Ability to perform activity with your normal technique	☐	☐	☐	☐	☐	☐
Ability to participate in your desired sport as long as you like	☐	☐	☐	☐	☐	☐

How would you rate your current level of function during your sports related activities from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

__ __ . 0 %

How would you rate your current level of function?

☐ Normal   ☐ Nearly normal   ☐ Abnormal   ☐ Severely abnormal

Dear Participant

You are being invited to volunteer to take part in a research project. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if anything is unclear or if you would like more information.

The ankle is one of the most injured areas of the body, and incorrect, or lack of appropriate treatment can lead to ongoing problems with the ankle. One of the most common limitations following ankle injury is a decrease in the ability to control and move the ankle freely. This can lead to further pain, loss of function, and further injuries. One way to treat this problem is to utilise a treatment method known as mobilisation. This treatment involves the therapist applying a passive oscillatory movement to the ankle for a set period of time. Although there are guidelines on the duration that this treatment should be administered, there is a lack of conclusive evidence to support these guidelines on duration of treatment. This study is therefore designed to investigate how different durations of mobilisation treatment affect the function of the ankle. The aim of which is to provide a clear conclusion as to which treatment duration provides the best outcomes for the patient.

You will be required to participate in 6 separate sessions of treatment and testing over a 2-week period. The total duration of each testing session will be no longer than 30 minutes. The procedure for each session will involve:

1. Measuring the function of your ankle using 5 different tests. The performance on these tests is directly controlled by you, so you do not need to worry about being forced into uncomfortable positions.
2. You will then receive the mobilisation treatment. This will involve lying on a massage couch and having your ankle mobilised by a Sports Therapist.
3. You will then have your ankle function measured again using the same methods as before the treatment.

Although there is the potential to feel some discomfort following treatment this should be minor and abate within 24 hours. If this does not occur or if you have any concerns, then please contact the researcher who will be able to advise you and ensure that any problems are dealt with appropriately.

If you decide to participate in this study, your participation and any information collected from you will be strictly confidential, and only available to the research team. Your participation is purely voluntary, and at no point will you be coerced into taking part. Your clinical relationship with the researcher is also independent of any involvement in this study.

The University of Gloucestershire research ethics committee has approved this study. Please contact Dr Malcolm Maclean (email: ███████████████), chair of the research ethics committee if you have concerns. Dr Maclean has no direct involvement in this study.

We would like to thank you, in advance, for your participation.

Researcher

Mr Christopher Holland

█████████████

Research Supervisor

Professor Mark De Ste Croix

█████████████

Dear Participant

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The ankle is one of the most injured areas of the body, and incorrect, or lack of appropriate treatment can lead to ongoing problems with the ankle. One of the most common limitations following ankle injury is a decrease in the ability to control and move the ankle freely. This can lead to further pain, loss of function, and further injuries. One way to treat this problem is to utilise a treatment method known as mobilisation. This treatment involves the therapist applying a passive oscillatory movement to the ankle for a set period of time. Although this treatment option has been shown to improve ankle function it is unclear as to how long these improvements last, and if the improvements can be enhanced through exercise. This study is therefore designed to investigate the effects of mobilisation on ankle function and to identify if improvements can be maintained or enhanced through exercise. The aim of which is to provide a clear conclusion as to the which treatment provides the best outcomes for the patient.

You will be randomly assigned to a one of two treatment groups and be required to participate in 3 separate sessions of treatment and testing over a week-long period. You will then be required to complete a daily home-based exercise routine for a 4-week period, including weekly re-testing. The total duration of each testing session will be no longer than 30 minutes. The procedure for each treatment session will involve the same procedure:

1. You will have the function of your ankle measured using 3 different tests. The performance on these tests is directly controlled by you, so you do not need to worry about being forced in to uncomfortable positions.
2. You will then receive the mobilisation treatment. This will involve lying on a massage couch and having your ankle mobilised by a Sports Therapist.

3. You will then have your ankle function measured again using the same methods as before the treatment.

Step 1 will be the only step repeated over the 4-week re-testing period

Although there is the potential to feel some discomfort following treatment this should be minor and abate within 24 hours. If this does not occur or if you have any concerns, then please contact the researcher who will be able to advise you and ensure that any problems are dealt with appropriately.

If you decide to participate in this study, your participation and any information collected from you will be strictly confidential, and only available to the research team. Your participation is purely voluntary, and at no point will you be coerced into taking part. Your clinical relationship with the researcher is also independent of any involvement in this study. All data will be held in accordance with current data protection legislation.

The University of Gloucestershire research ethics committee has approved this study. Please contact Dr Emily Ryall (email: ████████████), chair of the research ethics committee if you have concerns or require further information. Dr Ryall has no direct involvement in this study.

We would like to thank you, in advance, for your participation.

Researcher   **Research Supervisor**

Mr Christopher Holland   Professor Mark De Ste Croix

████████████████   ████████████████

PARTICIPANT HEALTH & CONSENT FORM

Health Questions and Exclusion Criteria

	Yes	No
1. Have you had any previous surgery to your lower limbs?	**Yes**	**No**
2. Have you ever had a fracture to your lower limb that required surgical realignment?	**Yes**	**No**
3. Have you had any musculoskeletal injury to your lower limb within the past 3 months	**Yes**	**No**
4. Do you have a history of cancer?	**Yes**	**No**
5. Do you currently have any infections?	**Yes**	**No**
6. Do you have any diagnosed spinal cord compression? (including urinary retention, bilateral neurological symptoms, saddle anaesthesia, loss of anal sphincter tone, or faecal incontinence)	**Yes**	**No**
7. Have you recently been unwell, or noticed any significant unplanned weight loss?	**Yes**	**No**
8. Do you have high blood pressure?	**Yes**	**No**
9. Do you have DVT?	**Yes**	**No**
10. Have you been diagnosed with any blood flow restrictions?	**Yes**	**No**
11. Are you currently using intravenous drugs?	**Yes**	**No**
12. Have you recently used steroids?	**Yes**	**No**
13. Are you currently on any medication?	**Yes**	**No**
14. Do you suffer from unremitting night-time pain?	**Yes**	**No**

If you have answered "Yes" to one or more of the above questions, please consult

the researcher for further advice and guidance.

Consent Questions

1. I understand that I have been asked to participate in a research study?	**Yes No**
2. I have read and received a copy of the information letter?	**Yes No**
3. I understand the benefits and risks involved in taking part in this research study?	**Yes No**
4. I understand that I am free to contact the researcher to ask questions and discuss this study?	**Yes No**
5. I understand that I am free to not volunteer, or to withdraw from the study at any time, without consequence and that my information will be deleted at my request?	**Yes No**
6. I understand that the researcher will keep my data confidential? I understand who will have access to your information?	**Yes No**

I agree to participate in this research study:

Participant's signature: _____

Participant's name (please print): _____

Contact No: _____

E-mail: _____

Date: _____

Researcher's signature: _____

Computer-generated random allocation sequence for study 4a and 4b

Participant	Group	Participant	Group
1	60	25	60
2	30	26	30
3	60	27	60
4	30	28	30
5	120	29	120
6	120	30	120
7	120	31	120
8	60	32	60
9	30	33	30
10	60	34	60
11	120	35	120
12	30	36	30
13	60	37	60
14	30	38	30
15	60	39	60
16	30	40	30
17	120	41	120
18	120	42	120
19	120	43	120
20	60	44	60
21	30	45	30
22	60	46	60
23	120	47	120
24	30	48	30

```
                    ┌─────────────────────────────┐
                    │ Assessed for eligibility (n=56) │
                    └─────────────────────────────┘
                                 │
                                 │        ┌──────────────────────────────┐
                                 │──────▶ │ Excluded (n=8)               │
                                 │        │ ♦ Not meeting inclusion criteria │
                                 │        │   (bilateral CAI as assessed    │
                                 │        │   using the CAIT)              │
                                 │        └──────────────────────────────┘
                                 ▼
                    ┌─────────────────────┐
                    │ Randomized (n=48)   │
                    └─────────────────────┘
```

Allocated to intervention (n=16)	Allocated to intervention (n=16)	Allocated to intervention (n=16)
♦ Received 30s of joint mobilisation (n=16)	♦ Received 60s of joint mobilisation (n=16)	♦ Received 120s of joint mobilisation (n=16)
♦ Did not receive allocated intervention (n=0)	♦ Did not receive allocated intervention (n=0)	♦ Did not receive allocated intervention (n=0)

Lost to follow-up (n=0) Discontinued intervention (n=0)	Lost to follow-up (n=0) Discontinued intervention (n=0)	Lost to follow-up (n=0) Discontinued intervention (n=0)

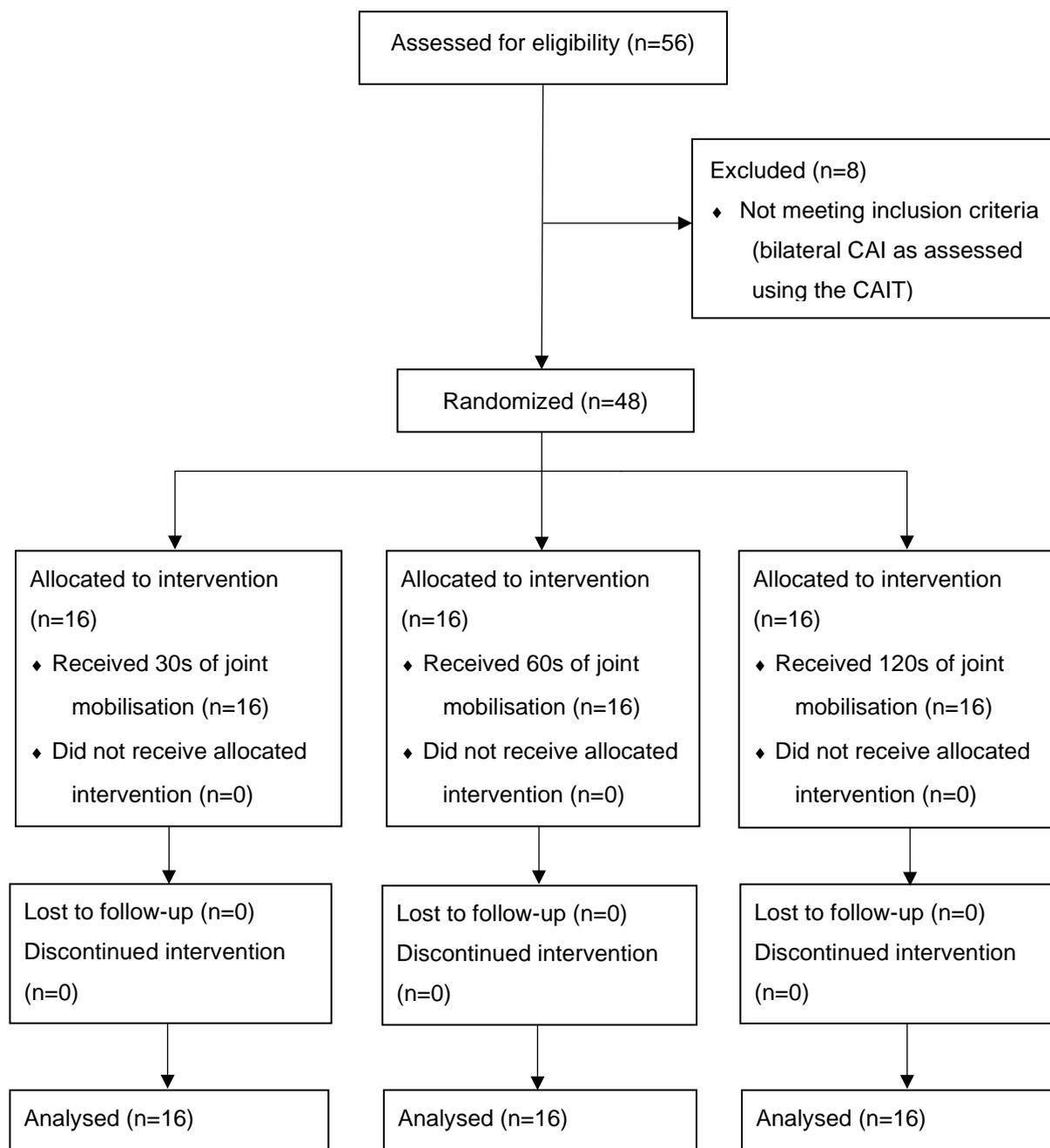| Analysed (n=16)	Analysed (n=16)	Analysed (n=16)

Figure 1. Flow diagram of participants. Abbreviations: CAI, chronic ankle instability; CAIT, Cumberland Ankle Instability Tool

Computer-generated random allocation sequence for study 5.

Participant	Group	Participant	Group
1	Rehab	25	Rehab
2	Control	26	Control
3	Rehab	27	Rehab
4	Control	28	Control
5	Rehab	29	Rehab
6	Control	30	Control
7	Rehab	31	Rehab
8	Control	32	Control
9	Rehab	33	Rehab
10	Control	34	Control
11	Rehab	35	Rehab
12	Control	36	Control
13	Rehab	37	Rehab
14	Control	38	Control
15	Rehab	39	Rehab
16	Control	40	Control
17	Rehab	41	Rehab
18	Control	42	Control
19	Rehab	43	Rehab
20	Control	44	Control
21	Rehab	45	Rehab
22	Control	46	Control
23	Rehab	47	Rehab
24	Control	48	Control

Rehabilitation Exercise Programme

The following exercises are designed to help improve your ankle mobility and function. These exercises must be completed daily and should follow the guidelines accurately. Full adherence is necessary and you will be asked to record how many daily sessions you have performed during the weekly testing sessions. If at any time you are feeling pain whilst exercising, then please stop and seek advice from your Sports Therapist.

Exercise 1:

To complete this exercise, you will need to use a standard height stair step and the non-elastic strap.

1. Adopt the position in the photo with the injured ankle on the step.
2. Whilst using the uninjured foot to pull backwards on the strap, perform a lunge.
3. The end position corresponds to the point at which the heel of your injured foot can no longer maintain ground contact.
4. Once in this position, hold for 20 seconds.
5. Repeat 15 times with 10 second rest between repetitions.

Exercise 2:

To complete this exercise, you will need 'star' or 'Y' marked out on the floor.

1. Position the injured foot in the centre of the star/Y.
2. Keeping your hands on your hips, perform maximal reaches with the uninjured foot in the forwards, backwards-lateral and backwards-medial direction.
3. Complete the movement with a single, light toe touch on the floor, before returning to the starting position.

4. Complete 15 repetitions in each direction. A repetition does not count if you lose balance, change the position of your stance foot or remove your hands from your hips.
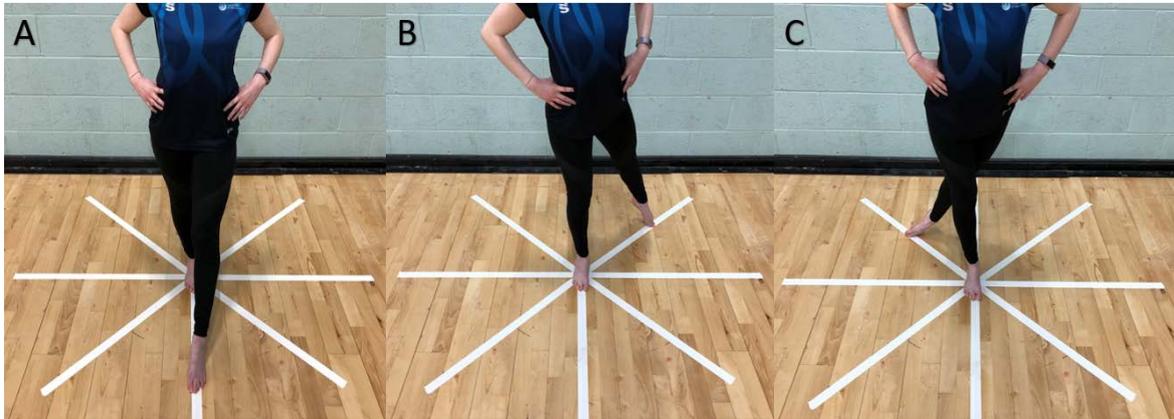
Balance directions and foot placement. Directions are described in relation to the stance foot. (A) Forwards, (B) Backwards-lateral, (C) Backwards-medial.

Dear Participant

You are being invited to volunteer to take part in a research project. Before you decide to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask if anything is unclear or if you would like more information.

The ankle is one of the most injured areas of the body, and incorrect, or lack of appropriate treatment can lead to ongoing problems with the ankle. One of the most common limitations following ankle injury is a decrease in the ability to control and move the ankle freely. This can lead to further pain, loss of function, and further injuries. Various treatment and rehabilitation techniques have been proposed to address the problems associated with this condition. Contemporary research on the use of mobilisation and corrective exercise has been recently conducted and has added to the clinical knowledge in regards to treating those with Chronic Ankle Instability (CAI). This study is therefore designed to disseminate the results of this research to you and to identify the effect that this may have upon your own clinical practice.

You will be asked to complete two evaluation questionnaires, one before and one after an information session detailing the results of the contemporary study. The procedure for the session will be as follows:

1. Prior to the session you will be asked to complete an evaluation questionnaire detailing your current knowledge and practice in the treatment of CAI.
2. You will receive a lecture detailing the background, rationale and objectives of the study, and presenting the findings of the research and how these can be implemented within clinical practice.
3. Following the session you will be asked to complete an evaluation questionnaire detailing how the results of the study may affect your own clinical practice.

If you decide to participate in this study, your participation and any information collected from you will be strictly confidential, and only available to the research team. Your participation is purely voluntary, and at no point will you be coerced into taking part. Your clinical relationship with the researcher is also independent of any involvement in this study. All data will be held in accordance with current data protection legislation.

The University of Gloucestershire research ethics committee has approved this study. Please contact Dr Emily Ryall (email: ███████████), chair of the research ethics committee if you have concerns or require further information. Dr Ryall has no direct involvement in this study.

We would like to thank you, in advance, for your participation.

Researchers

Mr Christopher Holland   Professor Mark De Ste Croix

███████████████   ███████████████

PARTICIPANT CONSENT FORM

Consent Questions

7.	I understand that I have been asked to participate in a research study?	**Yes**	**No**
8.	I have read and received a copy of the information letter?	**Yes**	**No**
9.	I understand the benefits and risks involved in taking part in this research study?	**Yes**	**No**
10.	I understand that I am free to contact the researcher to ask questions and discuss this study?	**Yes**	**No**
11.	I understand that I am free to not volunteer, or to withdraw from the study at any time, without consequence and that my information will be deleted at my request?	**Yes**	**No**
12.	I understand that the researcher will keep my data confidential? I understand who will have access to your information?	**Yes**	**No**

I agree to participate in this research study:

Participant's signature: _____

Participant's name (please print): _____

E-mail: _____

Date: _____

Researcher's signature: _____

Improving the Treatment of those with Chronic Ankle Instability

All questions contained in this questionnaire are strictly confidential. Your help is very much appreciated. Thank you in advance.

Name *(Last, First):*		☐ M ☐ F	**Main sport:**
Your primary email:			**Age:**

Are you currently practicing?	☐ Y ☐ N	**How long have you been practicing?**			**years**
How frequently are you practicing?	☐ <5hrs	☐ 5-15hrs	☐ 15-25hrs	☐ 25-35hrs	☐ >35hrs

SECTION 1

Please circle a response

	Strongly disagree				Strongly agree
	1	2	3	4	5

Ankle sprain injuries…..

1.	Have a high likelihood of recurrence	1	2	3	4	5
2.	Can have a negative impact on performance/quality of life	1	2	3	4	5
3.	Can lead to long term problems in ankle function	1	2	3	4	5

Treatment

4.	It is possible to treat chronic ankle instability with mobilisation	1	2	3	4	5
5.	It is possible to treat chronic ankle instability with exercise	1	2	3	4	5

SECTION 2

Please circle a response

I think my practice would benefit from…..:	Strongly Disagree			Strongly Agree	
6. A greater understanding of chronic ankle instability and its effects on function	1	2	3	4	5
7. A greater understanding of the use of mobilisations and exercise to treat ankle instability	1	2	3	4	5
8. Specific mobilisation and exercise protocols to improve ankle function in those with chronic ankle instability	1	2	3	4	5

Survey Ends

Thank you for your time and effort in completing the survey. Your assistance is greatly appreciated.

Please feel free to contact the lead researcher if you have any questions:

Mr Christopher Holland
University of Worcester
Email: ██████████████

APPENDIX 14.

Improving the Treatment of those with Chronic Ankle Instability

All questions contained in this questionnaire are strictly confidential. Your help is very much appreciated. Thank you in advance.

Name *(Last, First):*		☐ M ☐ F	**Main sport:**
Your primary email:			**Age:**

Why did you attend the workshop?   **Please tick all that apply**
1. I wanted to improve my practical skills   ☐
2. I wanted to help reduce injuries   ☐
3. I wanted to improve my knowledge and awareness   ☐

SECTION 1						

	Please circle a response					
Overall, how satisfied are you with the CAI workshop?	**Very Low**					**Very High**
4. Overall, my satisfaction with the workshop is	1	2	3	4		5
How would you rate your knowledge of CAI?	**Very Poor**					**Very Good**
5. My knowledge of CAI issues **before** the workshop was	1	2	3	4		5
6. My knowledge of CAI issues **after** the workshop is	1	2	3	4		5
How would you rate your knowledge of mobilisation to treat CAI?	**Very Poor**					**Very Good**
7. My knowledge of mobilisation treatment for CAI **before** the workshop was	1	2	3	4		5
8. My knowledge of mobilisation treatment for CAI **after** the workshop is	1	2	3	4		5
How would you rate your knowledge of exercise to treat CAI?	**Very Poor**					**Very Good**
9. My knowledge of exercise treatment for CAI **before** the workshop was	1	2	3	4		5
10. My knowledge of exercise treatment for CAI **after** the workshop is	1	2	3	4		5
Following the workshop, how likely are you to implement the research findings into your own practice?	**Very Unlikely**					**Very Likely**
11. My future treatment of CAI will take note of the research findings	1	2	3	4		5
12. My future treatment will follow the recommendations of the research study	1	2	3	4		5
How would you rate your confidence to deliver a CAI treatment programme following the workshop?	**Very Low**					**Very High**
13. My confidence to deliver a CAI treatment programme **before** the workshop was	1	2	3	4		5
14. My confidence to deliver a CAI treatment programme **after** the workshop is	1	2	3	4		5

15. **Do you think there is need for training to help people feel more confident about treating CAI? (please tick a response):**

    ☐ Yes   ☐ No   ☐ Don't know

16. **Overall, do you think the workshop provided you with the knowledge to use mobilisation and exercise approaches for CAI? (please tick a response):**

    ☐ Yes   ☐ No   ☐ Don't know

17. **Do you think you will use the presented information in your sessions? (please tick a response):**

    ☐ Yes   ☐ No   ☐ Don't know

	SECTION 2	

	Please circle a response				
To what extent do you think you:	**Disagree Strongly**				**Agree Strongly**
18. will use the information in all of my sessions for those with CAI	1	2	3	4	5
19. will be able to adapt the information to suit my needs	1	2	3	4	5
20. The information will be useful in the long term	1	2	3	4	5

Survey Ends

Thank you for your time and effort in completing the survey. Your assistance is greatly appreciated.

Please feel free to contact the lead researcher if you have any questions:

Mr Christopher Holland
University of Worcester
Email: ▮▮▮▮▮▮▮▮▮▮▮

Chronic Ankle Instability Workshop
The effect of mobilisations and exercise
Christopher J. Holland

UNIVERSITY OF GLOUCESTERSHIRE
at Cheltenham and Gloucester

University of Worcester

Additional Resources

• Available through Dropbox

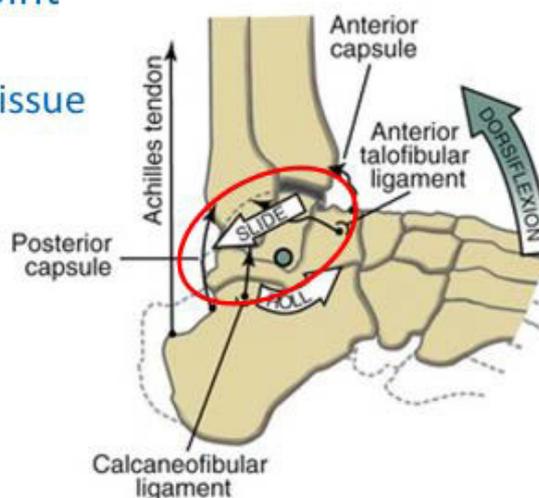• Specific resources = **Dropbox**

• Link below and in email:
  • https://www.dropbox.com/sh/iuhwtpeqgk9l5ds/AAAkVG4-crYGuwuezyAwBAJBa?dl=0

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The Problem

- Lateral ankle sprain
  - 3-5% all A&E (Cooke et al., 2003)
  - 22% sport (Fong et al., 2007; Gribble et al., 2016)
- Reoccurence >70% (McKay et al., 2001)
  - Instability, ↓ functional capacity, additional sprains (Wikstrom et al., 2009)
- Chronic ankle instability (CAI)
  - Mechanical (dorsiflexion, talar glide)
  - Functional (postural control)

Tibia (shin bone)
Fibula (lower leg bone)
Torn lateral ankle ligaments

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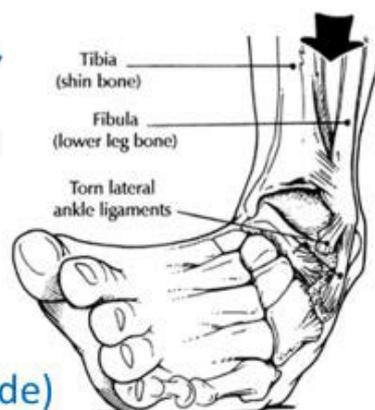
Chronic Ankle Instability

- Anterior-to-posterior joint mobilisations
  - Restore ROM through tissue elongation (Green et al., 2001)
  - Optimal dose?
    - Holland et al. 2015
- Self-mobilisation and rehabilitation

Anterior capsule
Achilles tendon
Anterior talofibular ligament
DORSIFLEXION
SLIDE
ROLL
Posterior capsule
Calcaneofibular ligament

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Objectives

1. Examine the effect of treatment durations during a 2-week talocrural joint mobilisation intervention.

2. Examine the effect of talocrural joint mobilisation followed by home-based rehabilitation exercises

3. Disseminate findings to practitioners

Methods

- CAI self confirmed
  - Cumberland Ankle Instability Tool (CAIT)
  - Foot and Ankle Ability Measure (FAAM) – ADL and Sport

- Unilateral symptoms (uninjured acted as control)

Measurements
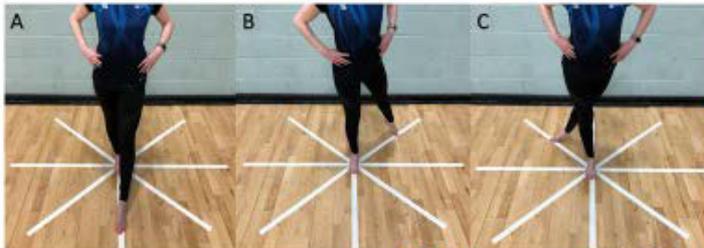
Mobilisation

- Joint mobilisation (Maitland)
  - GIV
  - Anterior-to-posterior

Clinical Implications

Anterior-to-posterior talar joint mobilisations improve mechanical function
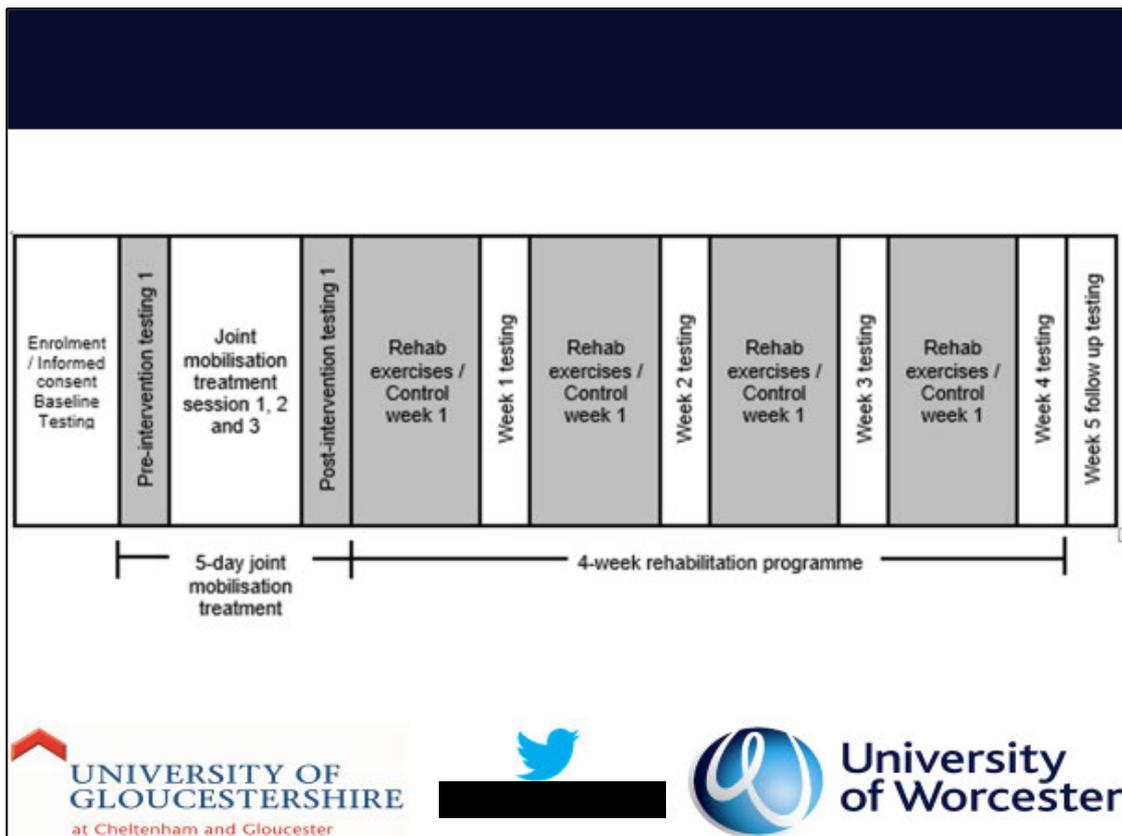
Some effect on functional movements

Increased treatment durations are more effective early on in the treatment process

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Study 2 – Mobilisation and Home Exercise

- 48 team sport athletes (22.5 ±3.5 years)

- 2 treatment conditions (contralateral control)
  - Mobilisation and exercise
  - Mobilisation

- 3 sessions of 120s joint mobilisation to each group over 5 days
  - Group 1 – home based exercise (4 weeks)
  - Group 2 – no additional treatment/rehab (4 weeks)

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Enrolment / Informed consent Baseline Testing	Pre-intervention testing 1	Joint mobilisation treatment session 1, 2 and 3	Post-intervention testing 1	Rehab exercises / Control week 1	Week 1 testing	Rehab exercises / Control week 1	Week 2 testing	Rehab exercises / Control week 1	Week 3 testing	Rehab exercises / Control week 1	Week 4 testing	Week 5 follow up testing

5-day joint mobilisation treatment

4-week rehabilitation programme

Home-based Exercise
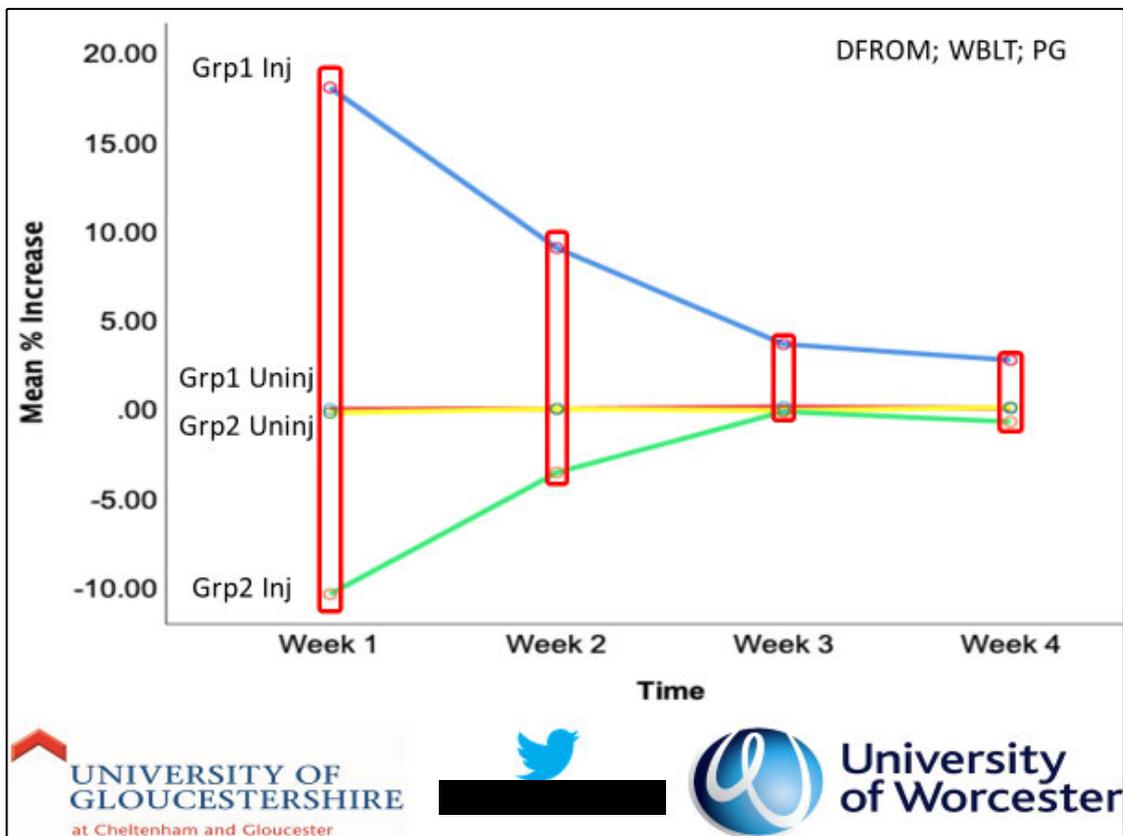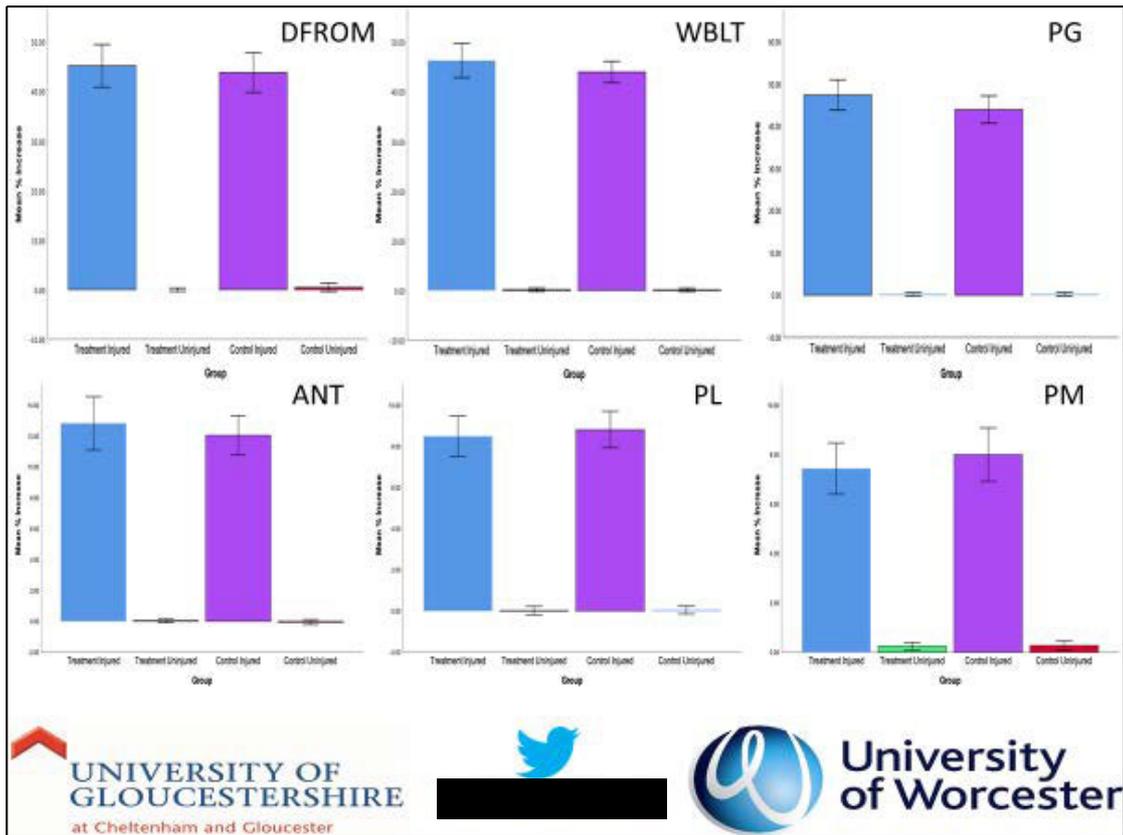

Dropbox

- Self-stretching / mobilisation with movement
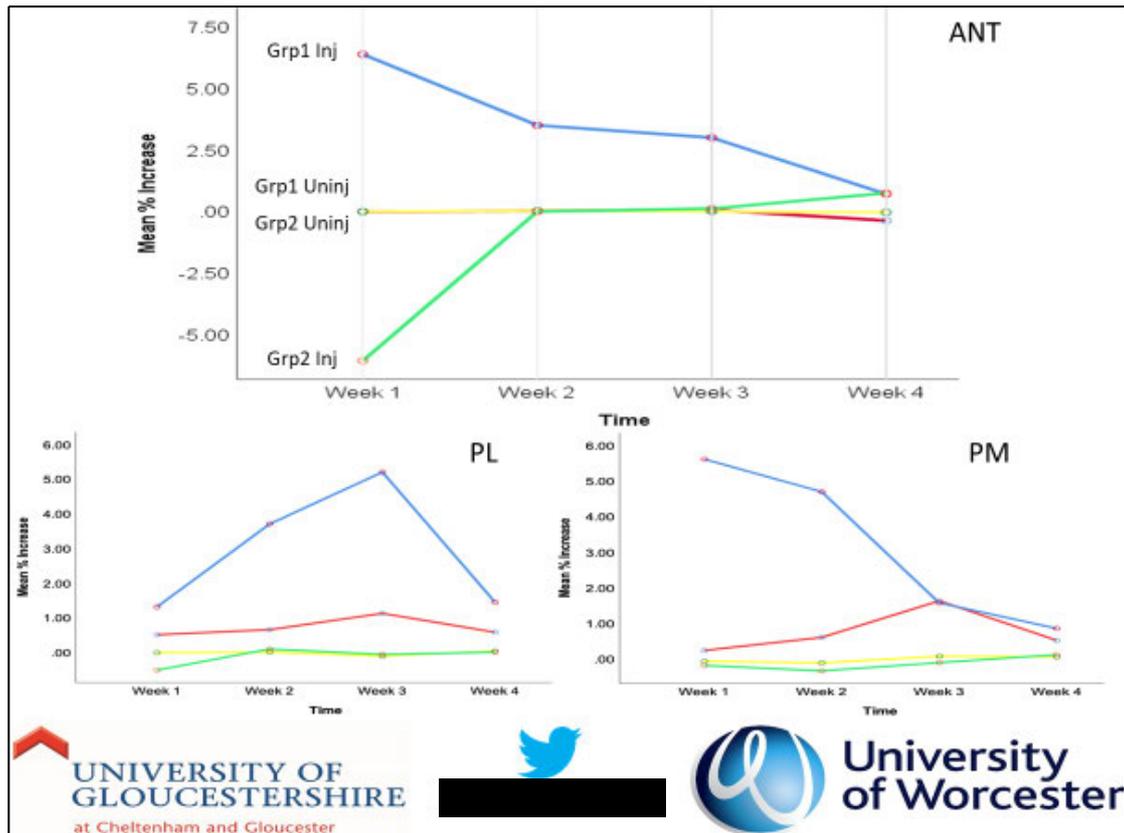 - 15 reps with 20 second hold at EOR

- SEBT
  - 15 reps in each direction

A   B   C

Clinical Implications

Home based exercise can improve mechanical and functional deficits following joint mobilisation treatment

Effects appear to be most prominent in the first 2 weeks of adherence

Practical Implementation

1. **Identify CAI**
   - Questionnaire (CAIT/FAAM)
   - Objective measures (DF-ROM, PG, SEBT)
2. **Week 1 (3 sessions)**
   - 120 seconds AP talocrural joint mobilisation
3. **Week 2-3 (Home based exercise)**
   - Self mobilisation
   - Dynamic balance
4. **Monitor**
   - Objective measures (weekly)

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Chronic Ankle Instability Workshop – The Effect of Mobilisations and Exercise

Additional resources available via Dropbox:

https://www.dropbox.com/sh/iuhwtpeqgk9l5ds/AAAkVG4-crYGuwuezyAwBAJBa?dl=0