



CARDIFF UNIVERSITY
School of Healthcare Sciences

Identifying Indicators of Functional Recovery After Ankle Sprain in Physically Active People

Ahmed Mansour Almansour

**Supervisors: Professor Nicola Phillips
Dr. Deborah Mason**

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ABSTRACT

Background: Ankle sprain is common and can lead to chronic ankle instability (CAI), characterised by decreased functional performance. However, there is still a limitation regarding the optimal approach used to assess functional recovery. This thesis aimed to explore the functional performance of those subjects and to investigate their progress plus to identify recovery predictor.

Methods: 60 subjects (Acute Sprain (AS)=20, CAI=20, Healthy=20) were recruited. Parameters investigated: decision-making (DMT) and task time (TT) under unanticipated and planned conditions, Time to Peak muscle activity (TTP), jump height, muscle strength, and dorsiflexion ROM. These were also used to investigate the progress of the AS=10 over a six-month period and to identify recovery predictor.

Results: The healthy subjects demonstrated faster DMT only during unanticipated conditions comparing with AS ($p=0.003$) and CAI ($p=0.001$). DMT was also longer in CAI compared with AS by 51.8ms ($p=0.03$). A significant difference was found in jump height between injured and non-injured ankles for the AS and CAI subjects and better dfROM in the healthy subjects. Measuring TTP revealed that the TTP occurred in a different order in each group. In the longitudinal study the AS subjects performed better DMT by 74.2ms and jump higher by 1.68cm when compared with the 1st visit. Additionally, Jump height found predictor of functional outcome score at 1-month using FADI-ADL% and also muscle strength (Eversion Con-PT, Eversion Con-PT/BW and Eversion Ecc-PT/BW) can predict the functional outcome at 12-month using FADI-Sport %.

Conclusion: This thesis suggest that using unanticipated conditions in functional tests could provide important performance outcomes such as DMT in assessing the ability to return to previous sporting activity. A combination between jump height and fast contact time is also useful. Overall the result provides a foundation for further investigations. Larger and more detailed studies are also needed to investigate muscle activity in response to an unanticipated condition.

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LIST OF ABBREVIATIONS AND GLOSSARY

AS	Ankle sprain
ANOVA	Analysis of variance
A&E	Accident and Emergency department
ADT	Anterior drawer test
ADL	Activities of daily living
ASIS	Anterior superior iliac spine
CAI	Chronic ankle instability
CM	Contact mat
cm	Centimetres
CMJ	Countermovement jump
CAIS	Chronic ankle instability scale
CNS	Central nervous system
DMT	Decision-making time
dfROM	Dorsiflexion rang of motion
EMG	Electromyography
FT	Flight time
FP	Force plates
FAI	Functional ankle instability
FADI	Foot and Ankle Disability Index
FPT	Functional performance tests
GAS	Gastrocnemius
ICC	Intraclass correlation coefficient
JH	Jump Height
kg	Kilogram
MAI	Mechanical ankle instability
ms	Milliseconds
m	Metre
m/s	Metres per second
N	Newton
Nm	Newton meters
r	Pearson correlation coefficients
PFT	Planned functional test
PL	Peroneus longus
PT	Peak Torque
PT/BW	Peak Torque/body-weight
SC	SiliconCOACH
SEM	Standard error of measurement
SD	Standard deviation
s	Second
SSC	Stretch-shortening cycle
TT	Task time
TA	Tibialis anterior test
TTT	Talar tilt test
TTP	Time to the peak
UFT	Unanticipated functional test
UK	United Kingdom

VID	Video-based method
VRF	Vertical ground reaction force
VM	Vector mat system
VBA	Visual Basic for Applications

CHAPTER 1 : THESIS STRUCTURE

This thesis is divided into nine chapters. In the first chapter, an overview of the outline of the thesis is provided. This will be followed by an introductory chapter including the motivation for undertaking the PhD study. The introduction chapter will firstly provide a background on the mechanics and epidemiology of lateral ankle sprain injury. This will be followed by the prevalence of recurrent ankle sprains that result in the development of chronic ankle instability (CAI). This will then lead to an explanation of the problem in terms of research investigating CAI.

Chapter 3, the literature review, includes three sections of relevant topics under the following areas: The first section in the literature review provides an overview of the literature relating to CAI. This is followed by a critical review of the literature relating to the neuromuscular control deficiencies in persons with CAI. Then a critical review of the literature related to research investigating clinical presentation and assessment is used to identify individuals with CAI. Based on the gaps in current evidence in the literature review, the purpose, aims and hypotheses of the current thesis are provided in Chapter 4.

Chapter 5 presents details of the preliminary studies that have been conducted prior to the main study in collaboration with a group of MSc students as part of their graduation projects. Methods, findings and discussion from this work are presented in this chapter.

Findings from this work were helpful with regard to the optimal measurement tools and protocol that were used in the main study.

Chapter 6 then presents a detailed description of the methods and procedures used in the main study. Subject sample, recruitment and the instrumentation used in the study are discussed in this chapter. Chapter 7 presents the results of the main study. Chapter 8 then provides the discussion considering the findings from the main study in context with the literature. Limitations and recommendations for clinical practice and directions for future research are also presented and discussed in this chapter. Chapter 9 concludes the thesis by summarising the main findings.

CHAPTER 2 : INTRODUCTION

2.1 Motivation for the study

My interest in undertaking postgraduate studies was developed during my work as a clinical physiotherapist over more than seven years; this experience helped me with the knowledge and development of the relevant skills. Later, having received a Master's degree in sport physiotherapy from Cardiff University, this served me to develop my practical skills and knowledge about research related practically to sport injuries. This also allowed me to grow in confidence and to work more independently in research. Both clinical experience and studying for an MSc degree enabled me to develop my professional work and knowledge, which allowed me to identify some limitations in research related to repeated ankle sprain. My research gradually increased in the area related to chronic ankle instability condition (CAI). The choice of undertaking a PhD study has been strongly motivated by a desire to gain a better understanding of this wide problematic condition that affects many individuals after experiencing an initial ankle sprain.

2.2 Background of ankle sprain injury

2.2.1 Mechanics of lateral ankle sprain

It is widely accepted that the mechanism of injury for a lateral ankle sprain occurs when the foot is in plantarflexion and inversion position. This usually occurs at the moment of foot contact, during changing direction manoeuvres, when the individual lands from a height or steps on an unstable surface (Konradsen and Magnusson 2000).

Therefore, it was believed that increase planter flexion foot position at initial contact is essential to predispose individuals to ankle sprain. However, the result of a real injury case was captured accidentally in biomechanics laboratories and found that plantarflexion is absent during the injury (Fong et al. 2009). Which suggested that planterflexion position is not required for injury to happen and internal rotation associated with inversion is play an important role. The authors in this study also found that the ankle at foot contact during the injury trial was more inverted by 6° and more internally rotated by 7° compared with the normal trials. During the normal trials the ankle was more externally rotated and slightly inverted. Fong and his co-workers found that the ankle was entered into pre-injury stage at 60 milliseconds after foot contact, the centre of pressure at this stage start to be shifted to the lateral aspect where the risk of ankle sprain may have been developed. At 110 milliseconds entered into injury stage, as the ankle started to increase inversion and internal rotation angles and reached its peak at 200 milliseconds. The authors in this study suggested that the preoneal muscle might not activate at 60 milliseconds to protect the ankle.

A lower planterflexion was also seen in another real injury case of female handball player captured during sidestep cutting manoeuvres in lab sitting (Kristianslund et al. 2011). In this study the inversion moment reached the peak at 138 ms and the peak of internal rotation at 167 ms after initial contact. Similar lower planterflexion was reported in two cases during the 2008 Beijing Olympics using video sequences (Mok et al. 2011). This technique was developed by Krosshaug and Bahr (2005) based on a model-based image matching (MBIM) motion analysis technique. Fong and his co-workers (2012) used this technique to investigate the mechanism of ankle sprain in five cases in Tennis players. They found that the peak inversion velocity ranged from 509 to 1488 deg/sec and the peak inversion was achieved at 90-170 ms.

These studies suggested that planterflexion position is not always required for ankle sprain injury to happen and instead, there was a trend of dorsiflexion and internal rotation. However, the inversion speed was also suggested to play an important role for the injury.

2.3 Epidemiology of lateral ankle sprain

2.3.1 Overview of lateral ankle sprain

The term ankle sprain is defined as an incident in which the ankle is forcibly inverted and twisted, resulting in a combination of swelling, pain and possible ligament damage of the ankle (Hertel 2002). The ankle was found to be the second most commonly

injured body site of all sport-related injuries, and lateral ankle sprain is the most common type of ankle injury (Fong et al. 2007). Although, damaged ligaments mostly take 6-12 weeks for healing, an early return to sport is commonly a problem in individuals with ankle sprains (Nelson et al. 2007; Hubbard 2008). Another problem is that 55% of those who suffer from ankle sprains do not seek medical care or visit hospital. In the United Kingdom, 302,000 patients with ankle sprains visited the Accident and Emergency (A&E) over a one-year study period (Bridgman et al. 2003; Hertel 2002). A recently published meta-analysis has reported that ankle sprains account for 3-5% of all A&E visits in the UK, with around 5,600 cases each day (Cooke et al. 2003; Doherty et al. 2014), incurring a significant annual health-care cost. Pain and swelling are common following ankle sprain, resulting in functional impairment. Residual symptoms are also common following ankle sprain and it has been estimated at 32-80% (Beynnon et al. 2002; Yeung et al. 1994). The most commonly reported mechanism of ankle sprain occurs when the foot is in plantar flexion and inversion position. This usually occurs at the moment of foot contact, during changing direction manoeuvres, when the individual lands from a height or steps on an unstable surface (Konradsen and Magnusson 2000).

2.3.2 Classification of lateral ankle sprain

Several grading systems have been used to grade ankle sprains resulting in highly subjective interpretations as they are often user dependent. Although, most authors have traditionally graded the injury based on three levels, many authors did not explain how

they defined these levels in their research. This makes comparison in the literature difficult. Some grading systems based on the number of ligaments that have been damaged ignore the functional status of the patient: Grade I: ATFL (one ligament), Grade II: ATFL & CFL (two ligaments) and Grade III: ATFL, CFL and PTFL (three ligaments) (Gaebler et al. 1997). Other systems have also been developed to simply classify ankle sprain injury based on the severity of the injury: Grade I: ligament stretched, Grade II: ligament partially torn and Grade III: ligament completely torn (Wexler 1998). Some researchers argue that these grading systems should not be used unless MRI examination or surgical treatment was provided. However, diagnosis of ankle sprain is usually performed in the Accident and Emergency department, using only radiography (X-ray). The X-ray is usually performed to simply rule out a fracture and ligaments do not show up on the X-ray (Chan et al. 2011). Ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI) scans are not commonly used to diagnose acute ankle sprains, unless there are other suspected injuries (Chan et al. 2011). This is because of the high cost, time consuming technique and availability problems. However, these techniques are more widely available for researchers than for clinical practitioners.

In the clinical setting, manual tests such as talar tilt and anterior drawer tests have been used frequently to diagnose the severity of the sprain. While these tests are easily performed, they are not accurate immediately following acute ankle sprain because of the pain and swelling (Chan et al. 2011). Therefore, the ability to bear weight and the level of the pain and swelling were suggested and used in the classification of sprains.

Another problem in classification was demonstrated in another study, which was based on clinical presentation alone: Mild (minimal functional loss, no limp, no or minimal swelling, tenderness, pain with reproduction of mechanism of injury), Moderate (moderate functional loss, unable to toe-rise or hop on injured ankle, limp when walking, localised swelling, tenderness) and Severe (diffuse tenderness and swelling, crutches preferred) (Jackson et al. 1974). A similar grading system was developed for specific outpatient clinical use (Mann et al. 2002). The system is based on scoring of pain, swelling and inability to walk. Each item was scored using 0 to 3 points (0 = none, 1 = mild, 2 = moderate, 3 = severe) and calculating the total score for the final grading: Grade I: 1–3 points, Grade II: 4–6 points and Grade III: 7–9 points.

Because of the problems with grading systems, a classification combining both clinical presentation from the anatomical damage and severity of injury is much better to provide a comprehensive assessment. Kaikkonen and his colleagues (1994) have developed a grading system with multiple components as illustrated in Table 2-1. This system will be used through this thesis to classify participants with ankle sprains.

Table 2-1: Ankle sprain grading system

		Clinical presentation
Grade I	Mild sprain	Stretch of the ligaments without macroscopic tearing, little swelling or tenderness, slight or no functional loss, and no mechanical instability of the joint.
Grade II	Moderate sprain	Partial macroscopic tear of the ligaments with moderate pain, swelling and tenderness, with some loss of motion and mild or moderate instability.
Grade III	Severe sprain	Complete rupture of the ligament with severe swelling, haemorrhage and tenderness, with loss of motion and considerable abnormal motion and instability.

2.4 Prevalence of recurrent ankle sprains

One of the major problems for many people after an initial ankle sprain is the high incidence of recurrence. Furthermore, it has been estimated that 32% of those who suffer from an initial ankle sprain can experience recurrent ankle sprains or residual symptoms resulting in the development of chronic ankle instability (CAI). The residual symptoms can present as pain, swelling, stiffness and instability. However, a risk increase to 80% has been reported for recurrent ankle sprain in the presence of a prior history of sprain (Beynon et al. 2002; Yeung et al. 1994). Functional impairment, which could limit participation in work, sport, recreation and even some daily home activities, was reported for those with residual symptoms (Hertel 2000; Leanderson et al. 1999; Yeung et al. 1994). This highlights the need for continued research into recurrent ankle sprain injuries.

There are many factors involved in the development of ankle instability, including

impaired proprioception, neuromuscular control, postural control, strength deficiency and pathologic laxity (Hertel 2002; Delahunt et al. 2010). Although repetitive ankle sprain is a widely studied condition, there is a current problem in the literature concerning this condition because of various definitions and terms used by researchers as well as a lack of standardised diagnostic criteria. This will be discussed in more detail in the literature review chapter. However, a history of repeated lateral ankle sprains and feeling of giving way were one of the early definitions used (Freeman et al. 1965). For inclusion criteria, a form of self-reported data was used in most studies. Participants were requested to report a history of one or more lateral ankle sprains that required protected weight bearing (Caulfield et al. 2004; Hubbard et al. 2004; Caulfield and Garrett 2004; Nakagawa and Hoffman 2004; Bernier et al. 1997; Matsusaka et al. 2001).

Also, the researchers have described the terms of this condition differently in their research. This symptom was described by Freeman early in 1965 as functional instability (FI). Other researchers used mechanical instability, residual instability/disability, and sprained ankle syndrome (Gutierrez et al. 2009). Recently, the term chronic ankle instability (CAI) has been used to define this condition by several authors (Hertel et al. 2006; Hertel 2002; Hertel and Olmsted-Kramer 2007; Hubbard et al. 2007a; Hubbard et al. 2007b). This definition appears more appropriate clinically as it may involve both mechanical and functional instabilities to varying degrees to describe an ankle with recurrent instability problems.

2.5 Statement of the problem related to investigating CAI

Change of direction and landing from a jump are often cited as the injury mechanism during lower extremity injury. Therefore, choosing a functional assessment that utilises this mechanism is helpful to present the condition of neuromuscular, joint stability, muscular strength and biomechanical abilities (Noyes et al. 1991; Young et al. 2001). However, for individuals with ankle sprains or for those who are diagnosed with CAI the clinical decision to allow the individual to return to normal activities or for athletes to return to sport has been an area of much debate. This may be because of the lack of availability of standardised assessment protocols related to this condition. This may also play a role in placing individuals at a risk of re-injury especially among the sporting population. There are a wide range of tests that have been used to address the functional performance of individuals with CAI but these studies have produced inconsistent findings. Investigating these individuals during dynamic activity such as cutting manoeuvres is warranted and could potentially provide researchers with a clearer insight related to impaired function in CAI. Insufficient neuromuscular control during such a dynamic activity could result in delay in processing the information, which has been frequently identified as delayed or reduced muscle activity. The proper muscle activation is necessary to allow the joint to perform safely. In other studies this was demonstrated by a greater inversion angle before and after foot contact (Doherty et al. 2015a; Doherty et al. 2015c; Lin et al. 2011).

Although, there is agreement that functional performance tests in CAI should be made based on their ability to stress the lateral aspect of the ankle, the fact that these

functional tests were measured through planned movement condition was not addressed in ankle research, especially in the sport population. This will be discussed in more detail in the literature review chapter. Consequently, this limited the validity of these studies. In sport, activity is not a pre-programmed or planned task, such as avoiding an opponent or reacting to a ball. Therefore, athletes need to modify their movement patterns frequently. Compared to a planned cutting manoeuvre, unanticipated tasks have validity for the present sport environment and challenge subjects who complain of ankle sprain. The unanticipated manoeuvre requires a more complex motor programme to process the information within the neuromuscular control system. In individuals with CAI this could present as delay in muscle activity and performance outcome such as a delay in decision-making time.

Unanticipated tasks have been included in studies related to the knee joint and it was found that the effect on the lower extremity is consistent with increased force on the knee mechanics (Kim et al. 2014; Weinhandl et al. 2013; Houck et al. 2006; Houck et al. 2007; Besier et al. 2001; Besier et al. 2003; Ford et al. 2005). Incorporating this type of test condition into assessment related to CAI could provide more appropriate information about an individual's ability to cope with returning to previous sporting activity level and help clarify the neuromuscular control deficiency to explain ankle instability. This may also help in reducing the incidence of recurrence by the development of more appropriate treatment guidelines and rehabilitation protocols.

Additionally, there could be a pattern of impairment following acute ankle sprain that

predicts individuals who are more likely to progress to CAI. Another problem in the literature is that most previous researches in ankle instability have only recruited individuals with unstable and healthy ankles. Comparison of individuals recovering from an acute episode of an ankle sprain, individuals with CAI and non-injured individuals would provide information on adaptations that develop in this population following ankle sprain. Assessment of individuals recovering from an acute episode of an ankle sprain over a typical recovery period of six months could allow researchers and clinicians to identify potential individuals who may develop CAI after an initial sprain and to develop an appropriate classification. Also, the ability to discriminate between these groups will subsequently give directions for future research and will hopefully lower the incidence of CAI.

Therefore, a key to understanding the potential CAI is to identify the neuromuscular control strategies associated with events similar to the injury mechanism. This can be achieved by using a new system developed in the School of Healthcare Sciences at Cardiff University for the purpose of simulating a scenario that is closer to a sport situation where the ankle sprain is the most likely injury. This thesis examines the proposed effect of an unanticipated task on functional performance and muscle activity in individuals following acute ankle sprains (AS), individuals who complain about recurrent incidence of ankle sprains (CAI) and individuals with stable ankles who have never experienced a sprain (Healthy). This thesis also examines objective testing including: jump height, self-reported functional assessments, ankle-dorsiflexion range of motion (ROM) and strength of ankle muscles.

2.6 Methodological Consideration

In clinical research, the ability of instruments or measurements to detect clinically meaningful depends on the extent to which researchers can rely on data as accurate (Portney and Watkins, 2009). There are two main types of reliability. The first type is the intra-rater reliability used multiple trials taken by one researcher on different events to establish the consistency of the measurement tool. The second type of the reliability is inter-rater reliability. The inter-rater reliability is used to measure the agreement among multiple researchers (Bruton et al. 2000).

Reliability defined as the quality of a measure that keeps reproducibility, which indicates the degree to which a test or measure produces stable and consistent values with small errors of measurement when the test is repeated in the same conditions (Portney and Watkins, 2009). Two types of errors of measurement may present: systematic error and random error. Systematic error may does not cause problems to the result of the reliability, which could be cause of learning, increased confidence or fatigue effects. This error is a non-random change, which may be presented when all subjects improve consistently their ability to perform the test in one trial. However, it creates problems of internal validity since the value is not the true representation of the quantity measured.

The other type of error of measurement is the random error, which could cause a problem to the reliability results. They occur due to unpredictable factors such as

biological error, physiological or psychological factors such as motivation. Random errors can be reduced by calculating average score of measurements (Portney and Watkins, 2009).

Researchers quantify reliability in a variety of ways based on the statistical concept of variance including: within-subject variation, change in the mean, and retest correlation (Portney and Watkins, 2009). The true result measured by calculating a ratio called the reliability coefficient that has a coefficient of 1.0 for maximum result. Reliability coefficients are simply represents a correlation between two or more variables such as Pearson's product moment correlation or the intraclass Correlation Coefficient (ICC). The less error variability indicates good reliability (Bruton et al. 2000). According to Hopkins (2000), use of the ICC is appropriate approach to computing an average correlation among two or more trials. The ICC is a measure of relative reliability, and range between 0.00 and 1.00, a maximum result of ICC represents higher reliability. Because the ICC measures only the strength of correlation between the two or more trials, Bland and Altman analysis could provide a useful data of agreement between them used in conjunction with ICC results. Another technique of calculating the reliability is to presents the measurement error. The standard error of measurement (SEM) is a measure of absolute reliability, with a low SEM indicates a high level of reliability.

To quantify if the instrument or test intends to measure what it is supposed to measure accurately called validity (Portney and Watkins, 2009). There are four types of validity

that are commonly used include construct, criterion, content and face validity.

Construct validity is the degree to which a test determines the extent to which the instrument measures the concept of interest (Brink et al. 2006). To establish the construct validity, evidence that instrument measures what it is supposed to measure (convergent validity) and also evidence that instrument does not measure unrelated construct (discriminant validity) are both required. Convergent validity refers to the degree to which an instrument correlates strongly with other instruments. Discriminant validity is providing evidence that instruments do not highly correlate and this is also referred to as divergent validity.

Validating an instrument against a previously validated instrument using Pearson's or Spearman's correlation coefficients referred to as Criterion validity. It consists of concurrent and predictive validity. Concurrent validity is examined by comparing results for the new instrument against a previously validated measure, often a gold standard measurement (Portney and Watkins, 2009). High degree of statistical relationship between the two instruments indicates strong criterion validity. Predictive validity is a measure of how the instrument or test has the capability to predict the future performance. Another type of validity employs individuals considered experts about the content area and referred to as Content validity. It is focused on an assessment of decisions of the experts that requires confirming the operational definitions of the tool or items. Lastly, is the Face validity that refers to validation measured by a group of experts to what extent a tool or items included in the instrument seem appropriate and

relevant to measure what it is supposed to measure (Brink et al. 2006).

Therefore, this thesis divided into three parts: Preliminary studies, cross-sectional study and longitudinal study. The preliminary studies mainly aimed to draw confident conclusions about data by examine the reliability and validity of the outcome measures calculated by vector mat system (new system) developed at the School of Healthcare Sciences at Cardiff University.

CHAPTER 3 : LITERATURE REVIEW

3.1 Structure of the literature review

This chapter is divided into three sections. The first section in the literature review provides an overview of the literature relating to recurrent ankle sprain injuries, followed by a critical review of the literature relating to the neuromuscular control deficits in persons with chronic ankle instability. Then a critical review of the literature related to research investigating clinical presentation and assessment used to identify individuals with chronic ankle instability is presented. Because of the limited research available that is specific to the unanticipated functional test for CAI, it was necessary to include studies from other research areas; therefore, unanticipated search was not specific to the CAI population. This aimed to identify and critically review studies related to unanticipated conditions used.

3.2 Search strategy

The search strategy was split into three searches to identify studies for the literature review. A computer search of the medical literature was carried out using the databases AMED, MEDLINE, CINAHL, SCOPUS, PubMed and Cochrane Library for all searches. Table 3-1 presents the research strategy used in each search. Articles were limited to the English language and were cross-referenced.

Table 3-1: Summary of search strategy and records of findings

	Search 1	Search 2	Search 3
Search strategy	1= "Chronic ankle instability" 2="Functional ankle instability" 3= "Mechanical ankle instability" 4= "Ankle instability" 5= "Unstable ankle" 6= "Repeated ankle sprains" 7= "Recurrent ankle sprains" 8= "Multiple ankle sprains" 9= 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 10= Electromyography 11= EMG 12= "Muscle activity" 13= "Pre activity" 14= "Pre contact" 15= "Pre-activation" 16= Preparatory 17= "peroneal reflex" 18= "Peroneal Activation" 19= "Peroneal Reaction" 20= "Reaction time" 21= 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 22 = 9 AND 21	1= "Chronic ankle instability" 2= "Functional ankle instability" 3= "Mechanical ankle instability" 4= "Ankle instability" 5= "Unstable ankle" 6= "Repeated ankle sprains" 7= "Recurrent ankle sprains" 8= "Multiple ankle sprains" 9= 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 10= "Functional performance" 11= "Muscle strength" 12= Questionnaires 13= "Self-reported" 14= "Dorsiflexion range of motion" 15= Laxity 16= 10 OR 11 OR 12 OR 13 OR 14 OR 15 17= 9 AND 16	1= Agility 2= "side-cut" 3= Sidecutting 4= "Side-Step" 5= "Cutting Manoeuvres" 6= "cutting movement" 7= "Changing Direction" 8= 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 9= Reactive 10= unplanned 11= Preplanned 12= unanticipated 13= 9 OR 10 OR 11 14= 8 AND 13
Results identified based on search strategy			
PubMed	90	233	93
Ovid (AMED +EMBASE + MEDLINE)	2853	529	154
Scopus	928	882	135
Results identified based on removed duplication			
NO	1766	1039	161
Studies selected based on titles and abstract			
NO	104 (49)	219 (163)	82 (58)
Studies selected for final review			
NO	48	119	54

3.3 An overview of the literature relating to recurrent ankle sprain injuries

3.3.1 Recurrence

It has been estimated that 32% of those who suffer from an initial ankle sprain can have recurrent ankle sprains or reported symptoms resulting in the development of chronic ankle conditions, and 72% of those with residual symptoms have functional impairment which could limit participation in work, sport, recreation and even some daily activities (Hertel 2000; Yeung et al. 1994). However, a risk increase of up to 80% has been reported for recurrent ankle sprain in the presence of a prior history of sprain (Beynnon et al. 2002; Yeung et al. 1994). The residual symptoms can present as pain, swelling, stiffness and a feeling of instability. A high rate of recurrent ankle sprain can lead to a pathological condition defined as chronic ankle instability (CAI) (Hertel 2002).

3.3.2 Costs of recurrent ankle sprain injuries

A recently published meta-analysis has reported that ankle sprains account for 3–5% of all A&E visits in the UK, with around 5,600 cases each day (Cooke et al. 2003; Doherty et al. 2014), which incurs a significant annual health-care cost. In the UK there is variation in how patients with ankle sprains were treated. Individuals commonly received tools such as crutches, Tubigrip® support and non-steroidal anti-inflammatory drugs following ankle sprain injury (Cooke et al. 2003). Recently, boots and braces have become a more common practice in the UK for those patients (Bridgman et al.

2003). The estimated cost for these devices is £60 for boots, £30 for braces, £12 for below knee plaster casts, and £2 for Tubigrip (Bridgman et al. 2003). With the high number of cases reported each day in A&E in the UK, this would equate to £3 million for boots, £1.5 million for braces, £0.6 million for below knee plaster casts, and £0.1 million for Tubigrip per year (Bridgman et al. 2003). For those with repeated ankle sprain, this cost may increase after each incidence of ankle sprain, which could possibly have a financial implication for the UK's health services.

3.3.3 Defining recurrent ankle sprain injuries

Recurrent ankle sprain injuries are a widely studied condition in research related to sports science and rehabilitation. However, there is a current problem in the literature concerning this condition, regarding not only the various definitions and terms used by researchers but also the fact that there is no standardised inclusion criterion for this condition. A history of repeated lateral ankle sprains and a feeling of giving way were one of the early definitions and criteria used (Freeman et al. 1965). Researchers used these criteria to define participants with recurrent ankle sprain in their studies. Participants had to report a history of one or more lateral ankle sprains (Caulfield et al. 2004; Caulfield and Garrett 2004; Hubbard et al. 2004). However, the number of repeated incidents used to defined groups in studies related to this condition varies from not specified (Bosien et al. 1955) to greater than seven (Konradsen and Magnusson 2000). Participants also had to report a history of an incident of subjective instability (Hubbard et al. 2004; Monteleone et al. 2014; Levin et al. 2015). Some studies also

required the incident of instability to have happened in the 12 months before recruitment (Brown et al. 2004), while other studies required the incident to have happened in the six months before recruitment (Matsusaka et al. 2001; Levin et al. 2015). However, researchers have mostly relied on participants to indicate their instability, which could also lead to that conflict among these studies. Muscle weakness, pain, and functional limitation were also required in some studies (Caulfield et al. 2004; Caulfield and Garrett 2004). Participants were excluded if they had a recent ankle sprain or incidence of giving way within the three months before the study (Boyle and Negus 1998; Monteleone et al. 2014), or a history of ankle fracture (Hubbard et al. 2004; Monteleone et al. 2014).

In addition, different researchers have used different terms in their research to describe this condition, which was described by Freeman early in 1965 as functional instability (FI). Other researchers used mechanical instability (MI), chronic ankle instability, residual instability/disability, and sprained ankle syndrome (Gutierrez et al. 2009). MI and FI are the terms that have been most commonly used by researchers. MI refers to anatomical changes or was clinically described as joint laxity resulting in hypermobility and increase in the accessory motion of the joint (Hertel 2002). These anatomical changes may occur as a result of one or a combination of the following: pathologic laxity, impaired arthrokinematics, synovial changes, and the development of degenerative joint disease (Hertel 2002). The laxity is usually assessed clinically with manual examination or with special instruments; more details will be given later. However, researchers have suggested that MI cannot independently explain all the

residual symptoms of recurrent ankle sprain (Delahunt et al. 2007). Consequently, some researchers have proposed the term FI to describe this condition, which causes another conflict in the literature because of the presence or absence of joint laxity. More characteristics were used to describe FI, but not all must be present to classify an individual with FI. Some studies include impaired proprioception, neuromuscular control, postural control, and strength deficits to describe it. However, studies investigating these impairments associated with ankle instability have produced inconsistent findings. Other studies rely on subjective complaints including a giving-way sensation in the ankle joint to describe it. In another study by (Hiller et al. 2011) the term perceived instability was used to replace functional instability. They suggested that this term could provide considerable insight into understanding of the impairments in participants with this condition.

Chronic ankle instability (CAI) has been recently used in different studies related to this condition (Hertel 2002; Yildiz et al. 2003; Hertel et al. 2006; Hertel and Olmsted-Kramer 2007; T. Hubbard et al. 2007a; Levin et al. 2012; Gribble et al. 2013; Dundas et al. 2014; Feger et al. 2014; Levin et al. 2015). This term appears to be more appropriate clinically, as it may involve both mechanical and functional instabilities to varying degrees to describe an ankle with recurrent instability problems (Hertel 2002). Therefore, the term CAI will be used throughout this thesis to describe a person with ankle instability.

Although there is no gold standard for identifying subjects with CAI, most of the studies used a self-report instrument to identify patients with CAI. This includes the ankle instability instrument (AII), Cumberland ankle instability tool (CAIT), the ankle joint functional assessment tool (AJFAT), the foot and ankle disability index (FADI) (Eechaute et al. 2007; Ross et al. 2008; Donahue et al. 2011; Rosen et al. 2013; Dundas et al. 2014; Wright et al. 2014; Hiller et al. 2006; Mckeon and Hertel 2008ab; Docherty et al. 2005; Docherty et al. 2006; Caffrey et al. 2009; Sharma et al. 2011; Doherty et al. 2015C). These instruments will be discussed later in more detail.

3.3.4 Injury mechanism of recurrent ankle sprain

The most reported mechanism of recurrent ankle sprain is similar to the initial ankle sprain, which involved plantar flexion and an inversion motion (Konradsen and Magnusson 2000). This commonly occurs at the floor contact moment, during change-of-direction manoeuvres or when the individual lands from a height or steps on an unstable surface (Konradsen and Magnusson 2000). Avoidance of recurrent ankle sprains requires appropriate ankle positioning and development of adequate muscle force to resist this mechanism of injury, which depends on the neuromuscular control system. Therefore, an understanding of the neuromuscular control system was considered very important in order to understand the impairments in participants with CAI. The deficits in neuromuscular control related to CAI will be reviewed in more detail in the next section.

3.4 A literature review relating to neuromuscular control

3.4.1 Overview

Neuromuscular control has been defined as the ability to produce action or movement in response to a stimulus through interaction between the neural and musculoskeletal systems (Enoka 2008). Both static (ligaments, cartilage, joint capsule, and bony articulation) and dynamic restraints (muscles and tendons) are required to work in response to forces applied to the joint during activities (Riemann and Lephart 2002). Effective functional performance depends on the ability of the neuromuscular control system to initiate and modify an appropriate muscle that is required to respond to the situations.

Following injury, afferent neural input is likely to be affected by decreasing sensory information, which then possibly affects the responses and increases the risk of further injury. Deficits in neuromuscular control have been linked to recurrent symptoms and development of instability in people with a history of ankle sprain (Gutierrez et al. 2012; Dundas et al. 2014; Gutierrez et al. 2009; Hertel 2008; Delahunt 2007; Delahunt et al. 2006a). This was investigated in many studies by quantifying the disruption to motor control strategies using kinematic and kinetic variables including assessment of muscle activity.

Alterations in this system during functional activities were proposed to cause muscles to be activated in an inappropriate manner (i.e. timing or amplitudes), interfering with foot positioning at the time of ground contact (Dundas et al. 2014; Suda and Sacco 2011). Appropriate movement and accurate positioning is very important to maintain safe activities and avoid the risk of another ankle sprain. This is provided by two mechanisms of motor control strategies: closed-loop system (feedback/reactive) and open-loop system (feedforward/preparatory) (Magill 2011). The next section will discuss these systems in more detail.

3.4.2 Closed-loop system (feedback/reactive)

The closed-loop system is used to correct or adjust continuous or long-duration tasks such as walking or maintaining posture that requires continued feedback. The feedback received from different sources including eyes, the vestibular system and mechanoreceptors. The information from these sources is processed at three levels in the CNS to control motor movement: 1) the spinal cord, 2) the brain stem and cerebellum, and 3) the cerebral cortex (Biedert 2000). In response to perturbations or during functional tasks, muscle response varies in the timing, recruitment order or amplitude. Normally, in response to quick action or perturbations, spinal level reflexes lead to rapid automatic reactions via a monosynaptic afferent pathway. In terms of response latencies, these were categorised into short-latency responses and long-latency responses (Schmidt and Lee 2005). The quickest response has short latencies of 30–50 ms because of the short travelling distance through a monosynaptic pathway

(Schmidt and Lee 2005). Response begins 50–80 ms following perturbation as integrated with other sources of information. Another response begins at about 120–180 ms and is termed the voluntary long-loop reaction, which helps to produce more stability (Schmidt and Lee 2005).

Freeman and his colleagues were the first who proposed the role of the mechanoreceptors, as early as 1965, in their study on individuals with a history of ankle sprain. They linked the disruption in the mechanoreceptors to the giving-way sensation and development of instability in people with a history of ankle sprain and termed it functional ankle instability (FAI). They also proposed that this disruption to the afferent neural input received from the mechanoreceptors (muscles, and cutaneous and joint receptors) would result in a too-late or low response to fully achieve the required response.

The importance of afferent information from mechanoreceptors to motor control was also investigated by removing this afferent input by administering anaesthesia to the joint and ligament (Konradsen et al. 1993; Hertel et al. 1996; Riemann et al. 2004; Khin-Myo-Hla et al. 1999). Therefore, it is thought that an alteration in afferent information from the mechanoreceptors in individuals with injury would possibly delay the motor response during unexpected movements. Mechanoreceptors are small sensory organs and classified on the basis of their location into three groups: I) muscle receptors, II) joint receptors, III) cutaneous receptors.

For a better understanding of how motor control could influence joint stability, the following sections will first describe mechanoreceptors located in the joints, muscles and tendons.

I. Muscle receptors

There are two types of receptors located in the muscles: muscle spindles and Golgi tendon organs (GTOs). Muscle spindles are stimulated when stress causing changes in the length of the muscle is applied to muscles (Winter et al. 2005). These muscle spindles include three components: 1) intrafusal muscle fibres, 2) sensory axons, and 3) motor axons (Gordon and Ghez 1991). The function of these receptors is to provide information to control muscle length (Gordon and Ghez 1991). Intrafusal fibres within the muscle are highly sensitive to the amount of load applied to the muscle. This function facilitates increases or decreases in the firing rate of the afferent signal, resulting in an appropriate contraction of the muscle. For example, when a muscle is stretched, the activity of muscle spindles will increase, and when the muscle is shortened, it will decrease (Westlake et al. 2007).

The importance and role of muscle spindles was identified early in research (Goodwin et al. 1972; McCloskey et al. 1983). These researchers used different isolation techniques (e.g. anaesthetisation and nerve blocking). The results revealed that muscle spindles are a vital receptor which influences and controls movement. Fitzpatrick and colleagues (1994) also found that subjects were able to maintain a standing balance when relying on receptors from leg muscle spindles. In this study, other sensory receptors

were removed from the feet using ischaemic anaesthesia; vision and vestibular receptors were also excluded.

The other type of muscle receptor is the Golgi tendon organs (GTOs). These receptors are located in the muscle–tendon junction. They are characterised by a very low threshold and a high dynamic sensitivity, which provide information regarding muscle tension (force) or change in tension during standing or activity (Stanfield and Germann 2008). The impulse from GTOs travels to the spinal cord, causing spinal reflexes associated with the ascending information. These spinal reflexes are an autogenic inhibition, which controls the force of contracting muscles (Stanfield and Germann 2008).

II. Joint receptors

Joint receptors consist of four types identified in the joint capsule and ligaments: Ruffini endings, Pacinian corpuscles, Golgi tendon organ-like endings, and free nerve endings (Johansson et al. 2000; Magill 2011). These receptors are classified according to how they respond to stimuli and by the following characteristics: (1) the joint state activity (static, dynamic, or both), (2) the stimulus intensity (low-threshold or high-threshold), and (3) based on how they respond to the stimuli, either by responding slowly (slowly adapting) or starting with a quick response and then becoming quiet (rapidly adapting) (Williams et al. 2001). Ruffini endings are slow adapting receptors and have a low threshold of detection for mechanical loading. Therefore, they are sensitive to position change, pressure, and the velocity of joint movement (Proske et al.

1988; Ferrell et al. 1987). Pacinian corpuscles are fast adapting with a low threshold. They are also described as dynamic mechanoreceptors because they are not activated during static positions and are sensitive to changes in velocity (Johansson et al. 2000). The Golgi tendon organ-like endings are slow adapting with high thresholds in detecting mechanical stress and are activated during extreme ranges of motion (Kandel et al. 2000). The free nerve endings are mainly activated when there is damage or deformation within the joint (Johansson et al. 2000).

Studies have supported the role of joint receptors in projecting to the gamma motor neurons and consequently the increased sensitivity of the muscle spindles. This sensitivity of the muscle spindles increases or maintains muscle stiffness. Therefore, injury affecting the joint would consequently result in a reduction of muscles stiffness, which was suggested in subjects with functional instability (Freeman and Wyke 1967).

The contribution of these mechanoreceptors to the neuromuscular system has been supported by studies using injection anaesthesia (Hertel et al. 1996; Feuerbach et al. 1994). Myers et al. (2003) studied the effects of injections on muscle firing characteristics during dynamic tasks. The researchers injected the lateral ankle ligaments to investigate the protective response of the peroneal muscles and found a decreased response amplitude.

III. Cutaneous receptors

Cutaneous receptors are located in the skin, which are stimulated by heat, cold or

mechanical deformations such as pressure (Refshauge et al. 1998). Researchers have supported the importance and the role of the cutaneous receptors in providing the CNS with sensory information to maintain balance and joint stability (Johnson 2001).

3.4.3 Open-loop system (feedforward/preparatory)

Appropriate muscle recruitment and timing is provided by the CNS in anticipation prior to movement without much feedback involvement, which has been termed the open-loop system (feedforward and preparatory motor control) (Schmidt and Lee 2005). To understand how the deficit in this system could influence joint stability and cause recurrent ankle sprain, studies related to CAI have been more focused on investigating the importance of muscle activity in ankles during sudden perturbations to achieve a successful functional performance and to protect the joint (Brown et al. 2004; Konradsen and Ravn 1991; Konradsen et al. 1998; Vaes et al. 2002; Delahunt et al. 2006b; Delahunt 2007; Lofvenberg et al. 1995; Palmieri-Smith et al. 2009; Santilli et al. 2005; Suda and Sacco 2011).

Electromyography (EMG) has been widely used to investigate muscle activity with a large variety of variables and methods. However, most of these studies tend to measure response under static conditions. Many studies have focused on the reaction time and onset of peroneal muscles during standing, walking and landing from hop. Some researchers reported a delay in the reaction time in individuals with ankle instability (Konradsen and Ravn 1990; Konradsen et al. 1998; Myers et al. 2003), but other

researchers did not find differences between groups (Konradsen et al. 1997). These inconsistent findings are explained by Vaes et al. (2002) as the variety in 1) inclusion criteria used to recruit subjects, 2) the severity and the frequency of ankle sprain incidence, and 3) methods used for inversion. However, there is an agreement that muscle pre-activation serves as an important function during complex dynamic activity by providing appropriate muscle activation. Consequently, in the absence of adequate preparatory mechanisms through pre-activation of muscles during these tasks, the joint is put at risk of injury (Riemann and Lephart, 2002). Because of the short time available to perform those tasks, the CNS depends on past experiences and learnt motor strategies to anticipate the joint loads during these tasks using the preparatory mechanism (Riemann and Lephart, 2002). Vision also provides important information to help the motor control system in advance of movement (Rosen et al. 2013). However, muscle activity will be discussed later in more detail.

Another area of investigation of neuromuscular deficits with CAI has focused on foot positioning and ankle joint angle at the time of ground contact. It was hypothesised that subjects with CAI will demonstrate different biomechanical strategies from those with no ankle instability during landing from hop, changing direction, walking or stepping down. Lin et al. (2011) evaluated the ankle position during running and stop-jump landing tasks and the CAI subjects showed a greater inverted ankle of the affected ankle in the late pre-landing phase during running. Greater inversion was also found in the CAI subjects during the stop-jump task in 70% of the post-landing phase. The author in this study has just reported running and jump-landing phase. Analysis of running-stop

phase could provide more information regarding the change that may occur in subjects with CAI.

Another study used 3-D video motion analysis and detected 6–7° greater inversion positioning by comparing 25 subjects with CAI and 25 healthy subjects during walking at their comfortable speed during the 100 ms pre to 200 ms post foot contact (Monaghan et al. 2006). A limitation of this study was that the left leg was chosen for analysis for all subjects in the control group. Similar results were reported in another study for walking on a treadmill, which could reduce variability of walking speed between trials and group (Delahunt et al. 2006a). A decrease in vertical clearance from the ground was also reported throughout walking (Delahunt et al. 2006a). It has been suggested that by remaining in greater inverted position, combined with decrease ground clearance, individual with history of ankle sprain may be in a greater chance for suffering recurrent injury. Regarding single leg downward jumps, Delahunt et al. (2006b) found that FI subjects had a more inverted position of the ankle joint compared to healthy individuals between time periods from 200 ms to 95 ms pre-initial contact. They also had a less dorsiflexed position of the ankle joint during the time period from 90 ms to 200 ms post-initial contact. Limitation in range of motion in dorsiflexion could be a factor contributing to this finding and would suggest that assessment of range of motion should be included in future study. More information about this assessment will be discussed later.

A study by Dundas et al. (2014) grouped subjects based on their CAIT scores into 3

groups: CAI participants with ankle instability (n = 11), those with a history of ankle sprain without instability (CPR n=9) and healthy participants (CTL n= 13). All participants performed a stepping-down task during continued walking. In this study participants with CPR demonstrated a protective motor strategy in a less plantar-flexed position during step down. CAI participants demonstrated a greater plantar-flexed position ($31.44 \pm 4.37^\circ$), compared with the CPR ($21.17 \pm 5.03^\circ$) and healthy group (25.59 ± 6.08), which could place the individuals in a high-risk position. However categorising subjects based only on their subjective CAIT scores may not be sufficient to differentiate these three groups. A less plantar-flexed position was also reported in another study in participants with acute ankle sprain compared with healthy subjects during walking at heel strike moment (Doherty et al. 2015b), and during drop vertical jump test in subjects six months post ankle sprain injury (Doherty et al. 2015a). These findings could be a strategy in participants with history of ankle sprain because of a deficit in motor control to prepare the joint in advance of movement and to protect the ligaments. However, the functional test used in these studies involved planned conditions, in which participants are aware of the trial that will cause them to prepare the joint in advance of movement. In another study found that the mechanically unstable group landed with more dorsiflexion position at initial contact than the control group and had more eversion compared with functionally unstable and control groups (Brown et al. 2008). A limitation was that no healthy group was included in this study. Therefore, differences observed may be the result of differences in the subjects recruited. However, because of the design of these studies, it is difficult to draw definitive conclusions regarding the ankle instability, longitudinal study design could help to clarify the cause of repeated

injury.

3.5 Literature review related to clinical presentation and assessment

3.5.1 Clinical presentation and assessment of CAI

A history of repeated lateral ankle sprains and reports of a feeling of giving way, especially during physical activity, are a common complaint among individuals with CAI. A variety of assessment tools and methods have been developed specifically to identify patients with CAI. These assessments include: self-reported functional assessment, ankle-dorsiflexion ROM test, laxity test, muscle strength, muscle activity using electromyography (EMG), and functional performance tests. However, studies investigating the impairments associated with CAI have produced inconsistent findings. These assessment methods will be discussed in more detail in this section.

3.5.1.1 Functional performance methods of measurement

3.5.1.1.1 Overview

A variety of functional performance tests (FPTs) are used to evaluate recovery in individuals who suffer a lower extremity injury, which require simple equipment and less time (Munn et al. 2002; Caffrey et al. 2009; Wikstrom et al. 2009; Sharma et al. 2011). These tests are used as criteria to evaluate joint stability, monitor progress towards normal activity, to determine an athlete's participation status and to facilitate the assessment, leading to more efficient and more effective treatment (Hertel 2002).

These FPTs provide objective data such as distance hopped, height and task time.

There is a wide range of tests that have been used to address the functional performance in individuals with CAI: triple-crossover hop, figure-eight hop, side hop, single hop, single-limb hurdle test, multiple hops in a zigzag pattern, square hop, hop for distance and agility test. However, some of these tests did not produce significant differences when comparing the performance between injured and uninjured limbs (Munn et al. 2002; Eechaute et al. 2008a) or when comparing these injured limbs with healthy subjects (Eechaute et al. 2008a; Buchanan et al. 2008; Wikstrom et al. 2009).

The fact that some of these tests are done primarily in the sagittal plane direction was suggested in the literature as a reason for not finding functional differences in ankle sprain injury (Docherty et al. 2005). The researchers suggested that these tests, such as single hop for distance, might stress the thigh muscles more than the lower leg musculature (Docherty et al. 2005; Wikstrom et al. 2009; Sharma et al. 2011). The direction of these tests is supported by Docherty et al. (2005), who reported a weak but positive relationship between the self-report scores (FAI index) and performance deficits in the figure-eight hop ($r = 0.31$) and side-hop tests ($r = 0.35$). This relationship did not exist in this study using up-down hop and single-hop tests. However, this functional test, which did not provide differences in ankle studies, was used in knee studies and showed differences (Noyes et al. 1991; Fitzgerald et al. 2001). Authors have indicated that choice of functional performance tests for the ankle should be made on their ability to stress the lateral aspect of the ankle joint and to simulate the mechanisms

that may bring about feelings of instability.

In another study the triple-crossover hop for distance was also not sensitive enough to predict functional differences among 16 subjects (Munn et al. 2002). In this study each subject hopped three times from a start line in a zigzag fashion, crossing over 15 cm tramlines. Another study using more subjects (n = 24) divided into three groups did also not find a significant difference (Wikstrom et al. 2009). Similar results were also reported using the crossover hop for six meters using 60 subjects (Caffrey et al. 2009). However, in this study, eight (27%) participants reported instability or giving way while performing this test, which allowed the data to be re-analysed using three groups: FAI subjects who experienced instability during testing (FAI-GW), FAI subjects who did not (FAI-NGW), and healthy subjects. A significant difference was found between FAI-GW, FAI-NGW and healthy groups, with worse results reported for the FAI limb than the uninjured limb in the FAI-GW. In a similar study using a hopping test, 10 of the 20 participants (50%) in the FAI group felt unstable during the test. Dividing participants according to feeling instability revealed a difference among groups. Asking participants if they felt unstable or not during functional tests could provide useful information to indicate which test puts more force on the ankle in these studies. In Caffrey et al.'s (2009) study, the figure-eight test and the side-hop test recorded the highest numbers of participants feeling ankle instability (43% and 47%, respectively). In another study, 96% of the FAI participants reported a feeling of instability during the square-hop test, followed by 93% who reported it while performing the side-hop test and 55% who reported it during the figure-eight hop test (Sharma et al. 2011).

The vertical jump is another example for the FPTs that have been used to address the functional performance. This test has received widespread recognition as a clinical test to evaluate performance and height is considered the most utilised parameter for the evaluation of the vertical jump. Force plates (FP) have been used to estimate the jump height by analysing the vertical ground reaction force (VRF) or Flight time (FT), which allows the jump impulse to be calculated as well as the take-off velocity and power (Cordova and Armstrong 1996; Larkins and Snabb 1999; Linthorne 2001).

The video-based method (VID) has been used to measure the vertical difference between two body landmarks (García-López et al. 2005). Flight time has also been used using a contact mat (CM). The CM is considered a simple and reliable method to calculate jump height in the clinical setting (Enoksen et al. 2009; García-López et al. 2005; Aragón 2000), besides being portable and less expensive than VID or FP.

Change of direction and landing from a jump are often cited as the injury mechanisms during lower extremity injury. Therefore, choosing FPTs that utilise this mechanism is helpful to present the condition of neuromuscular, joint stability, muscular strength and biomechanical abilities (Noyes et al. 1991; Young et al. 2001). However, the clinical decision to allow individuals with ankle sprain or those diagnosed with CAI to go back to normal activities or athletes to return to sport has been an area of much debate. This may be because of the lack availability of standardised assessment protocols related to this condition. This also may play a role in placing individuals at risk situation of re-

injury. However, in sport there is agreement that FPTs should be designed specifically to evaluate a variety of skills and recreate typical sporting movements.

Although there is agreement that functional performance tests in CAI should be made on the basis of their ability to stress the lateral aspect, the fact that these functional test were measured through planned movement patterns was not addressed in ankle research. The agility test is a good example of the FPTs that have been modified to better replicate similar conditions that are present during sport and also in order to increase the external validity of the assessments. In sport, some activity is not pre-programmed or planned and requires a response to sensory stimuli in order to produce movement that is not automated, such as avoiding an opponent (Young et al. 2002). Therefore, the agility performance test was redefined as quick change in velocity or direction of whole body in response to external stimulus (Sheppard et al. 2006; Oliver and Meyers 2009; Scanlan et al. 2015). Agility was divided by Young et al. (2002) into two parts: (a) planned agility and (b) reactive agility. Planned agility is used to describe movement patterns where the participants know the direction. When the movement pattern is unanticipated where an external stimulus was used it is defined as reactive agility (Gabbett et al. 2008; Young et al. 2002). Consequently, a proposed model was developed which incorporated more factors that could influence functional performance, including cognitive components (perception and decision making), physiological components (strength and power), and biomechanical components (kinematics and kinetics) (Young et al. 2002).

Researchers have started using unanticipated tasks to improve the validity and to minimise the learning effect. They suggested that incorporating this condition into functional tests related to lower extremity injury could also provide more appropriate information in assessing the ability to return to previous sporting activity (Farrow et al. 2005). Researchers mostly used the cutting manoeuvre that is commonly performed throughout sport, which could place the individual under a similar condition and injury mechanism. Cutting manoeuvres were also found to exhibit a great load on lower extremity biomechanics. This load was found to be increased when this manoeuvre was performed under unanticipated conditions. For the purpose of this thesis, the following sections will discuss the functional performance under the unanticipated conditions and the approaches that have been used for assessment.

3.5.1.1.2 Unanticipated condition in functional tests

Particularly, unanticipated conditions have been commonly included in studies related to the knee, and they found that by placing the participants under these conditions, a greater force on knee biomechanics was present when compared with planned conditions (Kim et al. 2014; Weinhandl et al. 2013; Houck et al. 2006; Houck et al. 2007; Besier et al. 2001; Besier et al. 2003; Ford et al. 2005). The researchers also suggested that there is an increased demand placed on the neuromuscular system in unanticipated conditions in functional tests. Other researchers referred to this condition in their studies as reactive agility. Research related to CAI also used unplanned techniques to investigate EMG activity using devices designed to supinate the ankle.

Different tools have been used to assess performance in unanticipated tasks, such as light cues, sounds, computerised direction indicators, video and human participation (Sheppard et al. 2006; Ford et al. 2005; Farrow et al. 2005; Duvnjak-Zaknich et al. 2011; Gabbett et al. 2008). However, the unanticipated tasks in these studies were performed in a more controlled environment than that of an actual sports game.

Some studies related to ACL deficiency used an unanticipated condition in their studies in order to understand the role of neuromuscular and biomechanical factors (Kim et al. 2014; Weinhandl et al. 2013; Houck et al. 2006; Houck et al. 2007; Besier et al. 2001; Besier et al. 2003; Ford et al. 2005). In another study, researchers used a computer monitor to initiate the unanticipated condition and provide a direction signal according to which participants proceeded. In this study the participants were instructed to initiate a forward jump before performing a cutting manoeuvre (Ford et al. 2005). Other researchers have used light cues in their studies to detect the direction. Upon passing the timing gate during the test, participants were given a light cue either for changing direction or a straight run. Participants were required to react to this stimulus and sprint as quickly as possible through the final timing gate. However, while these tests may not accurately replicate the unanticipated condition that athletes are presented with during sports, the results support the use of these methods. In these studies, the knee and hip were significantly affected when a change in direction was unanticipated (Kim et al. 2014; Weinhandl et al. 2013; Houck et al. 2006; Houck et al. 2007). While the reflex responses were also required to allow for postural adjustments, individuals during unanticipated task showed a limited ability to initiate appropriate proactive adjustments

of lower extremity muscles (Besier et al. 2003).

The distance between the point where the single cue was triggered and the point where the participants were required to react to this single cue was not consistent among these studies. In a study by Weinhandl et al. (2013), participants were instructed to respond to the stimulus presented as they passed through a timing gate placed 3 meters prior the force plate. In this study the participants were required to respond with a sidestep cut, straight-ahead run or quick stop. Kim et al. (2014) used random green or red light cues to signal the cutting direction. The direction was determined by using a photoelectric cell that was placed at 90% of the stride length before the centre of the force plate. In other studies the single cues were triggered at 50–65% of a stride length before the centre of the force plate (Houck et al. 2006; Houck et al. 2007). In other studies this distance was adjusted based on each individual's performance in performing a random order of tasks including a straight run, sidestep to 30° and 60° and a crossover cut to 30° (Besier et al. 2001; Besier et al. 2003).

Researchers in psychology studies have also assessed the response of athletes by simulating the sports scenarios on a computer screen. The researchers in these studies were interested in measuring the decision-making time (DMT) by asking the participants to respond verbally or by pointing or pushing a button (Araújo et al. 2005; Vaeyens et al. 2007). These response options, however, are not representative of the actual sports environment. Although this approach may be highly reliable for assessing DMT, the physical response during this test is not enough, resulting in limited

applicability to sports. In a study by Dicks et al. (2010), eye-tracking devices have been used to assess the gaze characteristics of football goalkeepers facing penalty kicks in different conditions. While this method may provide valuable data, use of goggles during the test could alter the performance, as the athletes are usually not using these goggles during real games. However, in the future similar goggles technology with virtual reality system could be available to provide more valuable data.

In sports science studies, unanticipated tasks were commonly used to discriminate between players' skill. Researchers in these studies used another approach to DMT assessment. They used life-sized players' images projected on to a screen placed in front of the subject as the external stimulus (Farrow et al. 2005; Duvnjak-Zaknich et al. 2011; Henry et al. 2011). Subjects were required to physically react to the movements of the projected image. In these studies video footage (50Hz) was used to identify the decision-making time. A frame-by-frame (within ± 20 ms) video recording was then used to generate data for analysis, and DMT was defined in each trial from the stimulus point and the first lateral movement of the foot which initiates the change of direction. A limitation of this method relies on the analysis of video recording, as it is difficult to generate accurate data using camera with video footage (50Hz). However, three different level skills were tested (high, moderate and low) in these studies, and DMT was found to be significantly shorter for the highly skilled players than the less-skilled players. While this form of reactive stimulus has some validity in sports as a result of applying a better sports scenario and investigating the DM responses by requiring players to react physically, some researches are arguing that a two-dimensional stimulus

is still unable to present the participant with a real sports scenario to measure decision-making time. Therefore, other researchers started using a different stimulus (Sheppard et al. 2006; Gabbett et al. 2008; Gabbett and Benton 2009; Veale et al. 2010, Young and Willey 2010)

Young and Willey (2010) investigated the relationship between the total time of the task and DMT and tester time by using a tester who initiates side-step movements to provide a stimulus for the participant to change direction. Thirty-one male semi-professional Australian rules football players were recruited in this study. The DMT was defined as the time from when the tester planted his foot to the time the participant planted his foot to respond by changing direction, while the tester's time was recorded as the first forward movement of the tester from when the body left the beam to the moment when the foot is planted for the final side step. The greatest relationship existed between DMT and the total time ($r = 0.77$), rather than response time ($r = 0.59$) or tester time ($r = 0.37$), indicating that the decision-making time was most responsible for the variance in the total time. This is consistent with findings of previous research, indicating that the decision-making component significantly contributes to reactive agility (Farrow et al. 2005; Gabbett and Benton 2009).

In other studies the participants were required to respond to movements by a human tester who performed one of four possible scenarios (Sheppard et al. 2006; Gabbett et al. 2008; Gabbett and Benton 2009; Veale et al. 2010). The four possible scenarios were presented in a random order that was different for each participant: (1) Step forward

with right foot and change direction to the left; (2) Step forward with the left foot and change direction to the right; (3) Step forward with the right foot, then left, and change direction to the right; (4) Step forward with the left foot, then right, and change direction to the left. DMT was identified within ± 5 ms for each trial using a high-speed video camera and defined as the time difference between the first definitive foot contact initiating the movement of the investigator in the final direction he moved his body and the first definitive foot contact initiating the response of the player. The analysis of the data using high-speed video footage in these studies allowed for a more precise identification of movement during the reactive agility test, compared with previous studies. However, limitation of this method relies on the examiner's technique, as it is difficult to standardise this technique throughout the study. In addition, this method will be difficult to apply in another study with similar examiner's movements, which may give different results.

3.5.1.2 Muscles activity

As has already been mentioned earlier, the information provided by the mechanoreceptors and visual, vestibular, and auditory systems is integrated by the CNS to generate a motor response. This was investigated in many studies by quantifying the disruption to motor control strategies using kinematic and kinetic variables. In this section the method used to quantify muscle activities in subjects with chronic ankle instability will be discussed.

Both preparatory and reactive mechanisms of muscle activation are required to help to perform dynamic activities safely (Caulfield et al. 2004). Specifically, in the ankle joint the peroneal muscles have been reported as the first response mechanism for unexpected inversion perturbation, thus providing more stability. Therefore, researchers have linked an alteration in the response or the ability to generate rapid eversion of peroneal muscles to instability and to an increased risk of re-sprain in individuals with CAI compared to healthy people. They linked the delay in response to the lack of or delay in afferent information from the mechanoreceptors located in the joints, muscles and tendons, especially during unexpected movements (Konradsen et al. 2005; Brown et al. 2004; Konradsen and Ravn 1991; Konradsen et al. 1998; Vaes et al. 2002; Delahunt et al. 2006b; Delahunt 2007; Lofvenberg et al. 1995; Palmieri-Smith et al. 2009; Santilli et al. 2005; Suda and Sacco 2011). Additionally, the tibialis anterior, extensor digitorum longus, and extensor digitorum brevis are important in the stabilisation of the ankle during plantar flexion (Hertel, 2002).

The majority of research related to CAI has focused on recording the latency of peroneal muscles as a defence mechanism during an inversion movement. Researchers have used different variables, including onset time, maximum amplitude, reflex latency and time to maximum amplitude (Vaes et al. 2002; Eechaute et al. 2009; Konradsen and Ravn 1990). Researchers in these studies have developed a device that contained a trapdoor for the purpose of placing the ankle in a sudden inversion mechanism. They used electromyography (EMG) to measure the muscles latency, which has been shown to be important in assessments of neuromuscular control in individuals with CAI. The

researchers thought that by placing the ankle into sudden inversion whilst the subject was standing it would simulate the mechanism of the ankle joint sprain. However, the finding of Konradsen and Ravn's (1990) study has supported the hypothesis of Freeman's study (1965) that shows a delay in the reaction time of the peroneal muscles for subjects with ankle instability in a comparison with healthy subjects due to the disruption in the mechanoreceptors, which results in a too-late or low response to fully achieve the required mechanism (mean 82 ms compared with 65 ms in healthy subjects). In this study they measured the reaction time as the time from beginning of trapdoor movement to the first observation of peroneal muscle response. Similarly, positive results have been reported in other studies (Konradsen et al. 1998; Myers et al. 2003). Alternatively, no differences were found between groups in several other studies (Konradsen et al. 1997). These inconsistencies in results presented among studies may exist because those studies have been performed mainly in controlled situations that are not precise enough to present real injury mechanisms (e.g. running, cutting, and landing) and also due to the differences in criteria used to identify individuals with ankle instability. Researchers also used different techniques to detect the first EMG signal, some researches have used a threshold level of 2 SD (standard deviation) and others go up to 10 SD.

Because ankle sprains mostly occur during dynamic movements, researchers have suggested that muscle response should be studied under similar conditions. However, EMG during a gait cycle was also investigated with the same variation related to activation of the peroneus longus (Delahunt et al., 2006a, Santilli et al. 2005). A study

by Dundas et al. (2014) investigated how CAI participants (n=11) performed step-down tasks, comparing those with a history of ankle sprain without instability (CPR n=9) and healthy participants (n=13). The CPR group shows increased activation of the tibialis anterior (TA) both before and after step down, which resulted in a less plantar-flexed position during step down. This was suggested as a protective mechanism prior to foot contact. Activation of peroneals pre and post contact was not significantly different between groups. However, the plantar-flexed position was higher in the CAI group ($31.44 \pm 4.37^\circ$) than the CPR ($21.17 \pm 5.03^\circ$) and the healthy group ($25.59 \pm 6.08^\circ$), which could place the individuals in a high-risk position. The method of the test was planned condition movement, in which participants are aware of the trial in advance of movement. Thus it is not known whether the different observed were the result of an adaptation to injury or because of the method used. Also, dorsiflexion ROM data were not included, so it is not clear whether the limitation in ROM influenced these finding or this result of motor strategy change. The root mean square (RMS) has been widely used in processing EMG signals by calculating the intensity and the duration of the EMG signal during activity (Criswell 2011). In Feger et al.'s study (2014), 15 subjects with CAI and 15 healthy controls were used to compare the EMG (RMS) area during lunges, single-limb balance exercises, the Star Excursion Balance Test (SEBT), and lateral hopping exercises in planned condition. The CAI subjects had less muscle activity in the ankle, knee, and hip during all these functional exercises than healthy controls. However, small sample size of subjects recruited could increase the potential risk of a type II error as standard deviation reported was large.

On the basis of these studies it has been concluded that the muscle response should be investigated with a more functional approach than standing or the gait cycle. Researchers have attempted to develop a device that would introduce a sudden inversion during functional activity. Some studies have utilised a walkway with built-in trapdoors to investigate ankle muscle response and have discovered significant differences (Palmieri-Smith et al. 2009; Hopkins et al. 2009). However, there still remains disagreement on the protocol used in some studies in those with CAI.

Since CAI is most common in athletes and physically active individuals, and given that the landing and changing direction (cutting manoeuvre) are more representative of a real sports activity that is related to the occurrence of ankle sprains, researchers in other studies have started investigating the EMG responses of ankle muscles in more complex activities related to sports, such as landing (Caulfield et al. 2004; Delahunt et al. 2006a; Suda et al. 2009; Gutierrez et al. 2012; Gehring et al. 2014). Both Caulfield et al. (2004) and Delahunt et al. (2006b) found a significant reduction in the pre-contact phase (pre IC) of peroneus longus muscles by calculating the integral EMG (IEMG) during single-leg downward jumps and single-leg jumps of distance in participants with ankle instability and controls. IEMG was calculated as a percentage of peak activity for both envelopes pre and post IC. However, the functional test used in these studies involved planned conditions, in which participants are aware of the trial that will cause perturbation.

Recently, researchers have begun to consider using unanticipated tasks to investigate

neuromuscular control in individuals with CAI, in which perturbation is randomised and thus unplanned. Gehring et al. (2014) found no statistical evidence when investigating the difference in neuromuscular control during standing, walking and jumping tests between three groups: 1) FAI+MAI (n=19) represented subjects with functional instability and mechanical instability according to the manual examination. 2) FAI (n=9) represented subjects with functional instability without mechanical instability. 3) Healthy control n=18). Specifically, during standing tests the platform was released within a period of 10 seconds after participants reached the correct position. Under the walking condition, the platform was released in 10 of 30 trials performed in a randomised order, and during the jump condition the platform was released once out of every 10 trials performed. While the researchers in this study used unplanned techniques to investigate EMG activity, making it difficult for the participants to predict the instant of the platform movement, the process with the release of the platform, from start to maximum, took 45 ± 1 ms during standing, 42 ± 5 ms during walking and 26 ± 1 ms during jumping. Therefore, this may have affected the outcome by allowing additional time for participants to predict the movement and to react appropriately.

A different approach was used by Gutierrez et al. (2012) to conduct the test under unplanned conditions. Forty-four subjects were recruited and divided equally into three groups, namely ankle instability (AI), individuals with a history of lateral ankle sprains without instability (LAS), and uninjured controls (CON). The researchers assessed muscle activity (EMG area) during drop-jump testing using a supinating device placed over a force plate. Two periods were defined on the basis of foot contact as the

preparatory time (200 milliseconds before) and the reactive time (200 milliseconds after). The EMG data were normalised to the maximum activity during the period in each trial for the tibialis anterior (TA) and the peroneus longus (PL). Twenty trials were presented randomly for each subject and 12 trials were used for analysis and categorised according to condition (supinating vs non-supinating) and type (known vs unknown). Participants in the AI group showed a significantly increase in the activation of PL muscles at 200 milliseconds before landing. Authors have speculated that this was due to participants trying to protect their ankle by activating their muscles throughout the trials because they know that the device and protocol of the assessment is designed to supinate the ankle. However, the motion speed of the device could influence the results in this study.

A lateral shuffle manoeuvre was used by Suda and Sacco (2011) to compare 18 healthy subjects with 16 individuals with ankle instability. The authors in this study process the muscle activity of the muscle of the tibialis anterior (TA), gastrocnemius lateralis (GL) and peroneus longus (PL) using the root mean square (RMS), the onset time, the peak magnitude and the time to peak. A lower value in the RMS of the PL muscle was found in the instability group before the ground contact when compared with the healthy group. Each participant was positioned to the left or right of the force platform, which depended on the foot evaluated, and asked to shuffle twice, stepping on the force platform using their evaluated foot in the second shuffle and back to the starting position. This manoeuvre was repeated until four valid trials were achieved; then it was used for analysis. However, the number of invalid trials was not reported, which could

be used as an indicator for a deficit caused by motor control. In this study the ground contact was initially identified through the force platform using a vertical ground reaction force component using 10 N. The ankle instability group has a different motor strategy than the healthy group, as presented by muscle onset. The GL activated significantly early, followed by the PL then TA, in the ankle instability group, whereas the GL and PL activated together at the same time and were then followed by the TA in the other group. The onset time was defined, as suggested by Santello and McDonagh (1998) and Suda et al. (2009) as the instant in time at which the distance between the normalised EMG signal and the reference line was the highest and was depicted in relation to the initial ground contact. Therefore, positive values represented activation prior to the initial ground contact. Negative values represented activation after the initial ground contact. However, muscle onset may not provide a good indication of the quality of movement that is required to complete the task in a safe manner.

3.5.1.3 Assessment of muscle strength

Muscle weakness is another factor that could present itself following an ankle sprain injury or in an individual with CAI and that could affect the ability of muscles around the ankle in response to joint loading during dynamic activities. This decrease in muscle strength was suggested to be due to the presence of arthrogenic muscle inhibition (AMI), which is defined as continuing reflexive inhibition following muscle or joint injuries (Rice and McNair 2010). The researchers have measured the AMI by evaluating the Hoffman reflex and quantifying motor neuron pool excitability (Gutierrez et al. 2009; Rice and McNair 2010). The AMI has been linked to weakness of quadriceps

muscles after knee injury (Hurley et al. 1994; Rice and McNair 2010). The AMI was present in the peroneal and soleus muscles of the injured limb in individuals with functional ankle instability (McVey et al. 2005). The studies have explained the cause of AMI at the injury site as the alteration of the afferent signal from the mechanoreceptors. However, the AMI is considered a protective and involuntary mechanism protecting against additional damage to the muscles by decreasing the motor neuron activation (Rice and McNair 2010). In regard to the CAI, the strength of ankle muscles has been widely investigated, mostly by evaluating the deficit in evtor and invertor muscles (Yildiz et al. 2003; Hartsell and Spaulding 1999; Leanderson et al. 1999; Kaminski et al. 1999; Willems et al. 2002; Bernier et al. 1997) and other studies assessed the dorsi and plantar flexors (Gribble et al. 2009; Fox et al. 2008; Naicker et al. 2007). Researchers have proposed two theories related to muscle weakness in individuals with ankle instability. They proposed that the concentric evtor muscle response is not enough to resist inversion and prevent ligament sprain (Kaminski and Hartsell 2002). They also highlighted the importance of eccentric invertor muscle response in order to control the later displacement of the ankle during activities (Hertel 2000). Another study reported a greater strength deficit in more proximal muscles of the involved leg, mainly in the hip abductors, when compared with the uninvolved leg in 23 subjects with CAI (Friel et al. 2006).

A variety of methods have been used to assess ankle muscles in patients with a history of ankle sprain. Weakness in peroneal muscles was reported early by Bosien and his colleagues (1955). They used manual muscle tests to investigate the deficit among 133

participants with ankle sprains. However, this method is considered highly subjective and lacks accuracy. Additionally it does not represent the dynamic nature of ankle movement. Isokinetic dynamometry provides a better assessment and is defined as an electromechanical tool that can provide objective values of an isokinetic muscle action for joints (Nitschke 1992). It has been used widely with different movement directions and contraction modes and also a variety of speeds. Therefore, the variety in methods may explain the inconsistency in the results among the studies related to strength in individuals with CAI using the isokinetic dynamometer. Additionally, there was the variety in criteria for determining subjects with ankle instability, as described earlier. While some studies have revealed strength differences between healthy subjects and individuals with CAI (Tropp 1986; Wilkerson et al. 1997; Hartsell and Spaulding 1999; Willems et al. 2002; Pontaga 2004; Yildiz et al. 2003), other studies found no significant differences (Negahban et al. 2013; Fox et al. 2008; Munn et al. 2003; Kaminski et al. 1999; Bernier et al. 1997). However, the reliability of measuring ankle muscles using the isokinetic dynamometer method was reported in different studies and varied (ICC 0.69 to 0.98) (Kaminski et al. 1995; Amaral De Noronha and Borges 2004; Sekir et al. 2008).

In regard to the results of studies that investigated strength, Tropp (1986) was one of the early studies to confirm evtor weakness between injured and non-injured ankles in individuals with functional ankle instability using the isokinetic dynamometer method. This result was based on the measurement of the peak torque at an angular velocity of 30°/s and 120°/s. The mean difference between ankles was 2.8±2.6 Nm at 30°/s and

2.3±2.3 Nm at 120°/s ($P < 0.01$). However, no significant difference was found in dorsiflexion strengths between ankles.

Invertor and evertor muscle strength was found to be significantly lower for subjects with acute ankle sprain ($n = 15$) when matched with subjects with CAI symptoms ($n = 15$) (Wilkerson et al. 1997). Subjects in the acute group were recruited 6 to 14 days post injury and the reported activity of walking was normal without discomfort. The deficits were significantly greater in invertor than evertor muscles and at an angular velocity of 30°/s rather than 120°/s. However, pain-avoidance behaviour and discomfort are important, especially when dealing with patients with acute musculoskeletal injury resulting in poor performance, which was not discussed in this study. Consequently, this study may not add new information by just comparing subjects with CAI with patients following acute injury. In another study, forty-nine subjects with CAI were recruited, and the results showed that only the invertors of the affected ankles were significantly lower in strength than the unaffected ankles with a mean of 22.7 ± 8.4 and 26.6 ± 8.5 Nm, respectively, using the Cybex II dynamometer at 30°/s and 120°/s (angular velocity) (Ryan 1994). However, this work only investigated muscle strength during concentric movement. In a similar study the eccentric invertor muscles were found to be significant lower in strength by 12% for the injured ankle at 60°/s (angular velocity) and lower in strength by 13% at 120°/s (angular velocity) (Munn et al. 2003). The difference was also found in a study by Bernier (1997) in the FAI group-by-limb for the eccentric invertor but not for eccentric eversion. These results in these studies support the role of eccentric action of invertor muscles in the giving-way sensation associated with CAI. In

another study considering peak torque, evtor muscles in the CAI group compared to the control group showed deficits when they are worked eccentrically in response to 120°/s velocity movements (28.9 ± 5.3 Nm) (37.3 ± 5.8 Nm $p < 0.01$) (Yildiz et al. 2003). Another study found that the peak torque was significantly lower when body weight was used to normalise data and it suggested using it for a better comparison (Willems et al. 2002). In this study 87 subjects and 174 ankles were recruited and divided into four groups. The control group consisted of 53 subjects, the instability group consisted of 10 subjects who had a history of more than three lateral ankle sprains with a sensation of giving way, the third group consisted of 17 subjects (20 ankles) who had a history of one to three ankle sprains in the two years before the study without any instability complaints, and the fourth group consisted of 8 subjects (8 ankles) who had one to three ankle sprains three to five years before and no complaints. Significant differences were found between the instability group and the other groups for eversion strength/body weight for both concentric and eccentric conditions at 30°/s rather than 120°/s (angular velocity) when researchers normalised the value of peak torque against body weight. No significant differences were reported using peak torque, inversion-to-eversion strength ratio or eccentric-to-concentric strength ratio. The eccentric/concentric ratio was also reported in another study with no differences between control and CAI groups (Hartsell and Spaulding 1999). However this method was used before in subjects with knee problems who showed a low eccentric-to-concentric quadriceps strength ratio (Bennett and Stauber 1986). This may be because the torque generated by quadriceps muscles compared with invertor and evtor muscles is high enough to show ratio differences.

However, the lack of differences in muscle strength in some studies was explained by Kaminski et al. (1999), who concluded that these results may be because all subjects had strengthening exercises during their rehabilitation after their ankle sprain. Tropp (1986) also linked the positive concentric eversion weakness in his study to the insufficient rehabilitation that was provided to the subjects. Another study also found no significant difference (Fox et al. 2008). Fifteen of 20 subjects (75%) were involved in a structured rehabilitation programme before being recruited.

Leanderson et al. (1999) recruited 73 subjects with two weeks of acute ankle sprain to investigate the isokinetic eversion-inversion concentric muscle torques at 30°/s and 90°/s (angular velocity). No rehabilitation or strength exercises were executed by subjects during the study, but some subjects wore an ankle brace or compression bandage. Assessments were then followed up at four weeks and at 10 weeks post injury. Although the evertor muscles improved throughout the follow-up period, the deficits were still statistically different and fewer in the injured ankle than the uninjured ankle. However, the invertor muscle was improved at 10 weeks following initial assessment and was not statistically different from the uninjured ankle and was about 40% better than the evertor muscle. This imbalance between muscles could cause instability in the ankle during dynamic activity. Similarities in the imbalance between invertor and evertor muscles in injured ankles tested at 120°/s were found in other study. The peak torque value for invertors was better than for evertors, with a mean of 21 ± 7.05 and 18.09 ± 3.83 Nm (Amaral De Noronha and Borges 2004). In another study the evertor peak torque was significantly lower at all velocities (30°/s, 60°/s, 90°/s and 120°/s),

while the inverter muscles were not found to be different, except during a velocity of 30°/s in subjects after recurrent lateral sprain (4–8 weeks from the last sprain) (Pontaga 2004).

No consistency is evident in sample sizes, velocity, participants' characteristics and results among the studies that used participants with CAI, which results in a difficulty to provide strong support for the weakness in ankle muscles as a potential factor in those participants with CAI. However, there is a belief that alteration in response or decreased ability to generate fast muscle force during activity typically observed in most athletic movements is a possible cause of instability and increases the risk of re-sprains in individuals with CAI. This is explained by the stretch-shortening cycle (SSC) function in which eccentric and concentric muscle actions occur (Chmielewski et al. 2006). A fast SSC means that an athlete can use the most muscle-tendon units to move fast. This could be quantified by a countermovement or a deep vertical jump to produce a high jump in a short amount of time (Chmielewski et al. 2006). Therefore, strength present in relation to the functional performance during a countermovement or a deep vertical jump could provide a better indication of how muscles perform during functional activities than strength measured independently using isokinetic dynamometers.

3.5.1.4 Questionnaires (Self-reported functional assessment)

Self-reported assessments have been widely used by clinicians and researchers, because of the ease of interpretation and the inexpensiveness of these assessment tools. Additionally, these tools have been identified as valid and appropriate for assessing

various aspects of impairment in clinical settings (Eechaute et al. 2007; Ross et al. 2008; Donahue et al. 2011). There are a variety of self-report assessments used for the evaluation of foot and ankle conditions. Some of these instruments were designed for use among individuals with rheumatoid arthritis, such as the foot function index (Saag et al. 1996). This instrument has since been modified for use with patients with osteoarthritis and described as the ankle osteoarthritis scale (Domsic and Saltzman 1998). In other studies the American orthopedic foot and ankle scale (AOFAS) was used, mainly in relation to outcomes of foot and ankle surgery (Kitaoka et al. 1994). While these instruments have been reported to be reliable, valid and sensitive, these instruments were developed to be used mostly with older people or just to quantify dysfunction in activities of daily living. Therefore, researchers have suggested to use an instrument that is more population specific.

With respect to evaluating individuals with chronic ankle instability problems there are several self-assessment instruments that have been developed and used in research related to ankle instability. This includes the ankle instability instrument (AII), the Cumberland ankle instability tool (CAIT), the ankle joint functional assessment tool (AJFAT), the foot and ankle outcome score (FAOS), the foot and ankle disability index (FADI), the foot and ankle ability measure (FAAM), and the foot and ankle instability questionnaire (FAIQ) (Eechaute et al. 2007; Donahue et al. 2011).

The AII was designed specifically to identify patients with CAI; this instrument requires either yes/no responses (Docherty et al. 2006; Docherty et al. 2005; Caffrey et al. 2009;

Sharma et al. 2011). Participants were required to answer yes to questions which asked if an ankle had ever been sprained before and if a feeling of “giving way” was ever present. Participants also needed to answer yes to at least one of the questions from five through to nine, which asked if instability was felt while walking on a flat surface, while walking on an uneven surface, during recreational or sports activity, while going up stairs, or while coming down stairs (Docherty et al. 2006). Test–retest reliability ranged from 0.70 (SEM = 0.28) to 0.98 (SEM = 0.06) for the individual items and 0.95 (SEM = 1.85) for the instrument overall (Docherty et al. 2006). Another study used a Likert-type scale with a response score range to include participants into or exclude them from the CAI group. This questionnaire assessment provides information about activities of daily living and sports tasks.

The CAIT consists of nine items, and each item is assigned a point value ranging from zero to five with a total score of 30. Researchers used the CAIT to identify patients with CAI who scored 24 or less (Rosen et al. 2013; Dundas et al. 2014; Doherty et al. 2015C) Another study used a score of less than or equal to 25 to distinguish the CAI group (Wright et al. 2014). This score was higher in another study (Hiller et al. 2006). The authors in this study used a score of 27 to identify subjects with CAI.

The FADI was described early in 1999 and has two modules: the activities of daily living and the sports module designed to assess functions related to sports activities (Martin et al. 1999). This instrument includes 34 items divided into three subscales: the activities of daily living (ADL) contains 22 activity-related items, the sports subscale

contained eight items, and the pain scale related to the foot and ankle numbered four. Each item can be scored on a four-point scale (from 0 to 4). Hale and Hertel (2005) found that the FADI and FADI sport are sensitive enough to identify functional limitation within the active population. While the FADI was designed to assess subjects with foot and ankle problems and was not designed to mainly quantify dysfunction related to ankle instability, the authors in this study reported moderate to good reliability over a six-week period, as well as the ability to measure the change during rehabilitation programmes, and the ability to distinguish between individuals with chronic ankle instability and healthy individuals. The FADI was then used as an inclusion criterion to identify participants for the chronic ankle instability group. Cut-off scores have been used in some studies to identify subjects with CAI with a score of $\leq 90\%$ on the FADI and $\leq 75\%$ on the FADI sport (Mckeon and Hertel 2008a; Mckeon and Hertel 2008b). In another study CAI subjects scored 88.7% for FADI and 74.8% for FADI sport (Hubbard et al. 2007b). Similarly, Brown et al. (2008) have reported mechanical instability group means of 89.1% (FADI) and 76.6% (FADI Sport) and functional instability group means of 94.2% (FADI) and 81.5% (FADI Sport). The scores were higher in other study, with average scores of 92.9% for FADI and 84.2% for FADI sport (Marshall et al. 2009). Similar scores were reported by Wikstrom et al. (2009) with mean scores of 95.2% for FADI and 92.9% for the FADI sport.

Similar results were reported in another study investigating the ability of FADI and FADI sport to discriminate between groups (Wikstrom et al. 2012). The FADI and FADI sport in Wikstrom's study have shown to have a specificity of 0.79 to 0.81 for

identifying ankle instability. The FAAM instrument is identical to the FADI except for the “sleeping” item and four “pain-related” items found in FADI. The reliability for this instrument had an ICC of 0.89 for activities of daily living and an ICC of 0.87 for the sports scale (Martin et al. 2005). Eechaute et al.’s 2007 study found that the FADI and FAAM were more appropriate for evaluating functional ability in subjects with ankle instability. This is because some tools such as FAOS do not contain important items related to ankle instability, such as feeling the ankle giving way and repeated ankle sprains. They also do not contain activities that may cause difficulty for people with a history of ankle sprain, such as walking or running on uneven ground.

Ross et al. (2008) used the Ankle Joint Functional Assessment Tool (AJFAT) in their study to distinguish subjects with functional instability (FI) from healthy subjects. They found that subjects who scored 26 or higher out of 48 were considered to have FI. In another study a score greater than 22 out of 48 points on the AJFAT was used to identify the group with ankle instability (Wikstrom et al. 2009). The AJFAT includes 12 items that rate pain, swelling and strength of the ankle. Function involves the ability to walk on uneven surfaces, overall feeling of stability, ability to descend stairs, ability to jog, ability to change direction when running, overall activity level, ability to sense a “rollover” event, ability to respond to a “rollover” event and ability to return to activity after a “rollover” event. Each item can be scored on a four-point scale (from 0 to 4). The authors in this study calculated sensitivity and specificity values to calculate receiver operating characteristic (ROC) curves. Sensitivity in this study was defined as the probability that individuals in the FI group were correctly identified as having ankle

instability. Specificity is defined as the probability that individuals in the healthy group were correctly identified as healthy. Also, positive and negative scores for each item were used to calculate ROC curves. Additionally, Ross et al. (2008) reported high test–retest reliability for AJFAT ($ICC_{2,1} = 0.94$ and standard error of measurement = 1.5 points). However, the AJFAT does not include items that are considered important, such as jumping activities. Although, the giving-way sensation and the recurrence of ankle sprains are the most important residual problems in individuals with ankle instability, the AJFAT, FADI and FAAM do not include an item referring to these problems.

Recently, researchers have developed instruments mainly for patients with chronic ankle instability and a test–retest reliability with an ICC of 0.84 (Eechaute et al. 2008). The CAIS instrument contains 14 items and consists of four subscales: impairments, a disability, participation and emotions. Each item can be scored on a five-point Likert scale, from five (best score) to zero points (worst score). The higher score means a higher degree of ankle stability. Subjects who scored 29 ($53.7\% \pm 12.6$) on the CAIS in this study were identified as having chronic ankle instability.

Another instrument was also designed for FAI: the identification of functional ankle instability (IdFAI) (Simon et al. 2012). The IdFAI has an excellent test–retest reliability with an ICC of .92 (Donahue et al. 2012). The IdFAI has 10 questions based on the CAIT and AII questionnaires divided into three factors (Docherty et al. 2006; Hiller et al. 2006). Factor 1 relates to a history of ankle sprain instability, factor 2 provides

information related to the initial ankle sprain, and factor 3 concerns instability during activities of daily living (Simon et al. 2014; Simon et al. 2012). A score of 10 was used to identify subject with FAI (Simon et al. 2012).

3.5.1.5 Ankle-dorsiflexion range of motion (ROM) assessment

A limitation of ROM is often seen following ankle sprain and mostly in dorsiflexion (DF) (Hubbard and Hertel 2006; Collins et al. 2004). This restriction in DF was reported to be due to tightness of gastrocnemius and soleus muscles or restriction in accessory motions (Denegar and Miller III 2002). It can also be restricted by a limitation in the normal posterior glide of the talus (Hubbard and Hertel 2006). The anterior translation of the distal fibula may also cause restriction in the ROM in patients following ankle injury (Hubbard and Hertel 2008). Limitation to this movement has also been identified as a contributing factor in individuals with chronic ankle instability (Morrison and Kaminski 2007; Collins et al. 2004; Hertel 2000). This contributes to abnormal movement during physical activity, which may stress the tissues around the ankle to produce a compensatory movement in order to maintain the function. Consequently, this will put the individual at risk of re-injury (Hubbard and Hertel 2006). The link between dorsiflexion and ankle sprain is further supported by a systematic review by De Noronha et al. (2006).

In clinical settings and research there are a number of techniques used to measure the ROM of dorsiflexion related to ankle problems, including the use of goniometers and inclinometers. However, most of these techniques rely on the examiner's technique

during the test. A weight-bearing lunge test (WBLT) has previously been used for the same purposes and was found to be highly reliable with an ICC of 0.99 (Bennell et al. 1998; Konor et al. 2012). This test is reported to be more accurate in presenting the actual ROM of dorsiflexion in more functional settings. Under this method the individual applies the knee-to-wall technique, in which the individual performs a weight-bearing lunge to place the ankle in maximal dorsiflexion. The individual places the foot on a tape measure, and the knee in a perpendicular position to the wall. The individual lunges forward until the knee touches the wall while the heel remains on the ground; then the distance from the great toe and the wall is measured.

WBLT was used to measure the relationship between dorsiflexion ROM and performance during a drop-landing task in subjects with CAI. A positive relationship was found with a value of 9.03 ± 2.33 cm for WBLT dorsiflexion ROM (Hoch et al. 2015). In another study positive relationships were found between values from the star excursion balance test (SEBT) with a value of 9.08 ± 2.46 cm for WBLT dorsiflexion ROM (Terada et al. 2014).

The WBLT was also shown to measure change after mobilisation intervention programmes and had the ability to distinguish between individuals with chronic ankle instability and healthy ones (Marrón-Gómez et al. 2015; Hoch et al. 2012a; Hoch et al. 2012b). A study by Hoch et al. (2012a) detected significantly less DF in CAI participants ($n=30$, mean \pm SD 10.73 ± 3.44 cm) compared with healthy subjects ($n=30$, mean \pm SD 12.47 ± 2.51 cm), using the WBLT. WBLT was used in another

study to investigate the effect of a two-week anterior-to-posterior ankle joint mobilisation on 12 subjects with CAI (Hoch et al. 2012b). Following joint mobilisation, the lunge distance increased by 1.4 cm from the baseline score (mean \pm SD 10.87 \pm 3.71).

3.5.1.6 Laxity methods of measurement

Standard radiography (X-ray) is usually performed after an acute ankle sprain to detect fractures or bony injury (Chan et al. 2011). Usually, patients with ankle sprain are X-rayed following clinical guidelines referred to as the Ottawa Ankle Rules. According to this guideline, X-raying is only recommended to those patients with 1) tenderness at medial or lateral malleolus, 2) tenderness at the base of the fifth metatarsal, 3) inability to fully bear weight full for four steps (Stiell et al. 1992). In case of CAI, laxity issues have been much debated in the literature in terms of their roles in identifying groups and the type of tools used. Researchers have attempted to identify laxity with more diagnostic accuracy by using different tools. Stress radiographs, MRI and ankle arthrometers (Lee et al. 2013; Brown et al. 2015) have shown great results in identifying the amount of ligament laxity. In a study by Hubbard et al. (2004) the stress X-ray and ankle arthrometer were used to record a significant mechanical laxity in 51 participants who reported a functional instability in a self-reported assessment. MRI sensitivity was assessed in studies of patients who received lateral ankle ligament surgical treatment. The result shows that MRI is a sensitive tool for detecting associated disorders in patients with chronic ankle instability (Trč et al. 2010; Kanamoto et al. 2014). However,

because of the high cost and time consumption, availability of these tools is limited. These tools are specifically used for research purposes and are of benefit mainly if surgical procedure was recommended to treat the ankle.

Ultrasound imaging has recently been used in research for patients with chronic ankle instability and described as dynamic ultrasound imaging (Hua et al. 2012; Lee et al. 2014). Ultrasound had a sensitivity of 97.7% and a specificity of 92.3% for ATFL injury when compared with arthroscopic results (Hua et al. 2012). Croy et al. (2012) also used this method to identify laxity among ankle sprain copers, subjects with chronic ankle instability and healthy subjects. The authors observed a greater length of the ATFL in both copers and chronic ankle instability groups. While this method is inexpensive, this tool is highly user dependent and is not available in most clinical settings.

Clinicians rely more on manual tests for assessing ankle ligament integrity in individuals with CAI, and they use the same tests that have been used following ankle sprain injury (Hertel 2000; Denegar and Miller III 2002). The anterior drawer test mainly assesses ATFL by evaluating the anterior displacement and uses the talar tilt test to evaluate the CFL. The anterior drawer test was found to be reliable with an ICC value of 0.88 for intra-tester reliability and an ICC value of 0.6 for inter-tester reliability (Parasher et al. 2012). However, the amount of laxity is the subject of disagreement. Therefore, clinicians compare the injured ankle with the healthy one.

A positive relationship was found between the stress ultrasound and manual anterior drawer test with a correlation coefficient value of 0.58 ($p = 0.001$). Also, there was a positive relationship between stress ultrasound and stress radiography with a correlation coefficient value of 0.73 ($p = 0.001$) (Lee et al. 2014). This indicated that the manual stress test is similar to other tests in examining ankle laxity. However, the ultrasound test provided a more accurate result.

3.6 Predictors of recovery following ankle sprain

With the large percentage of people reporting recurrent ankle sprains resulting in the development of CAI, researchers have tried to determine predictors of recovery following initial ankle sprain. Impaired in proprioception, neuromuscular control, postural control, ROM, and strength have shown to be present following ankle sprain. Therefore, it is important to investigate these deficits to predict recovery. A combination of ROM limitation and swelling measured during the 72-hour after injury were able to provide reasonably accurate for time to return to sport participation (± 4 days, $P = 0.95$) (Wilson and Gansneder 2000).

O'Connor et al. (2013) followed up with 85 patients with acute ankle sprain from Accident and Emergency department and sports injury clinic to investigate potential predictors including: age, BMI, gender, injury mechanism, previous injury, weight-bearing status, medial joint line pain, pain during weight-bearing dorsiflexion and lateral hop test. Recovery was determined from measures of subjective ankle function at

short (4 weeks) and medium term (4 months) follow ups. Multivariate stepwise linear regression analyses were undertaken to evaluate the association between the aforementioned variables and functional recovery. Authors reported that age, weight bearing status and injury grade collected at the first week after injury were able to predict functional status at week 4 using Karlesson score. They also found that pain on medial joint and during weight bearing ankle dorsi-flexion at 4 weeks explained the function outcome at 4 months. However, there were limitations to this study, level of physical activity were not reported. Van Rijn et al. (2008) in a systemic review found that sporting activity at a high level was a prognostic factor for residual symptoms following ankle sprain. Level of sporting activity is important not only to assess individual who at high risk of developing symptoms of CAI, but also to develop optimal rehabilitation program.

More recently, Doherty et al (2016) recruited 82 subjects to investigate predictors of recovery following initial ankle sprain at three time points (2 weeks, 6 months and 12 months). Several outcomes were measured and divided into 3 categories: 1) Questionnaires (CAIT, FAMMadl and FAMMsport), 2) Biomechanical (kinematic and kinetic outcomes) assessed by Codamotion setup and force plate, 3) Performance (dorsiflexion ROM and reach distance during Star Excursion Balance Test). Subjects were identified as CAI and copers based on CAIT result at the last time point (12 months). Data collected at the 2-week and 6-month time points and then used to evaluate which of them contribute to the final results at the 12-month. Authors in this study found that inability to perform single leg drop landing and vertical jump at 2-

week time point was predictor of CAI at the 12-month. Level of physical activity was also not reported in this study. Further research to investigate predictors of recovery following initial ankle sprain is warranted and could potentially provide clinicians with more appropriate information about an individual's recovery. Consequently, it would help in the development of more appropriate treatment aiming at reducing the risk of recurrent ankle sprain.

3.7 Summary

The literature reviewed supported the impact that CAI has on physical performance. While much work has been done to investigate functional performance, these studies have failed to provide consistent information to identify individuals who are more likely to progress to CAI. More evidence exists, however, for distinguishing differences between individuals with CAI and healthy subjects in functional assessments addressing the physical performance by utilising planned movements. Within sport, activity is often not a pre-programmed or planned task, which has not been considered in most research related to CAI. Recently researchers have begun to consider improving their work by using unanticipated tasks to improve the validity and to minimise the learning effect. However, some of these tools used are still expensive and rely on the examiner's technique, which could be a major factor limiting the use of these methods. The challenge for researchers is to develop simple methodologies and valid approaches to reflect the nature of sport, which may provide important information to improve understanding and treatment related to CAI.

Additionally, EMG has been used extensively to investigate motor control in individuals with CAI. Alteration in this system was proposed to cause muscles to be activated in an inappropriate manner (i.e. timing or amplitudes), interfering with foot positioning at touch-down, which may increase the risk of another ankle sprain. Research related to muscle activity has focused on recording the latency of peroneal muscles as a defence mechanism during inversion. Different variables have been used, including onset time, maximum amplitude, reflex latency and time to maximum amplitude. These studies also have failed to provide consistent results. These inconsistencies may exist because they have been performed mainly in controlled situations not challenging enough to present real injury mechanisms (e.g. running, cutting, and landing) and also because the differences in criteria used to identify individuals with ankle instability. Researchers have mostly focused on detecting the first EMG signal. However, the first onset of EMG may not be as important an indicator to protect against ankle sprain. Another variable such as time-to-peak could indicate how the muscles are appropriately activated to counteract the inversion action. Further investigation of motor control during unanticipated tasks in those with CAI is warranted and could potentially provide researchers with clear insight related to impaired function in CAI patients.

CHAPTER 4 : AIMS AND HYPOTHESES

Based on the literature reviewed, there is evidence to suggest that using unanticipated conditions in addition to more traditional functional performance tests could provide important performance outcomes. This could potentially provide researchers with a clear insight related to impaired function, especially related to decision-making time. This may also help in reducing the incidence of recurrence by the development of more appropriate treatment and rehabilitation protocols. However, this approach to functional performance testing has not been the subject of much research for subjects with a history of ankle sprain. Therefore, there is a need to investigate these subjects under unanticipated conditions.

The main objective of this thesis was to explore the functional performance and the neuromuscular control of subjects with a history of ankle sprain under unanticipated conditions. This study therefore involves two main hypotheses: Firstly, the knowledge gained by using this condition in functional assessment for subjects with a history of ankle sprain would provide more appropriate information about an individual's recovery than under conditions allowing preplanning. Secondly, the deficiency in neuromuscular control for subjects with a history of ankle sprain would be clearer under conditions requiring decision-making. Consequently, it would help in the development of more appropriate treatment aiming at reducing the risk of recurrent ankle sprain. In order to achieve the main objective and the main hypotheses this thesis includes three

parts: preliminary studies, cross-sectional study and longitudinal study. Specific aims for each study are presented below.

I. Preliminary studies

These preliminary studies aimed to determine the validity and the reliability of the vector mat system developed at the School of Healthcare Sciences at Cardiff University. Reliability values was considered acceptable if ICC value is > 0.6 (Portney and Watkins 2009). Also, this system was used in a pilot study to determine whether there was a difference between individuals with previous ankle sprain and those who were healthy subjects. More details about the aims of each study are provided in Chapter 5 (preliminary studies).

II. Cross-sectional study

The specific aims of this study were:

1. To compare individuals with a history of ankle sprain with healthy individuals using measures of functional performance, muscle activity, self-reported assessment, ankle-dorsiflexion ROM and muscle strength.
2. To determine optimal functional performance testing in individuals with a history of ankle sprain.

Hypotheses:

H1: There will be a significant difference between groups in functional performance parameters including: Decision Making Time (DMT), Task Time (TT), jump height

(JH) and contact time (CT).

H2: There will be a significant difference between groups in time to peak (TTP) of lower leg muscles in unanticipated cutting manoeuvre as measured by EMG.

H3: There will be a significant difference between groups in objective testing including: self-reported functional assessment, ankle-dorsiflexion ROM and muscle strength.

H4: There will be a significant difference between ankles within subject with history of ankle sprain in objective testing including: jump height, muscle strength, and ankle-dorsiflexion ROM.

III. Longitudinal study

The specific aims of this study were:

1. To monitor the changes of functional performance, muscle activity, self-reported assessment, ankle-dorsiflexion ROM and muscle strength, in subjects with acute ankle sprain over a six-month period.
2. To identify predictors of functional recovery.

Hypotheses:

H1: Subjects with acute ankle sprain would have significant changes in functional performance parameters including: Decision Making Time (DMT), Task Time (TT), jump height (JH) and contact time (CT) over a six-month period.

H2: Subjects with acute ankle sprain would have significant changes in time to peak (TTP) of lower leg muscles in unanticipated cutting manoeuvre as measured by EMG over a six-month period.

H3: Subjects with acute ankle sprain would have significant changes in objective testing including: self-reported functional assessment, ankle-dorsiflexion ROM and muscle strength over a six-month period.

CHAPTER 5 : PRELIMINARY STUDIES

5.1 Overview

As described in the literature review chapter, much work has been done investigating functional performance, yet these studies have failed to provide consistent information to predict which individuals are more likely to progress to CAI. However, some of the tools used in these studies are still expensive and rely on the examiner's technique, which could be a major factor limiting the use these methods. The challenge for researchers is to develop simple methods and valid approaches to reflect the nature of sport, which may provide important information to improve understanding and treatment related to CAI.

A new system (vector mat system) was developed in the School of Healthcare Sciences at Cardiff University to measure functional performance. The reliability and validity of this system was examined in collaboration with a group of MSc students from the School of Healthcare Sciences (Cardiff University) prior to the main study as part of their graduation projects. This chapter first provided details about the vector mat system, and then presented each study separately in full detail with the methods, results and discussion. Findings from this work would help to make decisions whether to include or exclude this system in the main study.

1. The reliability and validity of measuring jump height using the vector mat system in healthy subjects.
2. Reliability of measuring decision-making time and task time in cutting manoeuvres using the vector mat system in healthy subjects.
3. A pilot study to determine performance differences between healthy subjects and subjects with a self-reported history of ankle sprain using unanticipated and planned functional tests.

5.2 Ethical consideration

These studies were ethically approved by Cardiff University's School of Healthcare Research Ethics Sub-Committee in May 2012. All testing procedures were carried out in the Research Centre for Clinical Kinesiology (RCKK) laboratory, where access was restricted. Potential participants who met the inclusion criteria were given written information sheets before participating in the study. The participants volunteered to take part in these studies and they were free to withdraw at any time without giving any reasons whatsoever and were also allowed to discuss any concerns they might have with the researcher. A full explanation of the study procedure was provided and informed consent obtained from each subject. The anonymity of participants in any future publication of results was assured. All the participants' information collected during the studies was kept confidential and each participant was assigned a reference code. All information was kept secure in either a locked facility or a password-protected computer to which only those involved in the research would have access. The potential

severity of harm to both the researcher and participants was very low. However, there was a very minimal risk because a participant could have lost balance and fallen down during the study procedures.

5.3 Study 1: Reliability and validity of measuring jump height using the vector mat system in healthy subjects

5.3.1 Introduction

The vertical jump is another example for the FPTs that have been used to address the functional performance. This test has received widespread recognition as clinical test to evaluate performance and height is considered the most utilised parameter for the evaluation of the vertical jump. Force plates (FP) have been used to estimate the jump height by analysing the vertical ground reaction force (VRF) or flight time (FT), which allows the jump impulse to be calculated as well as the take-off velocity and power (Cordova and Armstrong 1996; Larkins and Snabb 1999; Linthorne 2001).

The video-based method (VID) has been used to measure the vertical difference between two body landmarks (García-López et al. 2005). Flight time has also been used using a contact mat (CM). The CM is considered a simple and reliable method to calculate jump height in the clinical setting (Enoksen et al. 2009; García-López et al. 2005; Aragón 2000), besides being portable and less expensive than VID or FP.

Numerous studies have shown the reliability and validity of the CM for determining jump height by comparing it against well-established methods such as FP (Enoksen et al. 2009; García-López et al. 2005). Although there are different results for height

between the CM and FP, the results of each method were consistent, which means they still could be used for a pre- and post-comparison. Enoksen et al. (2009) reported a 2.8 cm difference between the CM and FP during countermovement jumps (CMJs) and a 1.7 cm difference during a squat jump. The authors in this study showed that the contact mat was a valid and reliable instrument for measuring jumping. Another study by García-López et al. (2005) found strong correlation between the flight time off the contact mat and the force platform ($r=0.98$), with a 4 ms difference between the two methods in measuring the flight time. Based on a similar technique, a new CM called the vector mat system (VM) was developed (hardware and software). It was therefore necessary to verify the validity and reliability of this new equipment.

5.3.2 Aims

This study aimed to determine the reliability and the validity of the vector mat system that measures the vertical jump height via the flight time.

5.3.3 Hypotheses

H1: The vector mat system will demonstrate reliable scores for measuring the vertical jump height in healthy subjects.

H2: The vector mat will provide same reading of vertical jump height in healthy subjects as measured by the gold standard.

5.3.4 Methods

5.3.4.1 Subjects

Eighteen physically active subjects met the inclusion criteria and consented to participate in this study. The inclusion criteria were healthy subject without a previous a history of lower limb injuries within the last 12 months.

5.3.4.2 Instruments

I: Vector mat system

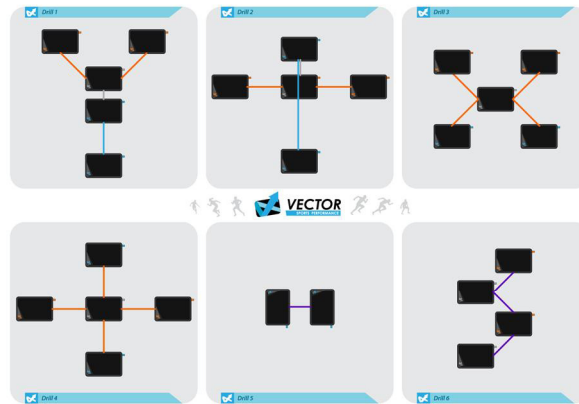
The vector mat system was developed in the School of Healthcare Sciences at Cardiff University. The system consists of five portable rubber mats with the added ability to be incorporated into a range of different configurations on the floor or mounted on walls. Each mat is 50 x 75 cm (long x wide) and covered by anti-slip rubber film (see Figure 5-1). The principle is based on the change in the force on pressure sensitive switches encased in the mats. When a force is applied to or removed from the mat, a small hardware system built into the mats allows them to communicate with the computer wirelessly. The software of the vector system was developed using Visual Basic for Applications (VBA) and can be used to control and record the information to a data file. Different protocol parameters can be collected by the software, such as total performance task time (TT), decision-making time (DMT), number of correct versus incorrect decisions and flight times (FT). At the end of the test, a graph representing these values is generated so that the evaluator can obtain immediate feedback. The system measures TT, DMT and FT in seconds.

Figure 5-1: The vector mat system: A) Rubber mats, B) Different configurations, c) Computer, D) Receiver

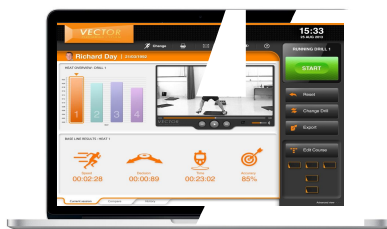
A



B



C



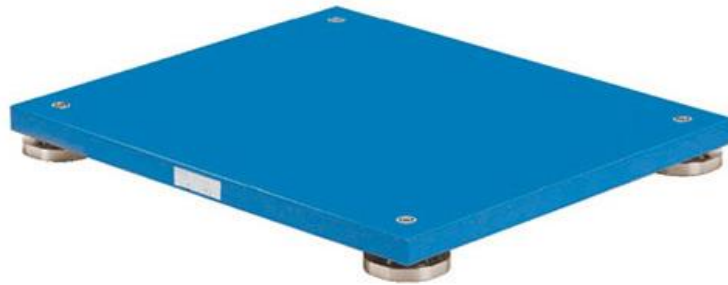
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II: Portable force platform (FP)

A Kistler portable force platform, which was 60 x 50 cm (long x wide) in size and 5 cm high from the floor (see Figure 5-2). The FP has piezoelectric or strain gauge transducers in each corner that allow it to calculate accurately the force applied to it (Linthorne 2001).

Figure 5-2: A Kistler portable force platform



III: Digital Video Camera

A Sony DCR-TRV19E camcorder equipped with a 2.5 inch liquid crystal display (LCD) and a Carl Zeiss Vario-Sonnar® lens with a digital-quality 800,000 pixel Advanced HAD CCD and 10x optical zoom/120x digital zoom.

IV: Computer (PC) with SiliconCOACH

This is software (version 6; supplied by SiliconCOACH Ltd) developed to analyse

movement by allowing the user to draw lines on still images between the anatomical markers so that the heights of the jumps can be measured accurately.

5.3.4.3 Procedures

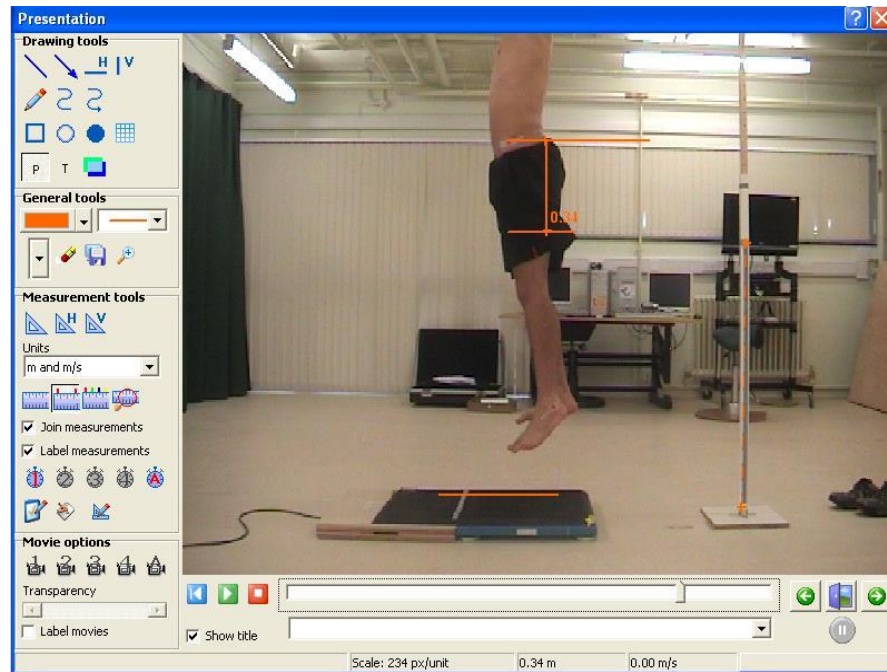
In this study the mat of the vector system was placed on to the portable force plate (FP). The purpose was to record the flight time (FT) on both pieces of equipment simultaneously. The FP was set at a sampling rate of 200 Hz, a force of 0.1 N and was zeroed with the contact mat placed on the FP. Therefore, measurements were not influenced by the weight of the contact mat. Jump height was also measured from the video recordings using SiliconCOACH 2D kinematic software (SC); a video camera was positioned laterally to the participant at a distance of 3.15 m away. One single marker was placed over the anterior superior iliac spine (ASIS) (Moir 2008) and a 1 m reference stick was placed behind the subject and used as a reference measurement in SiliconCOACH.

Each subject performed three CMJs from a portable force plate and a contact mat. Subjects were instructed to perform a CMJ with initial downward movement by flexing at the knees and hip and then rapidly extending the knees and hips with the arms thrust forward and upwards again to jump vertically as high as possible and descend on the same point. Subjects were also reminded of the importance of remaining on the mat until given the “stand off” command. Three practice trials were allowed, followed by three assessment trials with 30 s rest intervals between each trial. Jump height was then

calculated from flight time data collected using both the vector mat system (VM) and the force plate (FP) (Kistler Instruments, Inc., Amherst, NY), associated software for CM and purpose-written analysis programs in MATLAB 6.0 software (The Mathworks Inc., Natick, MA, USA) for FP. Flight time values (in seconds) were then converted to height values (in metres) using the following equation by Asmussen and Bonde-Petersen (1974): $\text{Height} = (g \times \text{ft}^2) / 8$, where the ft is flight time of the jump (s) and g is the acceleration of gravity (9.81 m/s^2). The height value is then converted to centimetres (cm) for analysis.

Simultaneously, the digital video data for each trial were downloaded and imported into SiliconCOACH software to measure the displacement of the ASIS marker following the subject's vertical jump. Systematic steps were used to measure the vertical jump height using SiliconCOACH, including the process of setting up the 1 m distance using the reference stick, which was placed behind the subject. This helped the software to measure the vertical jump height accurately. The process also included marking the ASIS points at the lower level when the subject was standing and at the higher point when the subject jumped. The SiliconCOACH then automatically measured the distance between the lower and higher marked points as shown in Figure 5-3.

Figure 5-3: Height jump measurement using SiliconCOACH software (Preliminary studies – study 1)



5.3.4.4 Statistics

Prior to statistical analysis, the normality of the data was examined. A repeated measures analysis of variance (ANOVA) was used to evaluate whether there was any variability within subjects' scores. The intraclass correlation coefficient (ICC) and Bland and Altman plot were used to examine the reliability of the vector mat. ICC was interpreted as follows: less than 0.20 = slight reliability, 0.21–0.40 = fair reliability, 0.41–0.60 = moderate reliability, 0.61–0.80 = substantial reliability and 0.81–1.00 = excellent reliability (Landis and Koch 1977). Reliability values was considered acceptable if ICC value is > 0.6 (Portney and Watkins 2009). To evaluate the validity, the correlation between VM, FP and SC for measuring vertical jump height was

examined using the Pearson correlation test. The agreement between the two systems was examined using the Bland and Altman plot. A repeated measures ANOVA was also used to evaluate whether there were any differences between instruments. The significance level (p value) was set at 0.05. All data were analysed using SPSS for Windows (version 16.0; SPSS Inc, Chicago, IL).

5.3.5 Results

Eighteen subjects, 2 females and 16 males, met the criteria and were recruited in this study. The mean age, height, and weight were 26.5 ± 4.8 years, 171.67 ± 8.2 cm, and 72.16 ± 15.8 kg as illustrated in Table 5-1. Using three successful trials, the reliability within session was calculated and the mean of height of these trials was used for validity analysis.

Table 5-1: Descriptive statistics of participants in the vertical jump height measures (Preliminary studies – study 1)

	N	Minimum	Maximum	M \pm SD
Age (year)	18	19	36	26.5 ± 4.8
Height (cm)	18	150	180	171.67 ± 8.2
Weight (kg)	18	55	119	72.16 ± 15.8

cm = centimetre; **kg** = kilogram; **M \pm SD** = mean \pm standard deviation

5.3.5.1 Reliability

Repeated measures ANOVA showed no variability within subject's measurements, as demonstrated by F value for VM, $F = 0.84$, $p = 0.44$; FP, $F = 0.39$, $p = 0.67$; and SC, $F = 2.07$, $p = 0.14$. A high degree of consistency was demonstrated across three trials (Excellent reliability): ICC = 0.84, 0.88 and 0.87 for VM, FP and SC, respectively (see Table 5-2).

Table 5-2: Reliability results of vector mat (VM), force plate (FT) and SiliconCOACH (SC) for measuring vertical jump height (Preliminary studies – study 1)

Test:	ICC	95% CI		ANOVA
		Lower Bound	Upper Bound	
VM	0.84	0.69	0.93	$F = 0.84$ $p = 0.44$
FP	0.88	0.76	0.95	$F = 0.39$ $p = 0.67$
SC	0.87	0.74	0.94	$F = 2.07$ $p = 0.14$

5.3.5.2 Validity

Table 5-3 outlines the result of height in centimetres (cm) using FP, VM and SC. The result shows a significant difference in height between the three instruments ($F = 45.3$; $p = 0.001$). Post-hoc analysis revealed that there was no significant difference between FP and VM in measuring height, with only a 2.5 cm difference. This difference was significant between FP and SC, with 11.5 cm, and between VM and SC, with a 14 cm difference.

Table 5-3: Comparison between the vector mat system (VM), force plate (FT) and SiliconCOACH (SC) for measuring vertical jump height (Preliminary studies – study 1)

	FP M±SD	VM M±SD	SC M±SD	ANOVA	Bonferroni
Height (cm)	24.4±4.5	21.9±4.5	35.9±5	F = 45.3 p = 0.001*	FP>VM p = 0.35 SC>FP p = 0.001* SC>VM p = 0.001*

ANOVA= analysis of variance; VM= Vector mat; FP= force plate; SC= SiliconCOACH; cm= centimetre; * Denotes significant at p<0.05

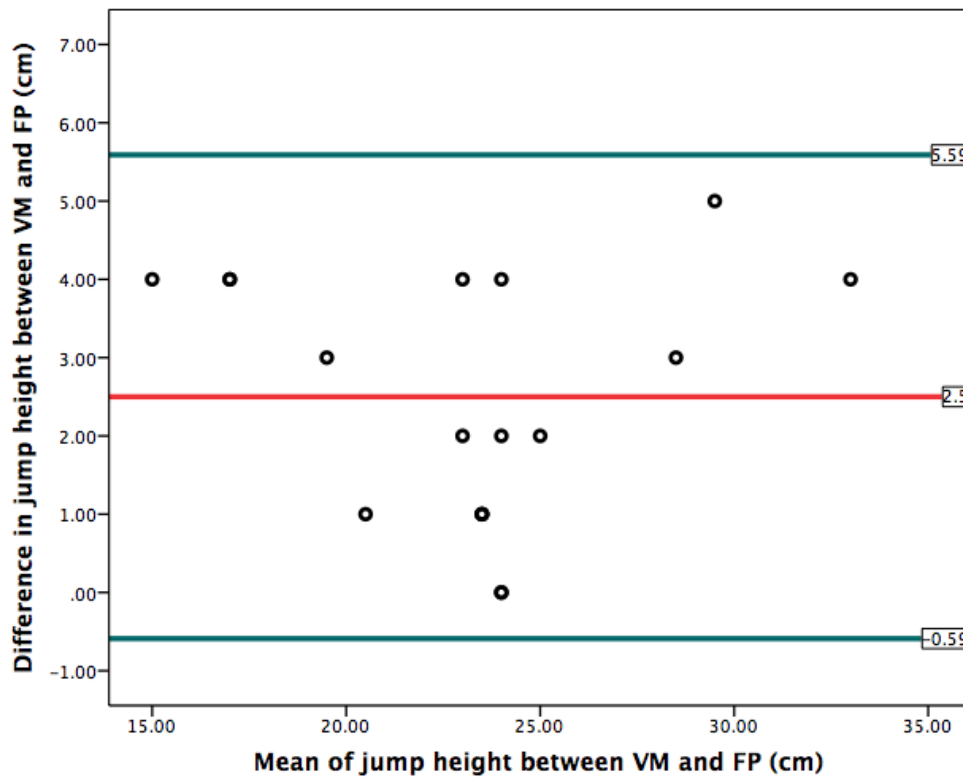
The Pearson correlation coefficients (r) test shows that there is a significant correlation between VM and FP (r = 0.939; p = 0.001) and between VM and SC (r = 0.847; p = 0.001) see Table 5-4. This is an excellent indication of criterion validity. Agreement between tools was graphically presented with Bland and Altman plot in Figure 5-4. The mean difference between VM and FP is 2.5 cm with a standard deviation of 1.58 cm. The lower limit of the 95% CI was -0.59 and the upper limit was +5.59. There is no systematic bias. All subjects' recordings fall between 95% CI limits of agreement.

Table 5-4: Correlation between the vector mat system (VM), force plate (FT) and SiliconCOACH (SC) for measuring vertical jump height (Preliminary studies – study 1)

Vertical jump height	r	Sig
VM Vs. FP	0.939	.001*
VM Vs. SC	0.847	.001*

r= Person correlation coefficients; VM= Vector mat; FP= force plate; SC= SiliconCOACH; * Denotes significant at p<0.05

Figure 5-4: Bland and Altman plot showing the relationship between VM and FP in measuring vertical jump height (Preliminary studies – study 1)



5.3.6 Discussion

A high degree of consistency was demonstrated (Excellent reliability) (ICC = 0.85 for VM). The results also displayed a significant relationship ($r = 0.939$; $p = 0.001$) between VM and FP in measuring height. Agreement between the two tools was also graphically presented with Bland and Altman plots, which show good agreement. From this result it can be concluded that the VM is a simple, reliable and valid tool for

measuring jump height. However, the minimal difference appears not to be extensive enough to cause problems for clinical interpretation with either tool. The potential reason for these discrepancies in the current study is that the force platform is a piezoelectric system; it is extremely sensitive to load. Considering that the flight time is defined as the time in the air between take-off and landing, the vector mat probably underestimates the height, because during the landing, at the instant when the foot touches the surface of the vector mat, the FP has already detected the event. Furthermore, the vector mat's rubber pad circuit switches on or off because of the signals recorded by the computer. The underestimation in the readings is possibly due to a data filtering program in the vector mat software that prevents the vector mat device from recording double switches on these pads' circuits. These findings are consistent with previous studies investigating the validity and reliability of similar contact mats (Enoksen et al. 2009; García-López et al. 2005). Although there were different results for height between CM and FP, the results with each method were consistent, which means they still could be used for pre- and post-comparison. Enoksen et al. (2009) reported a 2.8 cm difference between CM and FP during CMJs and a 1.7 cm difference during squat jumps. The authors in this study showed that the contact mat was a valid and reliable instrument for measuring jumping. Another study by García-López et al. (2005) found strong correlation between the flight time of the contact mat and the force platform ($r = 0.98$), with a 4 ms difference between the two methods measuring the flight time.

5.4 Study 2: Reliability of the vector mat system for measuring DMT and TT during cutting manoeuvres

5.4.1 Introduction

A variety of functional performance tests (FPT) have been developed to simulate sport activities, with the aim to assess when athletes can safely and efficiently return to their previous functional level (Munn et al. 2002; Caffrey et al. 2009; Wikstrom et al. 2009; Sharma et al. 2011). These tests combine multiple components, such as muscular strength, neuromuscular coordination, and stability, which could be affected following injury (Hertel 2002).

The majority of FPT tests used to date include various functional activities such as hopping, running and changing direction. However, there is some inconsistency in the literature regarding their ability to stress the ankle joint (Docherty et al. 2005; Caffrey et al. 2009; Sharma et al. 2011). Furthermore, these tests tend to be planned movement tasks, where the individual is not required to respond to a stimulus or command, which would be more typical of sporting activity (Caffrey et al. 2009; Wikstrom et al. 2009). Some researchers have started using unanticipated tasks to improve validity and to minimise the learning effect (Gabbett et al. 2008; Young et al. 2002). Incorporating this type of task into functional tests related to the ankle joint may provide more appropriate information about an individual's ability to cope with returning to sporting activity. The challenge for researchers is to develop simple methods and valid approaches to reflect the nature of sport, which may provide important information to improve understanding

and treatment related to CAI.

Numerous studies have investigated the reliability of this task (Veale et al. 2010; Sheppard et al. 2006; Gabbett et al. 2008). The participants in these studies were required to respond to movements by a human tester who performed one of four possible scenarios. DMT was identified within ± 5 ms for each trial using a high-speed video camera and defined as the time difference between the first definitive foot contact initiating the movement of the investigator in the final direction he moved his body and the first definitive foot contact initiating the response of the player. Sheppard et al. (2006) found that the functional test under unanticipated conditions in this study was reliable with the ICC value of 0.87 over the two testing sessions. A similar result was reported by Gabbett et al. (2008) with an ICC of 0.95. Veale (2010) reported a strong correlation ($r = 0.91$) between the mean results of two testing sessions. However, a limitation of this method is that it relies on the examiner's technique, as it is difficult to standardise this technique throughout the study. In addition, this method will be difficult to apply in another study with similar examiner's movements, which may give different results.

5.4.2 Aims

Therefore, the current study aims to investigate the reliability of functional scores using new functional tool (vector mat system): a means of measuring unanticipated functional test. Unanticipated component to this study was a cutting movement based on an

auditory cue.

5.4.3 Hypotheses

H1: The vector mat system will demonstrate reliable scores within day to measure DMT and TT during unanticipated functional test.

H2: The vector mat system will demonstrate reliable scores between days to measure DMT and TT during unanticipated functional test.

5.4.4 Methods

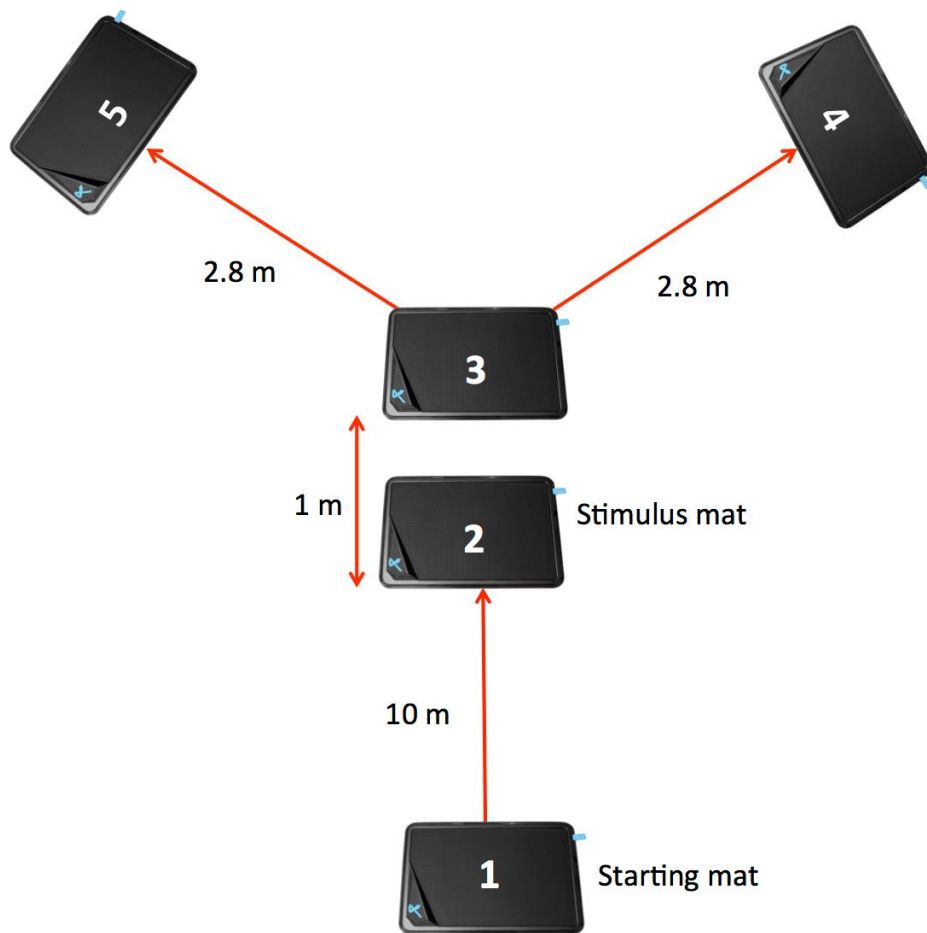
5.4.4.1 Subjects

Twenty-one physically active participants, 2 females and 19 males, met the inclusion criteria and consented to participate in this study. The inclusion criteria were healthy subjects without a history of lower limb injuries in 12 months.

5.4.4.2 Procedures

Subjects performed a cutting manoeuvre in response to an auditory command and then repeated it for a minimum of 1 day to maximum 10 days. The vector mats can be placed in any format, but, for the purpose of this study, it was set up as illustrated in Figure 5-5 with station 4 and 5 set at a 45° angle to station 3. The dimensions of this layout were determined by pilot trials prior to data collection. The distance between mat 2 and 3 was set at 1 m to allow the participants to react without missing the trigger mat.

Figure 5-5: The layout of the vector mats system used in the preliminary studies - study 2



Once the stimulus mat (2) was triggered, a random sequence of auditory cues with two decision options was displayed by speakers to precede a 45° cutting manoeuvre on the right or left side. The subject was instructed to respond as quickly as possible by changing direction and sprinting to the appropriate mat as commanded by the stimulus (right or left). All trials were performed on a 10 m runway at a standardised running speed of between 4 and 5.5 m/s; this was achieved by running with the researcher three times over the length of the test. Each subject was given two minutes to warm up on an exercise bike. Decision time was defined as the time from the moment the subject left station 2 until the moment the subject left station 3. The task time was defined from when the subject stepped on station 2 until the subject stepped on station 4 or 5.

5.4.4.3 Statistics

A repeated measures analysis of variance (ANOVA) was used to evaluate whether there was any variability within subjects' scores (in both test sessions day 1 and day 2). The intraclass correlation coefficient (ICC) and the standard error of measurement (SEM) were used to examine the reliability of functional scores using the vector mat system. ICC was interpreted as follows: less than 0.20 = slight reliability, 0.21–0.40 = fair reliability, 0.41–0.60 = moderate reliability, 0.61–0.80 = substantial reliability and 0.81–1.00 = excellent reliability (Landis and Koch 1977). Reliability values was considered acceptable if ICC value is > 0.6 (Portney and Watkins 2009).

Variability between both sessions (variation between day 1 and day 2) was calculated by means of the ICC and the SEM. The level of significance chosen for the statistical

analysis was $p < 0.05$. All data were analysed using SPSS for Windows (version 16.0; SPSS Inc, Chicago, IL).

5.4.5 Results

Twenty-one subjects, 2 females and 19 males, met the criteria and were recruited in this study. The mean age, height, and weight were 26.85 ± 5.24 years, 170.57 ± 6.11 cm, and 72.32 ± 12.27 kg, as illustrated in Table 5-5.

Table 5-5: Descriptive statistics of participants in the reliability study of the vector mat system (preliminary studies - study 2)

	N	Minimum	Maximum	M \pm SD
Age (year)	21	18	35	26.85 ± 5.2
Height (cm)	21	158	178	170.57 ± 6.11
Weight (kg)	21	55.20	93.50	72.32 ± 12.28

cm = centimetre; kg = kilogram; M \pm SD = mean \pm standard deviation

The best three trials of DMT in milliseconds (ms) for each subject were used to measure the reliability within day, and the mean was used to calculate the test–retest (between days) reliability. Tables 5-6 and 5-7 present the ICC with the 95% CI, ANOVA and SEM measuring DMT and TT. DMT within day 1 and day 2 has demonstrated excellent ICC values (0.814 and 0.73) and SEMs (70 ms and 83 ms) and a fair ICC value (390 ms) and SEM (110 ms) between days. The reliability of measurements of TT was

substantially lower with ICC values of 0.518 and 0.432 and SEMs of 360 ms and 360 ms within day 1 and day 2, and a poor ICC value (0.084) and SEM (390 ms) between days. No variability in DMT and TT between subjects' measurements was demonstrated by ANOVA results.

Table 5-6: Reliability results of the vector mat system for measuring DMT and TT (within day 1 and day 2) (preliminary studies - study 2)

Test:	Day 1				Day 2			
	ICC	95% CI	ANOVA	SEM	ICC	95% CI	ANOVA	SEM
DMT	0.814	0.660/0.913	F= 2.74 p= 0.10	70	0.73	0.528/0.867	F= 0.572 p= 0.57	83
TT	0.518	0.258 /0.743	F= 0.71 p= 0.93	360	0.432	0.163/0.684	F= 0.574 p= 0.56	360

ANOVA= repeated measures analysis of variance; ICC= the intraclass correlation coefficient; CI= the 95% Confidence Interval; DMT= Decision making time; TT= Task time; SEM= standard error of measurement * Denotes significant at p<0.05

Table 5-7: Reliability results of the vector mat system for measuring DMT and TT (between day 1 and day 2) (preliminary studies - study 2)

Test:	Day 1 vs Day 2 (Between Days)			
	ICC	95%CI	Sig	SEM
DMT	0.39	-0.041/0.697	0.037	110
TT	0.084	-0.351/0.490	0.355	390

ICC= the intraclass correlation coefficient; CI= the 95% Confidence Interval; DMT= Decision making time; TT= Task time; SEM= standard error of measurement * Denotes significant at p<0.05

Agreement between days was graphically presented with Bland and Altman plot in Figure 5-6. The mean difference between days for DMT is 11.9 ms with a standard deviation of 159.61 ms. The lower limit of the 95% CI was -300.93 and the upper limit was +324.73. There is no systematic bias, as the zero value was included in the 95%CI and the points were distributed evenly around the mean, with minimal random error. The plot showed two clear outliers. Agreement between days was graphically presented with Bland and Altman plot for TT in Figure 5-7. The mean difference between days for TT is 71.9 ms with a standard deviation of 548.77 ms. The lower limit of the 95% CI was -1003.68 and the upper limit was +1147.48. There is no systematic bias, as the zero value was included in the 95%CI and the points were distributed evenly around the mean.

Figure 5-6: Bland and Altman plot showing the relationship between day 1 and day 2 in measuring DMT (preliminary studies - study 2)

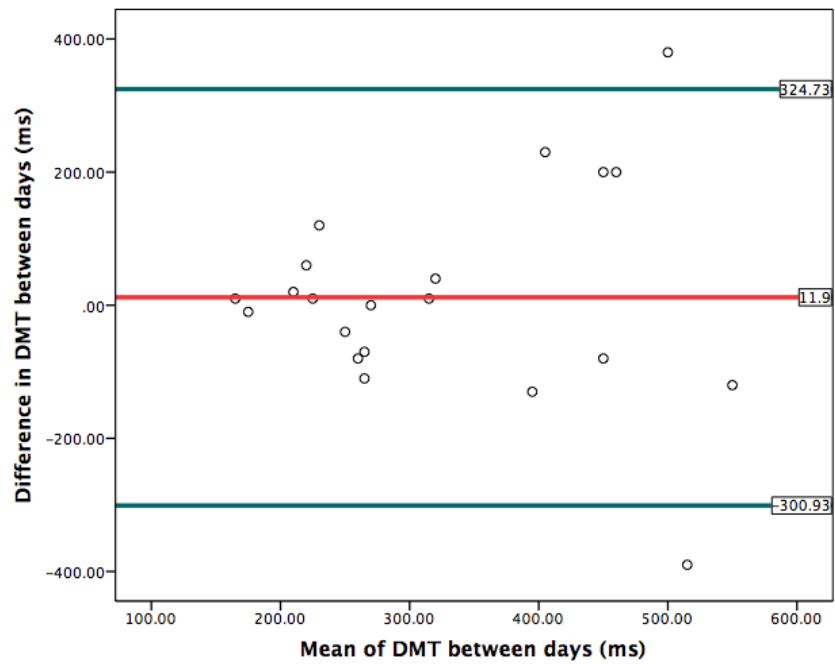
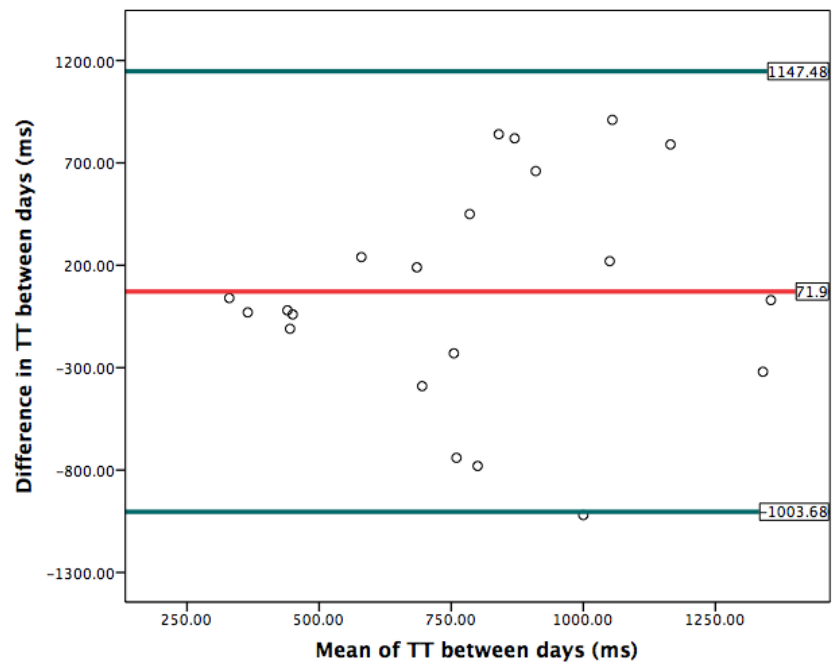


Figure 5-7: Bland and Altman plot showing the relationship between day 1 and day 2 in measuring TT (preliminary studies - study 2)



5.4.6 Discussion

Excellent ICC values (0.814 and 0.73) were reported in this study measuring DMT within day 1 and day 2 and a fair ICC value (0.39) was reported for between days. These results indicate that the vector mat system is a reliable tool for measuring DMT. The reliability of measurements of TT was substantially lower with ICC values of 0.518 and 0.432. The low reliability value in measuring TT was maybe because some of the subjects did not consistently continue running after the cutting movement to the end of the task, particularly if they were unsure of the accuracy of their decision. Additionally, variability was also noted in measuring DMT between days, which could be a result of a learning effect. This limitation will be avoided in the main study by increasing the number of practice trials to over three. However, the DMT was significantly associated with the TT ($r = 0.774$, $P = 0.00$), indicating that the DMT can reflect performance variance in the task time. Numerous studies have investigated the reliability of reactive agility testing using different instruments and methods to those used in the current study (Veale et al. 2010; Sheppard et al. 2006; Gabbett et al. 2008). Therefore, a comparison with these studies is difficult.

5.5 Study 3: A pilot study to determine performance differences between healthy subjects and subjects with a self-reported history of ankle sprain using unanticipated and planned functional tests.

5.5.1 Introduction

As mentioned earlier, there are a variety of functional performance tests (FPT) that have been developed to simulate sport activities to assess when athletes can safely and efficiently return to their previous functional level. However, there is some inconsistency in the literature regarding their ability to stress the ankle joint (Docherty et al. 2005; Caffrey et al. 2009; Sharma et al. 2011). Furthermore, these tests tend to be planned movement tasks, where the individual is not required to respond to a stimulus or command, which would be more typical of sporting activity (Caffrey et al. 2009; Wikstrom et al. 2009; Gabbett et al. 2008; Young et al. 2002). Incorporating unanticipated condition into functional tests related to the ankle joint may provide more appropriate information about an individual's ability to cope with returning to sporting activity.

The aim of this study, therefore, was to use the vector mat system in unanticipated functional test. The unanticipated component to this study was a cutting movement based on an auditory cue, and the premiss of the study was an investigation to discover whether there was a difference in the decision-making times of individuals with previous ankle injury and those of healthy subjects. Further comparisons were also made of task time using a standardised functional test, the T-drill, which is a valid

predictor of performance (Pauole et al. 2000) and not unanticipated test but a planned test.

5.5.2 Aims

The current study aims to investigate the difference in DMT between subjects with a history of ankle sprain (AS) and healthy individuals during unanticipated test using the vector mat system. Additionally, this study will investigate the relationship between performance in the unanticipated test and the T-drill test in both groups.

5.5.3 Hypotheses

H1: Subject with history of ankle sprain will demonstrate a significant difference in functional performance parameters compared with healthy subjects during unanticipated functional test.

H2: Subject with history of ankle sprain will demonstrate a significant difference in functional performance parameters compared with healthy subjects during planned functional test.

H3: There will be a significant relationship between unanticipated and planned functional tests in functional parameters in subjects with history of ankle sprain and healthy subjects.

5.5.4 Methods

5.5.4.1 Subjects

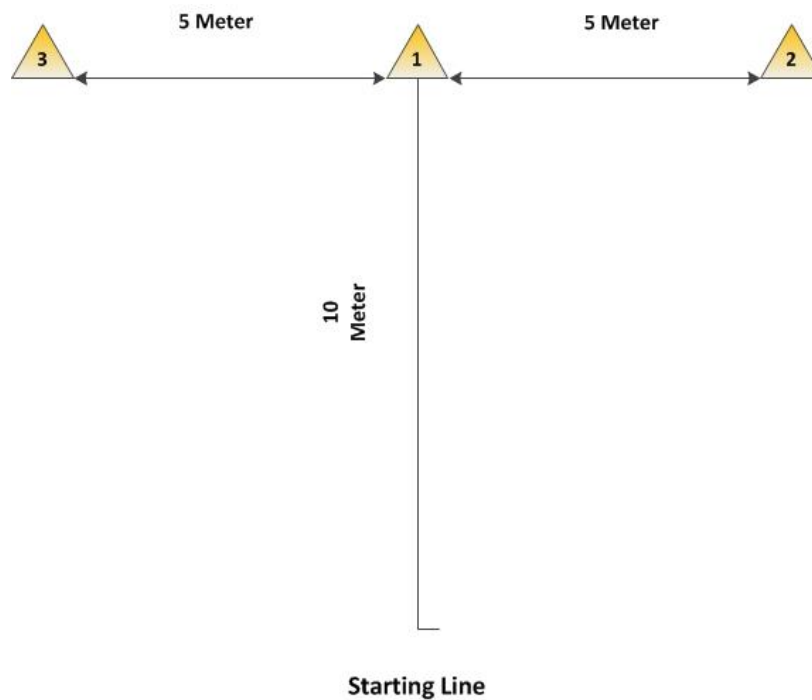
A group of 20 subjects, comprising 2 females and 18 males, 10 with a history of ankle sprain (AS) and 10 matched healthy individuals, met the inclusion criteria and consented to participate in this study. The inclusion criteria were healthy subjects without complaints of history of lower limbs injuries in the last year. The group with a history of ankle sprain complained of at least two sprains and give-way sensation during sporting activities.

5.5.4.2 Procedures

Twenty subjects first performed an identical cutting manoeuvre task as in the above reliability study using the vector mat system. Once the stimulus mat (2) was triggered, a random sequence of auditory cues with two decision options was played by speakers to precede a 45° cutting manoeuvre on the right or left side. The subject was instructed to respond as quickly as possible by changing direction and sprinting to the appropriate mat as commanded by the stimulus (right or left). All trials were performed on a 10 m runway at a standardised running speed of between 4 and 5.5 m/s; this was achieved by running with the researcher three times over the length of the test. Each subject was given two minutes to warm up on an exercise bike. Decision time was defined as the time from the moment the subject left station 2 until the moment the subject left station 3. The task time was defined from when the subject stepped on station 2 until the subject stepped on station 4 or 5.

Once the vector mat test was completed, the subject was allowed five minutes' rest; then the subject completed a T-drill test. For the T-drill test, the subject was shown the task once by the researcher and was asked to practice it once before the real test was performed. The subjects started on the starting line. On the command "Go" the subject was to run to cone 1 and touch the top of the cone, and then proceed using a side-stepping motion to cone two. Once cone 2 was touched, a sidestepping motion to cone 3 followed. The subject then took side steps back to cone 1, and then ran backwards to the starting line to finish the task. A stopwatch was used to record the time. The equipment was set up in a T shape as illustrated in Figure 5-8.

Figure 5-8: The layout of the T-drill test in the preliminary studies (study 3)



5.5.4.3 Statistics

Prior to statistical analysis, the normality of the data was examined. To investigate the difference in DM and TT between both groups, the independent t-test was used if the data were normally distributed and the Mann–Whitney test was used if they were not. To determine whether there was relationship between the reactive agility test and the T-drill test, a Pearson correlation test was used. The significance level (p value) was set at 0.05.

5.5.5 Results

Ten subjects with a history of ankle sprain and 10 matched healthy subjects were recruited. The mean age, height, and weight for each group were illustrated in Table 5-8. Each subject performed a cutting task in response to an auditory stimulus (measuring the DMT) and T-drill test (measuring TT). Data were found to be normally distributed for DMT and TT.

Table 5-8: Descriptive statistics of participants in the preliminary studies (study 3)

	Healthy Group M ± SD	Ankle Sprain (AS) M ± SD
Gender	9 Males, 1 Female	9 Males, 1 Female
Age (year)	27.5±4.76	25.8±5.08
Height (cm)	170±7.45	173±8.48
Weight (kg)	66±9.53	71.8±9.83

cm = centimetre; **kg** = kilogram; **M ± SD** = mean ± standard deviation

A significant difference in DMT was demonstrated between groups during the reactive agility test ($r = -2.3$; $p = 0.034$) (see Table 5-9). No significant difference in TT was demonstrated between groups during the T-drill test ($t = 1.96$ $p = 0.065$). The Pearson correlation value of $r = -0.312$ and $p = 0.18$ confirms that there was no significant correlation between unanticipated test and T-drill test in either group.

Table 5-9: Functional performance during reactive agility test and T-Drill test in the preliminary studies (study 3)

Outcome measure ↓	Healthy M ± SD	AS M ± SD	t
DMT (ms)	450 ± 77.32	525 ± 68.35	$t = -2.3, p = 0.034^*$
TT (s)	14.19 ± 0.86	13.22 ± 1.28	$t = 1.96, p = 0.065$

DMT = decision-making time; **TT** = task time; **ms** = milliseconds; **s** = second; **M±SD** = mean ± standard deviation; **t** = independent t-test. *Denotes significant at $p < 0.05$

5.5.6 Discussion

The difference in DMT was statistically significant ($p = 0.034$) between groups when performing the reactive agility test. The healthy subjects spent less time on a DMT (450 ms) compared to those subjects with a history of ankle sprain (525 ms), as demonstrated by the 75 ms delay in DMT in the AS group.

While the difference between groups was not significant during the T-drill test, a trend toward significance was noted with a 0.96 s difference, which could be due to the small number of subjects used in this study. However, the direction of the difference changed using the T-drill. The AS group was faster (TT = 13.22 s) than the healthy group (14.19

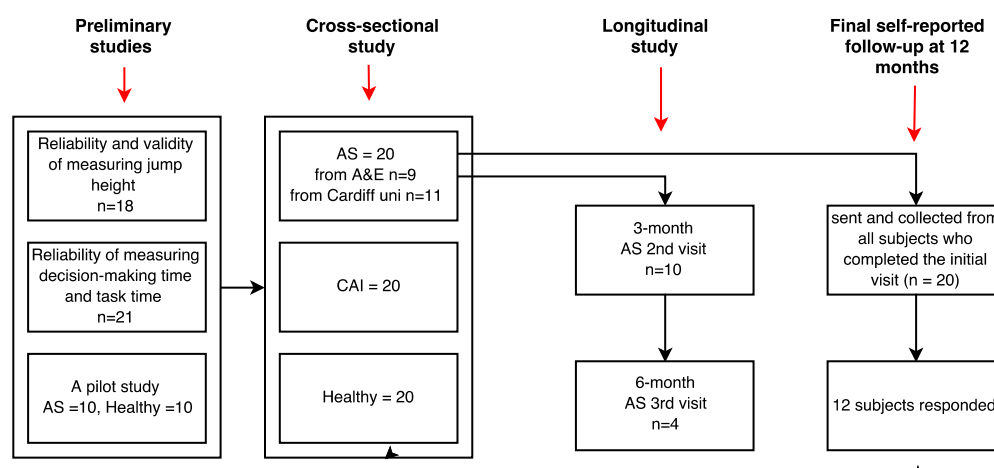
s) in performing the T-drill. The performance of the two tests in this study was not correlated, as demonstrated by $r = 0.173$, $p = 0.44$. This means that the performance of the subjects during the T-drill is not predicting the performance in the DMT. The above results support using the DMT to predict the performance of individuals with ankle sprain, and the traditional functional performance test, such as T-drill, should not be used alone.

CHAPTER 6 : METHODS

6.1 Study design

This was an observational study, to investigate individuals following acute ankle sprains (AS), individuals who complain about recurrent incidence of ankle sprains (chronic ankle instability) (CAI) and individuals with stable ankles who have never experienced a sprain (healthy). To compare individuals among these different groups at baseline, a cross-sectional study design was carried out. This design is commonly used to estimate the difference between groups on the outcomes investigated (De Vaus 2001).

The subjects in the ankle sprains group (AS) were also used to assess progress of those subjects over 6 months plus a final self-reported follow-up at 12 months. A longitudinal data collection was used to assess subjects during 3 visits (at 1 month, 3 months, 6 months post injury and a 12 month report). This progress of assessment for subjects who had initial ankle sprains could lead to better explanations and developing of better treatment guidelines for initial ankle sprains (see Figure 6-1).

Figure 6-1: Overview of the study

6.2 Ethical considerations

This study had already received ethical approval by Cardiff and Vale UHB as part of a larger ongoing series of investigations into changes following joint and soft tissue injury. Reference/project title: 10/OAE/4976: Arthritis Research UK Biomechanics and Bioengineering Centre Multi-project (REC Reference: 10/MRE09/29). At least one week was given for all potential subjects to review the information sheets and consider their participation before being contacted to discuss their involvement decision. During the session, the study protocol was verbally explained for each subject and opportunity for questions was provided, the subject then signed the consent forms. Subjects were informed that participation was voluntary and they could withdraw from the study at any time. However, subjects were reimbursed for reasonable travel expenses as needed.

6.3 Study sample

6.3.1 Study population

Physically active subjects were recruited equally into 3 groups, namely ankle sprain (AS), chronic ankle instability (CAI) and the healthy group. Subjects also were matched for marginal means in their demographic characteristics (such as gender, age, height and weight) since a difference across groups could have an influence on some kinetics and kinematic variables' results (Wikstrom et al. 2006).

6.3.2 Sample size calculation

A total of 63 subjects were planned to be recruited , 21 in each group. This was based on a priori power calculation using GPower3 software and data taken from a preliminary study of 10 subjects with a history of ankle sprain (AS) and 10 healthy subjects.

This preliminary study was undertaken in collaboration with a group of MSc students as part of their graduation projects to determine performance differences between healthy subjects and subjects with a self-reported history of ankle sprain using unanticipated and planned functional tests. The sample size and power calculation were assessed using the decision-making time (DMT) data, as the primary outcome measure in the main study. These data reported mean values of 525 ± 68.35 ms and 450 ± 77.32 ms for subjects with a history of ankle sprain and healthy individuals respectively (see Chapter 5 section 5-5). These values indicated a standard difference of 1. The minimum sample

size was calculated using this standard difference and a power of 0.80 ($\alpha= 0.05$). Each group therefore needed a minimum of 17 subjects. However, due to dropout risk, which could affect the power of the study, I attempted to recruit about 21 subjects per group to minimise this risk, whilst aiming to limit the dropout as much as possible by motivating participation.

6.3.3 Inclusion criteria

Recruited subjects were placed into groups according to the inclusion criteria listed below. This criteria was based on a previous study by Docherty et al. (2006) and a systematic investigation by Delahunt et al. (2010), who recommended a list of key inclusion criteria that should be addressed when investigating CAI subjects. This also recommended by the International Ankle Consortium (Gribble et al. 2013). All subjects were engaged in physical activity during recruitment into the study defined as being performed at least 1-3 days (30-90 min) per week of cardiovascular, resistance training and sports-related activity. Any subject found to undertake limited sporting activities during the assessment after ankle sprains or due to symptoms of CAI will be excluded. Physical activity levels were categorised according to Noyes et al. (1989) (Table 6-1). Only subjects on Level 1 (4-7 days/week) and Level 2 (1-3 days/week) were included as it was thought that those will be most representative of the sporting population who were involved in team or competitive sports. Being more attuned to sport and subsequently cutting movements, it was also thought that these subjects would be less likely to affect the results through a learning effect or poor cutting action.

1. **Ankle sprain group (AS):**

Definition:

Defined as an incident in which the rear foot was inverted or supinated, resulting in a combination of swelling, pain and time lost, or modification of normal function for at least one day (Hertel 2002).

Criteria:

- Ankle sprain Grade I or II (4-8 weeks post), this was described in the introduction chapter.
- Free from previous ankle fractures.
- No head or acute lower extremity injuries within the past 12 months.
- Engaged in physical activity at least 1-3 days a week (30-90 min) during the first assessment session.

2. **Chronic ankle instability group (CAI):**

Definition:

Defined as a history of at least two lateral ankle sprains of the same ankle, which required a period of protected weight bearing and/or immobilisation, current giving-way of the ankle, and feelings of instability (Delahunt et al. 2010).

Criteria:

- History of at least two unilateral lateral ankle sprains

- Ankle instability instrument - Yes to Q 1-4 - and Yes to at least 1 of Q 5 through to 9 in Appendix A
- No head or acute lower extremity injuries within the past 12 months
- Free from previous ankle fractures
- Experienced at least one episode of the ankle giving-way within the past year
- Engaged in physical activity at least 1-3 days a week (30-90 min) during the assessment.

3. **Healthy group:**

Definition:

Defined as no history of lateral ankle sprain or lower extremity injuries within the past 12 months.

Criteria:

- No history of lateral ankle sprain
- No acute lower extremity injuries within the past 12 months
- No history of neurological conditions
- Answered NO to all questions on the ankle instability instrument
- Engaged in physical activity at least 1-3 days a week (30-90 min) during the assessment.

Table 6-1: Sport Activity Rating Scale used to categorise sport activity for all subjects (Noyes et al. 1989)

	Points	Sports
Level I 4-7 days/week	100	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics).
	95	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling).
	90	No running, twisting, jumping (running, cycling, swimming).
Level II 1-3 days/week	85	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics).
	80	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling).
	75	No running, twisting, jumping (running, cycling, swimming).
Level III 1-3 times/month	65	Jumping, hard pivoting, cutting (basketball, volleyball, football, soccer, gymnastics).
	60	Running, twisting, turning (racquet sports, baseball, hockey, skiing, wrestling)
	55	No running, twisting, jumping (running, cycling, swimming).

Level IV No sports possible	40	ADL with no problems.
	20	ADL with moderate problems.
	0	ADL with severe problems.

6.4 Visits and recruitment strategy

Subjects were recruited into 3 different groups according to the inclusion criteria as previously mentioned in section 6.3.3. Initial power calculation determined that 63 subjects should be recruited, 21 in each group. Information about how sample size was determined can be found in Section 6.3.2. To achieve those numbers of subjects, recruitment was carried out from January 2013 to January 2015. This period included the initial recruitment and the follow up for AS group. However, due to difficulties in recruitment, the sample size was not achieved. During this period a total of 60 subjects were recruited (AS = 20, CAI = 20, Healthy = 20). Further information about the visits and recruitment strategy will be explained in the next section.

a. Initial assessment

The initial assessment was conducted for all subjects in all groups. Subjects in the AS group were recruited through the physiotherapy screening unit in the Accident and Emergency department (A&E) at the University Hospital of Wales, Cardiff. Patients who attended the A&E unit with acute ankle injuries were referred to the physiotherapy unit for physiotherapy screening. This unit offers extended services of physiotherapy

within the A&E unit to provide a link between the emergency unit and physiotherapy department, which takes place 2 days a week. Any potential subjects were approached and invited by the responsible clinician to participate and sign the permission to contact form. To help in identifying potential subjects for this group, the clinicians (physiotherapists) were provided with a brief outline of the inclusion and exclusion criteria. Patients who consented received an information pack, containing information sheets and a map. Sufficient time of at least one week was given to review the information sheets and consider participation before being contacted to discuss the involvement decision. The researcher (the PhD student) was responsible for contacting all patients to discuss the study and arrange an appointment to attend the Research Centre for Clinical Kinesiology (RCCK) at Ty Dewi Sant (Heath Park Campus, Cardiff) to conduct the 1st assessment visit. Once the appointment was made, a reminder via text message or phone call was given to each subject. Only 15 consents of permission-to-contact were received from the physiotherapy-screening unit in the Accident and Emergency department (A&E) at the University Hospital of Wales, Cardiff. Six of those 15 potential subjects refused to participate or were not eligible for the study. The main reason to refuse to take part in this study were because of lack of time due to study or work commitments or because they are not interested in research. However, due to the long time on waiting lists there are a high number of patients with ankle sprains who were referred to the physiotherapy-screening unit and failed to turn up for their appointment. An alternative plan was implemented to recruit subjects into this group via flyers posted in and around Cardiff University and email announcements were also sent to staff and students in the department of the School of Healthcare Sciences. Sports

teams who compete for the university were also invited through email and visited for the same purposes. Any injured individual who was interested in participating was contacted to determine their eligibility to the criteria. A total of 11 subjects were recruited from this method. While this could be recognised as a different population, which considered a potential bias in recruitment, only those subjects who visited and received medical diagnoses were included. All subjects were also similar in their demographics and level of sport activity. Additionally, a period of 4-8 weeks post-injury before conducting the 1st assessment to move safely back to normal activity was applied to all subjects in this group. After the first visit, participants in this group were contacted again to arrange the follow up visit. Further information about the follow up visit can be found in the following section.

Subjects in the CAI group were recruited via flyers posted in and around Cardiff University and email announcements were also sent to staff and students in the department of School of Healthcare Sciences for recruitment purposes. Sports teams who compete for the university were also invited through email and visited for the same purposes. Interested voluntary subjects were contacted to determine their eligibility to the CAI criteria. An appointment was arranged for the subject to attend the Research Centre for Clinical Kinesiology (RCCK) at Ty Dewi Sant (Heath Park Campus, Cardiff) to conduct the assessment visit. Once the appointment was made, a reminder via text message or phone call was conducted to each subject. All recruited subjects had chronic ankle instability, as determined through the Ankle Instability Instrument (Appendix A) (Docherty et al. 2006, Caffrey et al. 2009). This instrument contains 9 questions for

assessing instability in individuals with a history of ankle injuries. Subjects with CAI needed to answer yes to questions 1 and 4, which asked if an ankle had ever been sprained before and if a feeling of “giving-way” was ever present. Also, an answer of yes should be recorded for at least 1 of questions 5 through to 9 regarding whether instability was felt while walking on a flat surface, an uneven surface, during recreational or sport activity, or while going up or coming down stairs. A total of 20 subjects were recruited in the CAI group.

Subjects in the healthy group were recruited via flyers posted in and around Cardiff University and email announcements were also sent to staff and students at the department of the School of Healthcare Studies for recruitment purposes. Any voluntary subjects were contacted to determine their eligibility to the criteria of this group. An appointment was arranged for each subject to attend the Research Centre for Clinical Kinesiology (RCCK) at Ty Dewi Sant (Heath Park Campus, Cardiff) to conduct the assessment visit. Once the appointment was made, a reminder via text message or phone call was made to each subject. A total of 20 subjects were recruited in the healthy group in two different times in order to match groups. Twelve subjects were recruited at the beginning of the study, and the remaining 8 subjects were recruited at the latter part of the study.

b. Follow-up visit

Loss of follow-up has been a problem in this study with ankle sprain group, as subjects were free to withdraw from the trial at any time. The study was designed to assess each subject in the ankle sprain group at 3 stages post-injury. Each of the subjects were encouraged during the first visit in an attempt to minimise loss of follow-up, and reminder texts and telephone calls were made to follow up those who were scheduled for follow up. However, term-time and holidays were considered in the booking schedule for those subjects who were students. During the follow-up visit each subject was instructed to wear the same footwear for each visit.

Of the 20 subjects included in the AS group in the 1st assessment, only 10 subjects were included in the 1st follow up while the 2nd follow up was composed of only 4 subjects. At 12 months post injury those subjects who completed the 1st visit were followed up with a web-based self-reported functional assessment that checks their current functional ability and their ankle stability during sport.

6.5 Assessment procedures**6.5.1 Overview**

Assessment procedure was similar in both studies; the cross-sectional and the longitudinal study and for this reason this section applies to both studies. Each subject on arrival at RCCK firstly received an explanation and instructions on the protocol and the purpose of the study and then they were asked to read and sign the consent form.

Details of demographic information including height and weight were obtained prior to starting the assessment and then recorded on the data sheet (Appendix B). Height was measured in cm using a SECA and weight was measured in Kg using SECA scales. All subjects were asked to indicate the level of sport/leisure participation that they felt reflected their customary activity. Sports and activity participation levels were categorised according to Noyes et al. (1989) (Table 6-1 in section 6.3.3). The skill leg was identified for each subject by asking which leg they preferred to use when kicking a football. No training for 24 hours or heavy meal 2 hours prior to the assessment visits for all subjects in all groups was emphasised to minimise any effects of training or fatigue on the results. All assessment visits were done wearing comfortable clothes and their own trainers. After completion of the initial screening, each subject was asked to complete two self-reported functional assessments, followed by a range of motion and laxity tests of the ankle joint before they performed functional performance tests and muscle strength assessment. Healthy subjects were not asked to complete the self-reported functional assessments as the inclusion criteria for this group could allow for assumptions of a maximum score. The following section will outline information about instruments, data collection and how this data is processed.

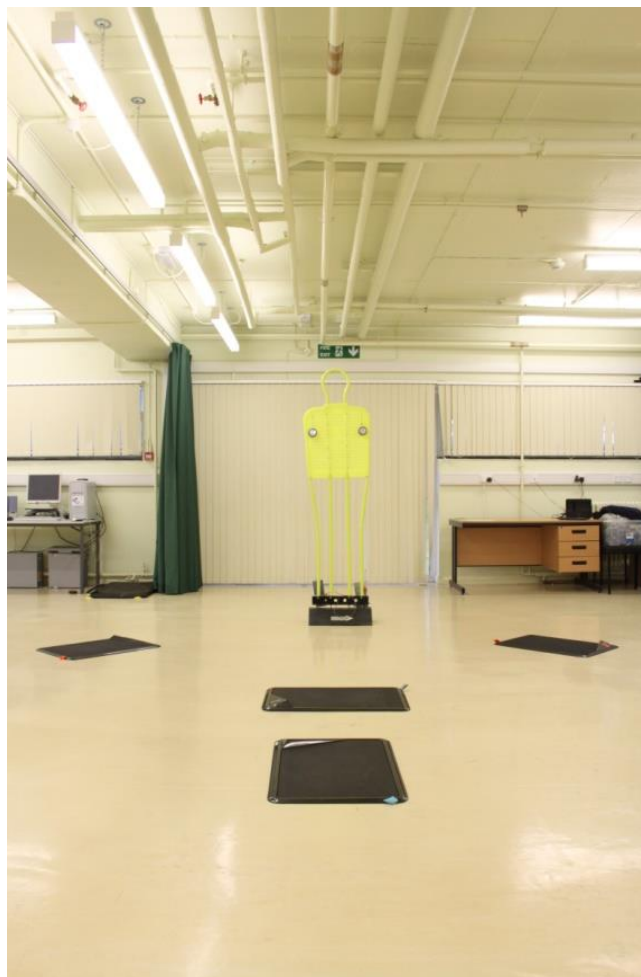
6.5.2 Instrumentation

6.5.2.1 Vector mat system

This instrument was described in more detail in a different chapter (see chapter 5 section 5.3.4.2). This system was developed at the School of Healthcare Sciences at

Cardiff University and consists of 5 rubber portable mats with the added ability to be incorporated into a range of different configurations on the floor or mounted on walls. Each mat was 50 x 75 cm (long x wide) and covered by anti-slip rubber films. The system was connected to the computer via a built-in wireless system (hardware). The software of the vector system was developed using visual basic for applications (VBA). Different protocol parameters can be collected in the software such as total performance task time, decision-making time, number of correct versus incorrect decisions and flight times. This is achieved by utilising a series of pressure sensitive switches encased in the mats (see Figure 6-2). These pressure sensitive switches will activate LED lights (cues) randomly either to left or right, which will indicate the direction in which the subjects had to respond. The common limitation in most functional tests is that they are all simple task speeds and were pre-planned, where the individual is not required to respond to a stimulus or command. However, researchers have begun to consider improving their work by using unanticipated tasks to improve the validity and to minimise the learning effect, this was discussed in more detail in the literature review chapter (Kim et al. 2014; Weinhandl et al. 2013; Houck et al. 2006; Houck et al. 2007; Besier et al. 2001; Besier et al. 2003; Ford et al. 2005; Sheppard et al. 2006; Ford et al. 2005; Farrow et al. 2005; Duvnjak-Zaknich et al. 2011; Gabbett et al. 2008). This system was designed to assess functional performance in unanticipated movement, in an effort to more replicate the environment of sport. Additionally, this system was assessing jump height via flight time.

Figure 6-2: Vector mats system



6.5.2.2 Isokinetic dynamometer (Kin.Com®)

The Kin.Com® 125E Plus (Chattanooga Group, Inc., Hixson, Tennessee, USA) is an isokinetic dynamometer testing device, integrated with a computer, touch screen and software to provide strength data from muscle actions (see Figure 6-3). This Kin.Com® dynamometer allows for precise and reliable measurement varying from (ICC 0.69 to

0.98) (Kaminski et al. 1995; Amaral De Noronha and Borges Jr. 2004; Sekir et al. 2008).

Figure 6-3: Isokinetic dynamometer (Kin.Com®), which was used to measure muscles strength

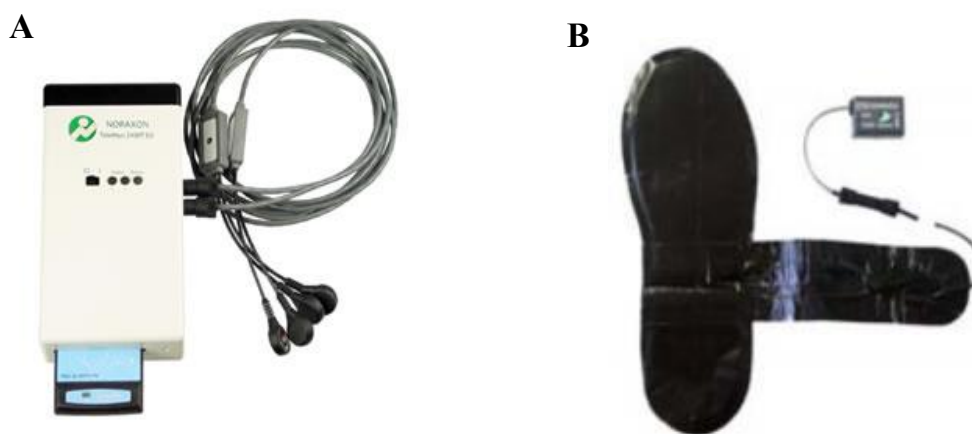


6.5.2.3 Electromyography (EMG)

The EMG is used to measure the electric activity and change of muscles during activities (Criswell 2011). The TeleMyo™ 2400T G2 Transmitter (Noraxon Inc., Scottsdale, Arizona, USA) with 8 channels was used to send data by wireless transmission to a notebook (see Figure 6-4 A). EMG data was recorded at 1500 Hz using conductive adhesive hydrogel surface electrodes (Kendall™ Meditrac 230; Tyco

Healthcare, Hampshire, 102 PO13 0AS, UK) with a circular contact area of 10 mm². The electrode contacts were 18 mm in diameter. EMG data was saved using the MyoResearch XP Clinical Application software (Noraxon Inc., Noraxon Inc., Scottsdale, Arizona, USA) and was filtered. The variability was minimised by standardising electrode placement. Foot contact points in each trial were identified using foot-switch and video cameras. The foot-switch system includes four sheets of conductive rubber, covering the forefoot and the rear foot of the shoes (see Figure 6-4 B). This system was connected with the TeleMyo™ 2400T G2 Transmitter. EMG data was processed using a purpose-written programme in Matlab (R2007a, Mathworks, Natick, USA).

Figure 6-4: Electromyography (EMG). **A**, TeleMyo™ 2400T G2 Transmitter. **B**, Foot-switch system, which was used to quantify muscle activity



6.5.3 Data collection and processing

To test the study hypotheses in this section data collection procedures were divided into two sections as primary and secondary outcome parameters. A summary of the dependent variables will be presented in section 6.5.3.3. As mentioned earlier, assessment procedure was similar in both studies; the cross-sectional and the longitudinal study and for this reason this section applies to both studies.

6.5.3.1 Primary outcome parameters

The primary outcomes in both studies were collected during functional performance test using the vector system and data from Electromyography (EMG). Three tests were used for measure functional performance, namely the unanticipated functional test (UFT), with unplanned single change of direction to the left or right, planned change of direction functional test (PFT), also to the left or right, and lastly the single deep vertical jump test (DVJ). Following a number of practice trials prior to starting the test trials, each subject was informed that if any discomfort or pain were felt during this assessment it would be discontinued immediately. EMG data was collected during this unanticipated functional test.

1. The unanticipated functional test (UFT)

During the UFT the vector mats system was used. Four mats were positioned, as shown in Figure 6-5. The dimensions of this figure were determined by running preliminary studies described in a different chapter. Mat numbers 4 and 5 were set at 45-degree

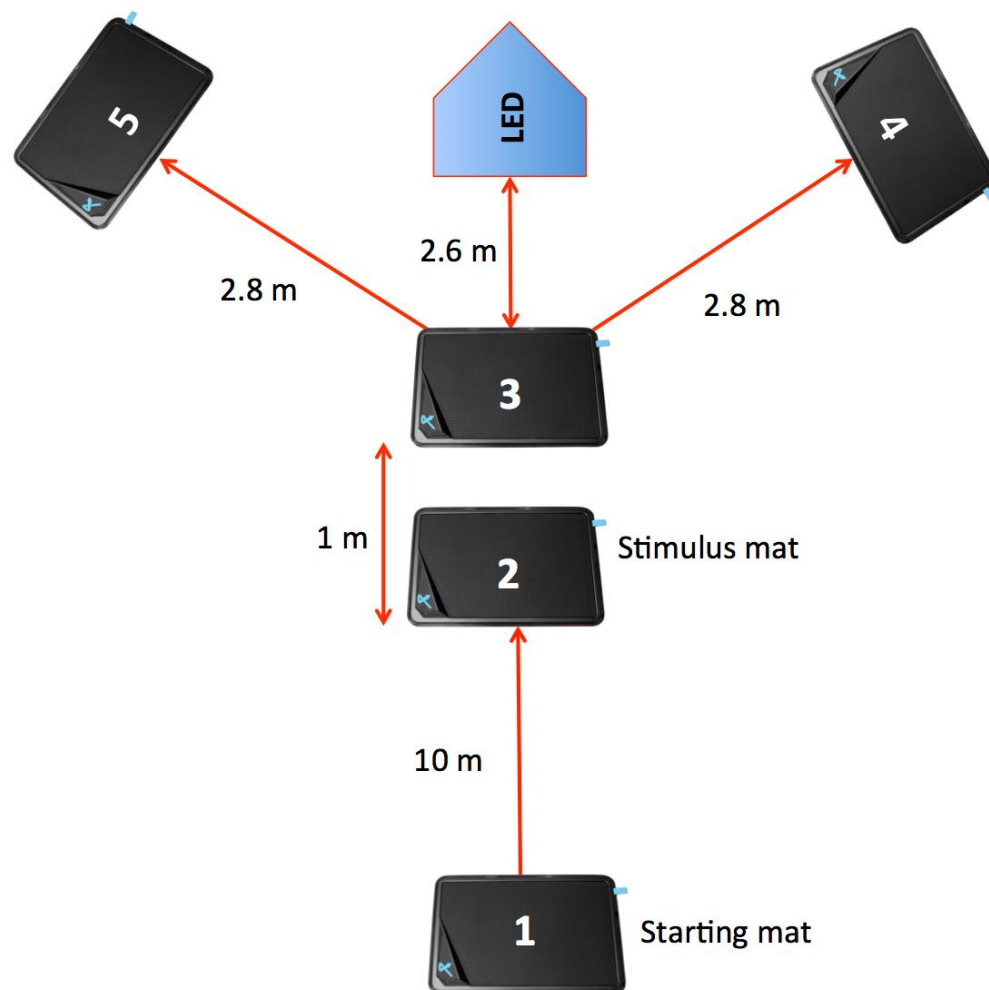
angles to mat number 3. The distance between mats 2 and 3 was implemented at 1 metre to allow the participants to react without missing the trigger mat. A light cue was positioned in a straight line at 280 cm from mat 3. Each subject was instructed to begin each trial 30 cm before the starting line. All trials were performed on a 10 m runway at a running speed at 4.7 ± 0.56 m/s. When subjects stepped on the stimulating mat (number 2) during this test, LED lights were activated either on their left or right. This indicated the direction in which the subjects had to respond as quickly as possible by changing direction, targeting a cutting angle of 45° relative to the original direction of motion (see Figure 6-5). Each subject was also instructed to emphasise accuracy of movement (decision-making accuracy). The vector system controlled the unanticipated element during the test, thus allowing an objective evaluation of functional performance in unanticipated action. To eliminate learning effect and intra-individual variability, subjects first completed 10 practice trials, after which they performed 10 test trials. Any trials in which a participant did not complete the course as outlined was recorded as a faulty trial and the subject was asked to perform the trial again. Speed was also controlled and calculated from the first mat to the second mat.

Decision Making Time (DMT) and Task Time (TT) in milliseconds (ms) were the outcome variables of interest for UFT tests, these were provided and recorded by the vector mat system, and then extracted to a separate Excel spreadsheet. The DMT was defined as the time from the moment the subject left station 2 until the moment the subject left station 3. The TT was defined from when the subject stepped on station 2 until the subject stepped on station 4 or 5. All trials were checked on video clips by the

researcher (the PhD student) and then by the second assessor using criteria as illustrated below, this was performed to avoid a selection bias. However, the second assessor was blind of the subject group. The best three trials that were checked and recorded as acceptable were used for analysis.

1. Correct direction based on the LED lights stimulation either on left or right.
2. Stepped correctly on the mat (number 2 and 3) (stepping on the edge or taking further steps outside the mat were not acceptable).

Figure 6-5: Mats' position during the unanticipated functional test (UFT) and the planned functional test



2. Planned functional test (PFT)

The vector mats system was also used in the planned functional test. The position of the mats was identical to that used for the unanticipated functional test. In this test the LED lights were deactivated and each subject was informed about direction prior to the start of each trial. However, the same direction sequences were used among all subjects. Each subject performed 10 test trials. Any trials in which a participant did not complete the course as outlined was recorded as a faulty trial and the subject was asked to perform the trial again.

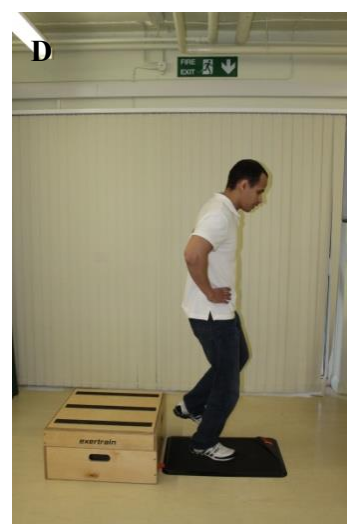
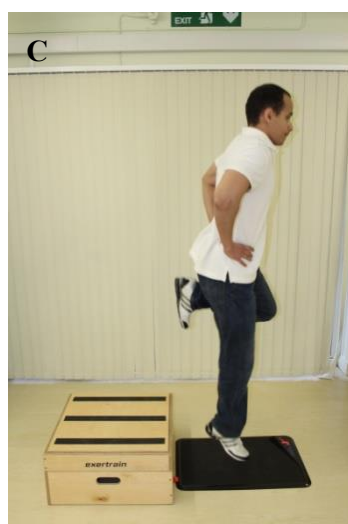
Decision Making Time (DM) and Task Time (TT) in milliseconds (ms) were the outcome variables of interest for PFT test, this was provided and recorded by the vector mat system, and then extracted to a separate Excel spreadsheet. The mean of the best 3 trials was used for analysis.

3. Deep vertical jump (DVJ)

All DVJ tests were carried out on the same mat (50 x 75 cm) using the vector mat system. This test involved dropping from a 45 cm high box, landing on the mat, an immediate maximal vertical single leg jump, and then landing on the same mat. To concentrate on lower extremity explosiveness, subjects were required to keep their hands on their waist during each trial (see Figure 6-6). Following the 3 practice trials on each leg, a 5-minute rest was given. Subjects were then asked to perform 3 single leg jumps on each leg starting with the dominant leg. Trials in which a subject failed to achieve full contact with the mat during the first and second landings were excluded.

In this test, the flight time and contact time were generated using the vector mat system, 3 trials on each ankle were evaluated recorded as (Injured and Non-Injured) for AS and CAI groups, and (skilled and non-skilled leg) for healthy group. Flight time data was then extracted to an Excel spreadsheet and transferred to jump height in metres using the following equation: $h = (g \times t^2) / 8$ (Asmussen and Bonde-Petersen 1974). The average was then calculated for both and transferred to centimetres (cm) for the jump height and in milliseconds (ms) for contact time before they were used in the analysis.

Figure 6-6: Deep vertical jump (DVJ) A: starting position, B: dropping, C: vertical single leg jump, D: landing



3. Muscle activity

EMG data was collected throughout the entire unanticipated functional test at a sampling rate of 1500 Hz using a surface EMG system (TeleMyo™ 2400T G2 Transmitter with an 8-channel) and pre-amplifier. EMG data was recorded from 3 muscles on each leg, the tibialis anterior (TA), the peroneus longus (PL), and the lateral gastrocnemius (GAS) using pairs of surface electrodes (10 mm²) (Kendall™). Electrodes were placed on both legs in accordance with the guidelines suggested by the European recommendations for surface electromyography (Hermens et al. 2000). The location for each electrode was chosen in order to maximise the signal while avoiding crosstalk. In particular, each electrode was positioned during contraction over the belly of the muscle. Before placement of the electrodes, subjects were positioned supinely on a treatment table, the skin area was shaved where necessary and cleaned with isopropyl alcohol to reduce the source impedance. A reference electrode was placed over the medial part of the tibia. The pre-amplifier cables were securely attached to the subject's body using adhesive tape (Micropore; 3M Healthcare, D-41453 Nuess, Germany) to minimise the risk of artefacts due to cable movement. Once the electrodes were placed and the cables fixed, the raw signal was visually checked for any distortion using the MyoResearch XP Clinical Application software. EMG data was processed using a purpose written programme in Matlab (R2014b, Mathworks, Natick, USA). One camera was placed so that all cutting moments during unanticipated test were recorded. Camera viewer and zoom function were adjusted to help to identify the moment of foot contact and changing direction moments on the mat (number 3).

For the purposes of this study, the leg that was used to initiate first contact on the mat before changing direction was considered. This portion of the cutting movement is considered important as previous studies have demonstrated alteration of the ankle muscles just before foot contact in subjects with chronic ankle instability, which was considered as a factor to cause instability and to cause re-sprains (Brown et al. 2004; Konradsen and Ravn 1991; Vaes et al. 2002; Delahunt et al. 2006b; Delahunt et al. 2007; Lofvenberg et al. 1995; Palmieri-Smith et al. 2009; Santilli et al. 2005). Additionally, this contact phase was often cited as the injury mechanism during dynamic activity.

The EMG data were firstly processed within MyoResearch XP Clinical Application software (Noraxon Inc., Scottsdale, Arizona, USA). All trials were firstly checked using video recordings saved within MyoResearch XP Clinical Application. This was checked frame by frame until the moment corresponding to foot contact was identified on the mat (number 3). There are some limitations in identifying the foot contact moment due to the slow speed camera used. However, footswitch was used to overcome this limitation and identify an accurate foot contact moment. Crosstalk signal from other muscles could be a problem associated with protocol used onset muscle activation especially during functional activities (Guidetti et al. 1996). However, this problem is less when the peak time identification is used.

A new window was set for these trials including the first foot contact on the mat (number 3) as determined by the visual inspection and 100 milliseconds before and 300

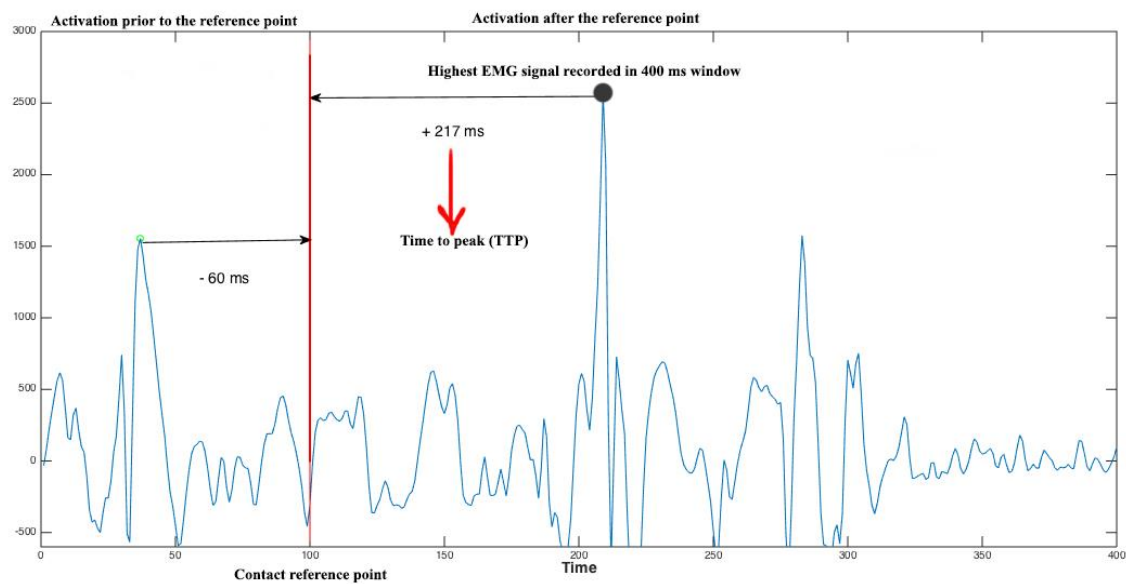
milliseconds after this contact. This 400 milliseconds window time was saved as a new data file and then was full wave rectified and low pass filtered using a second order Butterworth filter with a 50 Hz cut off frequency. Data was then extracted to the Matlab file and saved for further analysis.

The second stage of the processing was to import this Matlab files to a purpose-written Matlab programme. This programme code was developed by Professor Robert van Deursen (School of Healthcare Sciences at Cardiff University). Within this programme the footswitch signal was processed using value set at (0 and 1), so a value 0 represented if the foot is off the ground, and a value 1 if the foot was contacting the ground. Contact reference point was identified by the rise in footswitch signal, to the value 1. This was to avoid the possibility of false signal during foot contact in footswitch data. Two phases were defined in relation to this reference point in order to establish an analysis window time. The negative values (-) presented activation prior to foot contact and positive values (+) presented activation after foot contact (see Figure 6-7). This short window time before foot contact for muscle activity was chosen to represent the motor control strategy as suggested by Santello and McDonagh (1998).

This programme was developed to calculate the time to the peak of muscle activity during an unanticipated test (cutting manoeuvre). Time to peak (TTP) was calculated as the time between the highest EMG signal and the contact reference point using two criteria: 1. Highest EMG signal recorded in 400 ms window. 2. Occurring shortly related to the contact reference point in case if there was two or more similar peak EMG

signal. Therefore, Negative values (-) presented to activation prior to this contact reference point and Positive values (+) presented to activation after this reference point.

Figure 6-7: Time to the peak calculation of muscle activity during an unanticipated test



6.5.3.2 Secondary outcome parameters

The secondary outcomes in this study were collected from each subject using: self-reported functional assessment, ankle-dorsiflexion range of motion (dROM), laxity and muscle strength assessment.

1. Self-reported functional assessment

Self-reported disability was assessed using the following questionnaires: (1) The Foot and Ankle Disability Index (FADI) contains two components; one assesses activities of daily living (FADI-ADL %) and the other is essential to sporting activities (FADI-Sport %) and (2) the chronic ankle instability scale (CAIS %). Both have been found to be valid and reliable tools for assessing limitations in patients with CAI (Hale and Hertel 2005; Eechaute et al. 2008b).

The FADI-ADL % and FADI-Sport % are scored separately as percentages, with 100% representing a higher level of physical performance, while the low percentage (%) in CAIS indicates a high level of physical performance. The healthy subjects were not asked to complete these self-reported assessments as the inclusion criteria for this group could allow assumption of a maximum score, implying no restriction in activities of daily living or sports such as running, change of direction etc. therefore, in comparison between groups a maximum score was scored for healthy subjects (FADI-ADL =100%, FSDI-Sport =100% and CAIS = 0%). Following the screening test each subject was asked to complete the FADI and CAIS by choosing the best answer that described their present condition compared to the pre-injury level.

a. The Foot and Ankle Disability Index (FADI)

This instrument includes 34 items divided into 3 subscales: the Activities of Daily Living (ADL) contains 22 activity related items, the Sports subscale contained 8 items and pain related to foot and ankle numbered 4 items, which were all scored separately. Each item was scored on a 4-point scale (from 0 to 4) with 4 being “no difficulty” and 0 being “unable to do”. N/A responses were not counted. The FADI scored a total of 136 points (No Disability) (Appendix D).

b. The chronic ankle instability scale (CAIS)

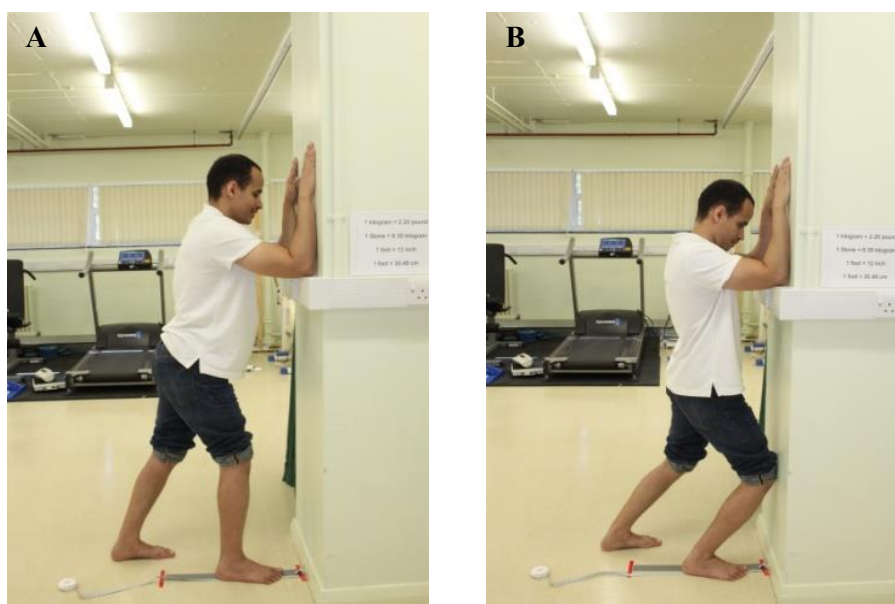
This instrument contains 14 items and consists of 4 subscales: impairments, a disability, participation and emotions. Each item was scored on a 5-point Likert scale, from 4 (best score) to 0 points (worst score). The CAIS scored a total of 56 points (Appendix D). If an item was rated as not applicable (N/A) it was not counted.

2. Ankle-dorsiflexion range of motion (dROM)

The dfROM was measured using a weight-bearing lunge using the knee-to-wall principle. This test was performed using a protocol previously described by Hoch and McKeon (2011), and Konor et al. (2012). The knee-to-wall was performed in a standing position with the heel in contact with the ground, the knee in line with the second toe, and the big toe 10 cm away from the wall. Balance was maintained by allowing contact with the wall using two hands (see Figure 6-8 A). Participants were asked to lunge forward, directing their knees toward the wall (in line with the second toe) until their

knees touched the wall (see Figure 6-8 B). The foot was progressed away from the wall 1 cm at a time and the subject repeated the lunge until they were unable to touch the wall with their knee without lifting the heel from the ground. Once the knee was not able to touch the wall, the foot progressed in smaller increments towards the wall until the knee made contact with the wall with the heel in contact with the ground. This progression towards the wall allowed a measurement to be obtained to the nearest millimetre. If the participant was not able to touch their knee to the wall without lifting the heel from the ground at the initial 10 cm start position, the participant was asked to move his or her foot forward towards the wall 1 cm at a time until they could touch their knee to the wall while keeping the heel on the ground. At the point when the knee made contact with the wall, the foot was progressed in smaller increments away from the wall to allow a measure to be obtained to the nearest millimetre. Maximal dorsiflexion ROM was defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel (Bennell et al. 1998). The researcher monitored heel contact with the ground by lightly placing their fingers on the heel to feel for heel movement, while also visually examining the heel. Finally, the distance was recorded of the big toe from the wall to the nearest 0.1 cm. Participants were allowed three practice trials per limb and completed one test trial per limb starting with the right ankle. The dfROM was measured for both ankles using tape measure. The distance (in cm) for each ankle was recorded and then transferred to an Excel spreadsheet.

Figure 6-8: Ankle-dorsiflexion range of motion (dROM) assessment using the knee-to-wall method. A, Initial participant position. B, Finishing position



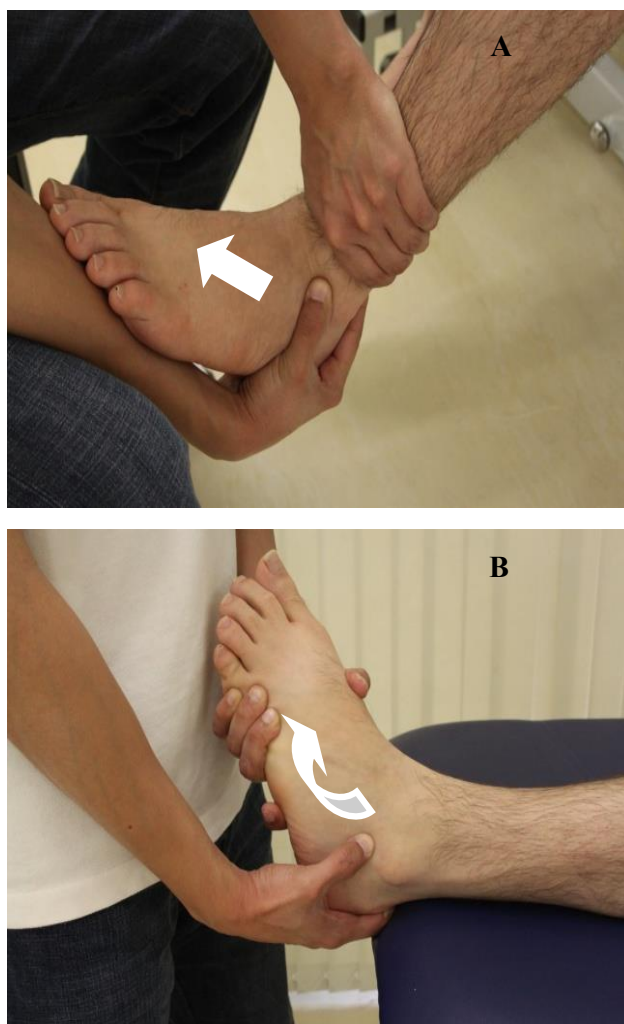
3. Laxity

Ankle joint laxity was assessed manually using the anterior drawer test (ADT) and the talar tilt (TTT) on each ankle. For the ADT, the subject was in a sitting position with their knee flexed in order to help eliminate gastrocnemius muscle tension. The amount of movement occurring at the talocrural joint was determined by palpating the movement that occurred between the talus and malleoli, using the thumb and index finger on the lateral and medial aspects, respectively (see Figure 6-9 A). Similar to those described previously by Ryan (1994), this movement was graded as:

- 1 = Very hypomobile
- 2 = Slightly to moderately hypomobile
- 3 = Normal
- 4 = Slightly to moderately hypermobile
- 5 = Very hypermobile

The talar test was performed with the subject supine and the ankle in plantar flexion (see Figure 6-9 B). The examiner's thumb was used to detect the gapping between the lateral malleolus and the talus. This movement was graded as for the anterior drawer test. It was considered positive if it was graded 4/5 or 5/5 or if it received a grading of at least two grades greater than the unaffected ankle on either instability laxity test (Ryan 1994). Positive and negative graded were used for final analysis.

Figure 6-9: The assessments used to assess the laxity in ankle joint: A, Anterior drawer test. B, Talar tilt test



4. Isokinetic Strength Measurement

Isokinetic testing of the ankle invertor and evertor muscles were performed at a velocity of 120°/s for both ankles in eccentric and concentric contractions, using Kin.Com® 125E Plus (Chattanooga Group, Inc., Hixson, Tennessee, USA) using software version 5.30. The rationale for choosing this speed was based on a meta-analysis study by Arnold et al. (2009) , who suggested performing the test at only 1 velocity above 30°/s and below 240°/s. However, running pilot trials prior to data collection also helped to determine the chosen speed. The order of right or left ankle and which contraction types were randomly determined by a coin toss. Each subject was appropriately positioned in a supine position as illustrated in Figure 6-10 and the ankle was positioned in starting position so that it became 10° of plantar flexion, using a manual goniometer. The knee of the test leg was positioned at 10° flexion to allow for more isolated movement and reduced the contribution of hamstring muscle during inversion and eversion and the other leg was extended (Lentell et al. 1988).

All trials were performed with the subjects wearing their shoes, which were tightly secured to the dynamometer footplate with two straps, which in turn crossed to the dorsum of the foot, attached to the footplate. The range of motion stop angles from eversion to inversion direction were set at 20° of eversion and 30° of inversion (Sekir et al. 2008), and vice versa from inversion to eversion. In concentric contraction each subject was asked to push to right or left in both inversion and eversion direction. In eccentric contraction each subject was asked to resist the direction.

Subjects familiarised themselves with the dynamometric system by submaximal force of muscle contraction before the testing procedure, a two-minute rest was provided, and subjects had to perform 3 sets of 5 maximal repetitions at 120°/s. The muscle strength was obtained by measuring maximal force moments (torque) during isokinetic ankle inversion and eversion movements. To ensure that a maximal effort was attained, all subjects received consistent verbal encouragement during each trial. A two-minute rest period was provided between the test for inversion and eversion to prevent the build-up of fatigue and there were 30 seconds between repetitions. The test was then performed with the contralateral leg.

In each test the isokinetic dynamometer software reported the average value of peak torque (in Nm) out of 3 sets and 5 repetitions for both eccentric and concentric contractions of both the right and left ankle, and for each group of muscles (INV/EVER). Then, all the strength measures in this study were normalised to each subject's body weight (i.e. peak-torque/body-weight PT/BW).

Figure 6-10: Participant position during Isokinetic testing of the ankle invertor and evertor muscles using Kin.Com®



6.5.3.3 Dependent variables summary

Table 6-2: Overview of the parameters investigated in both studies.

Primary Parameters		Test	Scale
Functional performance tests			
1-	Decision Making Time (DMT)	Unanticipated (UFT) and Planned test (PFT)	Millisecond (ms)
2-	Task Time (TT)	Unanticipated (UFT) and Planned test (PFT)	Millisecond (ms)
3-	Jump Height (JH)	Deep vertical jump	Centimetre (cm)
4-	Contact time (CT)	Deep vertical jump	Millisecond (ms)
Electromyography			
1-	Time to the peak (400 ms window)	Unanticipated (UFT)	Positive/Negative Millisecond (ms)
Secondary Parameters		Test	Scale
Muscle strength assessment			
3-	Peak Torque (PT)	Isokinetic strength	Newton-meter (Nm)
4-	Peak Torque/body-weight (PT/BW)	Isokinetic strength	Numeric %
Self-reported functional assessment			
5-	The Foot and Ankle Disability Index: (ADL-FADI) and (Sport-FADI)	Questionnaires	Numeric %
6-	The chronic ankle instability scale (CAIS)	Questionnaires	Numeric %
Joint movement			
7-	Ankle-dorsiflexion range of motion (dfROM)	Knee-to-Wall test	Centimetre (cm)
8-	Laxity	Ant drawer and Talar Tests	Positive/Negative

6.6 Statistical Analysis

The present study includes two different studies: a cross-sectional study and a longitudinal study. SPSS software (version 20.0; SPSS Inc., Chicago, IL) was used for statistical analyses. An alpha level was set a priori at $p < 0.05$ to determine statistical significance for all tests.

6.6.1 Cross-sectional study

Figure 6-11 includes a summary of the statistical analysis used in this study. Descriptive analyses for subject demographics were presented in the form of means and standard deviations (SD). A one-way ANOVA (analysis of variance) was used to determine that the three groups were not significantly different in age, height or weight.

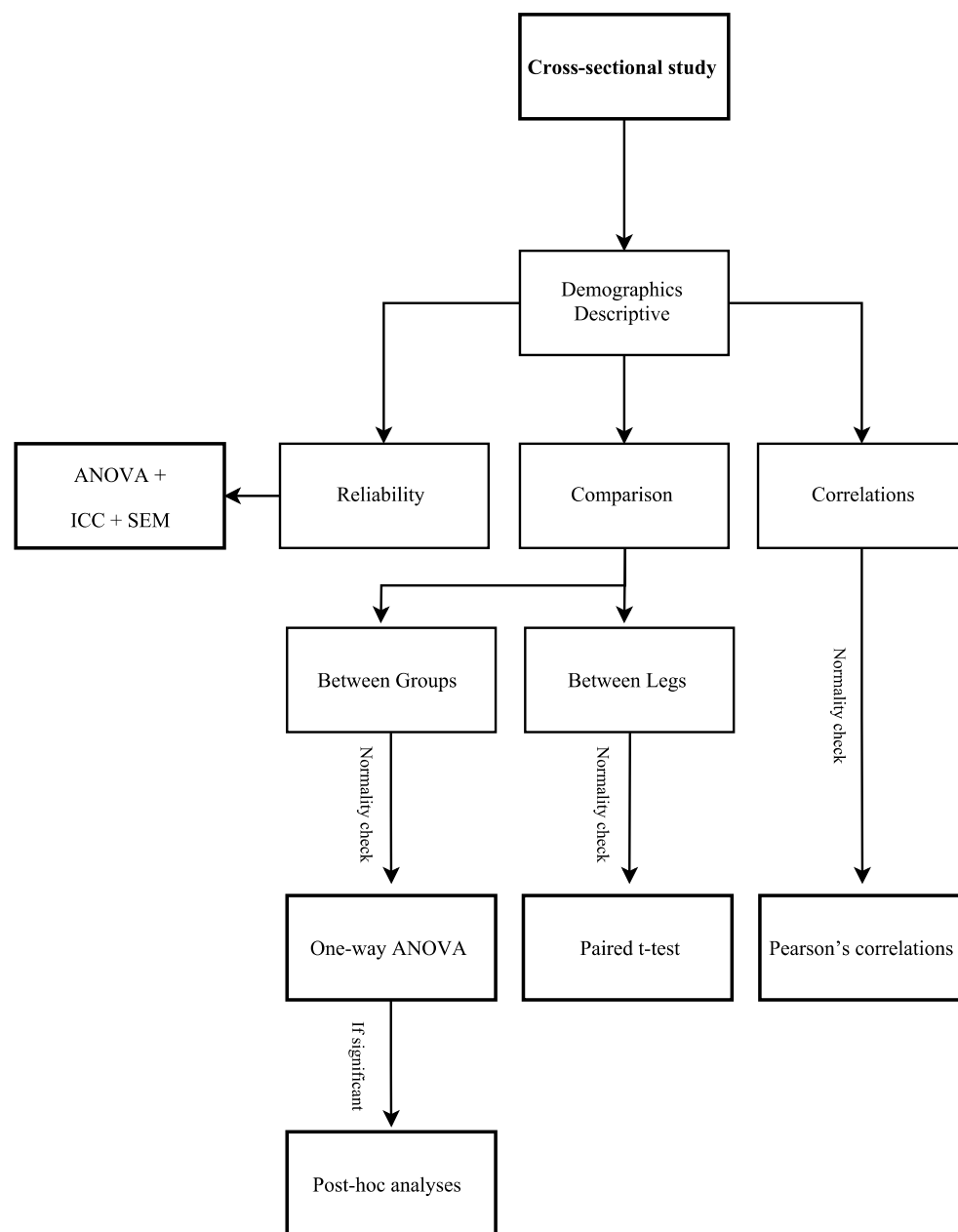
Firstly, to evaluate test re-test reliability, a repeated measures analysis of variance (ANOVA) was used to evaluate if there was any variability within subject scores. Then the intraclass correlation coefficient (ICC) was calculated and interpreted as follows: less than 0.20 = slight reliability, between 0.21–0.40 = fair reliability, 0.41–0.60 = moderate reliability, 0.61–0.80 = substantial reliability and 0.81–1.00 = excellent reliability (Landis and Koch 1977). Additionally, measures of absolute reliability were expressed as the standard error of measurement (SEM). The following outcome measurements were evaluated for reliability: 1) Decision making time (DMT) and task time (TT) in milliseconds (ms) during the unanticipated and planned functional test, 2) Contact time (CT) and jump height (JH) during a deep vertical jump (DVJ), 3) Time to

peak (TTP) of the tibialis anterior (TA), the peroneus longus (PL), and the lateral gastrocnemius (GAS) using EMG, 4) ankle-dorsiflexion range of motion (dfROM) using the weight-bearing lunge test. The reliability of measuring ankle muscles using isokinetic dynamometer method was reported in different studies (Kaminski et al 1995; De Noronha and Junior 2004; Sekir et al. 2008). Therefore, the reliability of isokinetic dynamometer was not reported in the current study.

Secondly, a one-way ANOVA (analysis of variance) was conducted to examine whether there were statistically significant differences among the three groups namely AS, CAI and healthy in terms of the outcome measures investigated at baseline. Post-hoc analyses were conducted on any significant findings using Bonferroni. However, ANOVA assumes that data is normally distributed, therefore, in the case where normality was not shown, the non-parametric Kruskal-Wallis test was used to compare between groups. Kolmogorov-Smirnov tests of normality were used since there was sample size of more than 50 subjects used in this study (Elliott and Woodward 2010), which was to determine if the dependent variables were normally distributed. Histograms and Q-Q plots were also used visually to check the normality.

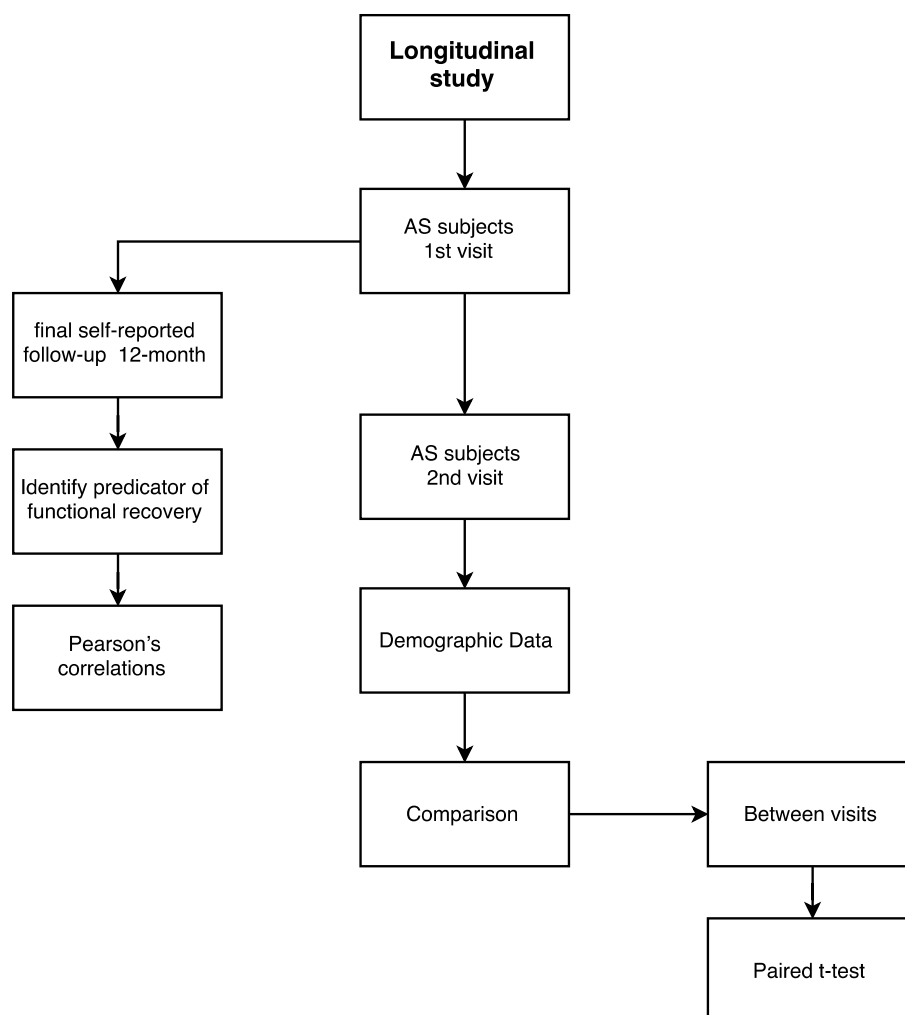
Where both ankles had been tested, the dependent variable was compared between the injured and non-injured in AS and CAI groups and between skilled and non-skilled legs in the healthy group using a paired t-test. Effect sizes were calculated for each parameter based on differences between groups.

Pearson's correlations were conducted to evaluate if there was any relationship between selected variables. Pearson's correlations assume that data is normally distributed, therefore, in cases where normality was not shown the non-parametric Spearman's correlation coefficient was used. Because approach speed and muscle strength were expected to influence the functional tasks, the correlations examined were: 1) Approached speed and Decision Making time (DMT) and Task time (TT) during the unanticipated functional test (UFT) and planned functional test, 2) muscle strength data and DMT, TT, contact time (CT) and jump height (JH). Additionally, the group's performance in functional tasks was evaluated for correlation with self-reported functional assessment.

Figure 6-11: Statistical analysis used in the cross-sectional study

6.6.2 Longitudinal study

Figure 6-12 includes a summary of the statistical analysis used in this study. Paired t-test was used to examine whether there were statistically significant differences between visits. Prior to running the analysis for t-test, variables were checked for normality as described in the section above.. The mean and standard deviation of each variables were presented in charts and used for descriptive analysis for both visits and compared with healthy and CAI groups. To identify predictor of functional recovery after ankle sprain, Pearson's correlations were conducted and divided into 3 parts to evaluate if there was any relationship between the self-reported functional assessment (FADI-ADL%, FADI-Sport % and CAIS%) and results of functional performance.

Figure 6-12: Statistical analysis used in the longitudinal study

CHAPTER 7 : RESULTS

7.1 Overview

This was an observational study, including two studies, a cross-sectional study and a longitudinal study. The first study was to investigate whether there were any statistically significant differences between individuals following acute ankle sprains (AS), individuals who complain about recurrent incidence of ankle sprains (CAI) and individuals with stable ankles who have never experienced a sprain (Healthy). The second study analysed the progress of subjects in the AS group over 6 months plus a final self-reported follow-up at least 12 months after the onset of injury. Therefore, the second study involved 3 visits and 12 months' post injury self-reporting (at 1 month, 3 months, 6 months post injury and a 12 month report). Both studies investigated the same outcome measures, which included parameters related to functional performance, muscle activity, self-reported functional assessment, assessment of range of motion, muscle strength assessment and laxity assessment as detailed in Table 7-1. This chapter is therefore presented in two sections relevant to the study design.

Table 7-1: Overview of the parameters investigated in the cross-sectional and the longitudinal studies.

Primary Parameters		Test	Scale
Functional performance tests			
1-	Decision Making Time (DMT)	Unanticipated (UFT) and Planned test (PFT)	Millisecond (ms)
2-	Task Time (TT)	Unanticipated (UFT) and Planned test (PFT)	Millisecond (ms)
3-	Jump Height (JH)	Deep vertical jump	Centimetre (cm)
4-	Contact time (CT)	Deep vertical jump	Millisecond (ms)
Electromyography			
1-	Time to the peak (400 ms window)	Unanticipated (UFT)	Positive/Negative Millisecond (ms)
Secondary Parameters		Test	Scale
Muscle strength assessment			
3-	Peak Torque (PT)	Isokinetic strength	Newton-meter (Nm)
4-	Peak Torque/body-weight (PT/BW)	Isokinetic strength	Numeric %
Self-reported functional assessment			
5-	The Foot and Ankle Disability Index: (ADL-FADI) and (Sport-FADI)	Questionnaires	Numeric %
6-	The chronic ankle instability scale (CAIS)	Questionnaires	Numeric %
Joint movement			
7-	Ankle-dorsiflexion range of motion (dROM)	Weight-bearing lunge	Centimetre (cm)
8-	Laxity	Ant drawer and Talar Tests	Positive/Negative

7.2 Result related to the cross-sectional study

In this section demographic data for all groups will be presented first, followed by reliability figures for all outcome measures as appropriate. Then results related to group comparisons will be presented in a format similar to the methods chapter and divided into two sections: primary and secondary outcome parameters. Lastly, an investigation of the relationships between the outcome measures, as appropriate, will also be presented using Pearson or Spearman correlation coefficients. All significant levels have been highlighted with an asterisk.

7.2.1 Demographic Data

Sixty subjects (AS = 20, CAI = 20, Healthy = 20) aged between 19 and 44 years were included in this study. Table 7-2 presents descriptive statistics for the characteristics of all subjects included. The age, weight and height ranges for participating subjects were 19–44 years (yrs), 53–90 kilograms (kg) and 157–190 centimetres (cm), respectively.

One-way ANOVA was used to ensure the groups were statistically equivalent in age, weight and height. The levels of sporting activity of the sixty subjects were presented according to Noyes et al. (1989). However, activity levels I and II were used to describe the duration of participant's activity (4–7 days/week and 1–3 days/week, respectively). The sporting level in each group is presented descriptively in Table 7-2.

Table 7-2: Demographic characteristics of subjects who participated in the cross-sectional study

Demographic (M±SD)	AS	CAI	Healthy	ANOVA
Gender	F=5, M=15	F=7, M=13	F=5, M=15	N/A
Age (year)	25.85 ± 6.55 (19 – 40)	27.05 ± 6.58 (19 – 41)	30.55 ± 6.57 (20 – 44)	F=2.76 p=0.072
Weight (kg)	73.37 ± 10.31 (55 – 89)	68.75 ± 8.86 (53 – 87)	69.99 ± 10.85 (50 -90)	F=1.15 p=0.32
Height (cm)	173.57 ± 6.63 (160 – 186)	172.15 ± 5.69 (158 – 180)	172.60 ± 7.90 (157 – 190)	F=0.23 p=0.79
Activity Level	Level I= 8 Level II= 12	Level I= 13 Level II= 7	Level I= 9 Level II= 11	N/T
Time since injury (Days)	41.59 ± 10.7	N/T	N/A	N/T
Laxity	Positive= 6 Negative= 14	Positive= 4 Negative= 16	N/T	N/T

AS= ankle sprains group; CAI= chronic ankle instability group; M±SD= mean±standard deviation; NT= Not Tested; NA= Not Applicable; kg= kilograms; cm= centimetres; *Denotes significant at p<0.05.

7.2.2 Reliability for selected parameters

To evaluate test re-test reliability, firstly a repeated measures analysis of variance (ANOVA) was used to evaluate if there was any variability within subjects' scores. Then the intraclass correlation coefficient (ICC) was calculated and interpreted as follows: less than 0.20 = slight reliability, between 0.21–0.40 = fair reliability, 0.41–0.60 = moderate reliability, 0.61–0.80 = substantial reliability, and 0.81–1.00 = excellent reliability (Landis and Koch 1977). However, the ICC value is limited by the fact that it is influenced by intersubject variability of scores (Atkinson 1998). For this reason, the standard error of measurement (SEM) is presented. The SEM provides information about how much within subject variability can be expected on scores on

repeated measurements (Atkinson 1998). Results of test–retest reliability are presented in Table 7-3 for the following outcome measurements: 1) Decision making time (DMT) and task time (TT) in milliseconds (ms) during the unanticipated and planned functional test, 2) Contact time (CT) and jump height (JH) during a deep vertical jump (DVJ), 3) Time to peak (TTP) of the tibialis anterior (TA), the peroneus longus (PL), and the lateral gastrocnemius (GAS) using EMG, 4) ankle-dorsiflexion range of motion (dfROM) using the weight-bearing lunge test.

The reliability of the DMT and TT during unanticipated and planned functional tests was calculated from three trials after removal of all invalid trials in all groups. The DMT in the AS group demonstrated different ICC values during both tests with fair reliability during the unanticipated test (ICC = 0.34) and moderated reliability (ICC = 0.65) during the planned test. The reliability of DMT in the other groups was reported with moderate to substantial ICC values during both tests (0.55 to 0.72). The reliability of TT compared with DMT was lower during both tests with ICC values ranging from 0.20 to 0.83 and a high SEM (92.09 – 132.85). No variability in DMT and TT between subjects' measurements for any group was demonstrated by ANOVA results.

The reliability of the contact time (CT) and jump height (JH) during the deep vertical jump (DVJ) was calculated from three successful trials. The result of the CT showed moderate to excellent ICC values (0.70 to 0.90) in all groups. However, the best CT reliability result was reported for the healthy group. No variability in subject's measurements for any groups was demonstrated by ANOVA results. The SEM was

small in all groups with values of 62.9, 73.6 and 46 ms for AS, CAI and healthy, respectively. The jump height (JH) was reported with moderate ICC values (0.66 to 0.78) for all groups and no variability between subjects' measurements. The SEM was small in all groups and ranged between 0.91 and 1.14 cm.

The reliability of time to peck (TTP) using EMG was calculated from three trials after removal of all invalid trials in all groups. The result of the TTP showed slight to moderate ICC values (-0.002 to 0.54) in all groups.

The reliability of dfROM was calculated from three trials on the injured ankle in AS and CAI groups and on the skilled leg in the healthy group. The dfROM showed excellent reliability for AS and CAI groups with an ICC value of 0.94 and 0.90, respectively. The repeated measures ANOVA value indicated variability between subjects' measurements in either of the two groups, as demonstrated by the respective F-values (14.4 and 13.09) and p-values (0.001 and 0.001). However, the healthy group demonstrated substantial reliability with an ICC value of 0.72 in this test with variability between patients' measurements, as demonstrated by the F-value (22.06) and p-value (0.001). The SEM was small in all groups with values of 0.63, 0.66 and 0.65 cm for AS, CAI and healthy, respectively.

Table 7-3: Reliability for selected parameters in each group in the cross-sectional study

Outcome	Group	ANOVA	ICC	95% CI		SEM
				Lower Bound	Upper Bound	
Unanticipated DMT	AS	F= 1.29 p= 0.28	0.34	0.064	0.622	70.87
	CAI	F= 1.13 p= .33	0.67	0.442	0.839	50.34
	Healthy	F= 0.36 p= 0.70	0.72	0.508	0.865	18.78
Unanticipated TT	AS	F= 0.64 p= 0.53	0.68	0.453	0.844	62.15
	CAI	F= 1.68 p= 0.20	0.76	0.571	0.887	70.01
	Healthy	F= 0.36 p= 0.62	0.42	0.142	0.680	132.85
Planned DMT	AS	F= 0.58 p= 0.56	0.66	0.427	0.833	34.88
	CAI	F= 0.78 p= 0.46	0.55	0.288	0.768	40.30
	Healthy	F= 2.29 p= 0.11	0.65	0.415	0.828	45.36
Planned TT	AS	F= 0.006 p= 0.99	0.83	0.680	0.922	57.18
	CAI	F= 0.066 p= 0.93	0.51	0.246	0.745	73.02
	Healthy	F= .195 p= 0.82	0.20	-0.063	0.505	92.09
CT	AS	F= 0.51 p= 0.54	0.70	0.485	0.856	62.9
	CAI	F= 0.26p= 0.76	0.45	0.171	0.700	73.6
	Healthy	F= 0.412 p= 0.66	0.90	0.809	0.957	46
JH	AS	F= 0.53 p= 0.58	0.76	0.570	0.887	0.91
	CAI	F= 0.122 p= 0.88	0.78	0.602	0.898	0.91
	Healthy	F= 0.97 p= 0.38	0.66	0.433	0.836	1.14
Time to the peak	AS	F= 1.49 p= 0.25	0.39	0.017	0.75	N/T

(TA muscles)	CAI	F= 0.413 p= 0.66	0.24	-0.161	0.73	N/T
	Healthy	F=0.397 p= 0.67	0.41	0.019	0.77	N/T
Time to the peak (PL muscles)	AS	F=2.16 p=0.14	0.29	-0.067	0.69	N/T
	CAI	F=0.002 p=0.97	0.38	-0.054	0.80	N/T
	Healthy	F=1.25 p=0.31	0.45	0.065	0.80	N/T
Time to the peak (GAS muscles)	AS	F=0.032 p=0.96	0.22	-0.12	0.64	N/T
	CAI	F= 6.7 p=0.011	0.54	0.068	0.88	N/T
	Healthy	F=4.5 p=0.025	-0.002	-0.28	0.47	N/T
dfROM	AS	F= 14.4 p= 0.001*	0.94	0.876	0.973	0.63
	CAI	F= 13.09 p= 0.001*	0.90	0.801	0.955	0.66
	Healthy	F= 22.06 p=0.001*	0.72	0.513	0.867	0.65

dfROM= Dorsiflexion range of motion; CT= contact time; JH= jump height; DMT= Decision Making Time; TT= Task Time; ANOVA= repeated measures analysis of variance; ICC= the intraclass correlation coefficient; CI= the 95% Confidence Interval; N/T= not tested. *Denotes significant at p<0.05

7.2.3 Comparison between groups related to the outcome parameters

The Kolmogorov–Smirnov test, histogram and Q-Q plots of each variable were checked for normality. The majority of variables appeared sufficiently normal to meet the ANOVA assumptions. Only the Foot and Ankle Disability Index (FADI) and the chronic ankle instability scale (CAIS) appeared skewed. Because all subjects in the healthy group were rated with a maximum score in these self-reported functional assessments, the normality was rechecked without using the healthy group and was

shown to be sufficiently normal to meet the ANOVA assumptions.

One-way ANOVA was conducted to investigate whether there were statistically significant differences among the three groups in terms of the outcome measures investigated at baseline, as illustrated earlier in Table 7-1, p 146. Between-groups comparisons were considered significant if $p < 0.05$. When significant differences were identified, post-hoc analyses were conducted using Bonferroni. Where both ankles had been tested, the dependent variable was compared with the injured and non-injured in AS and CAI groups and with the skilled and non-skilled leg in the healthy group using a paired t-test. Effect sizes were calculated for each parameter and interpreted using Cohen's guidelines.

7.2.3.1 Primary outcome parameters

I. Measure of functional performance during unanticipated functional test (UFT) and planned functional test (PFT)

During the UFT each subject completed 10 trials, as described previously in the methods chapter, the approach speed was statistically equivalent among groups ($F = 0.156$, $p = 0.85$) at AS = 4.75 ± 0.59 , CAI = 4.69 ± 0.59 , healthy = 4.65 ± 0.52 m/s. To evaluate the DMT and TT in milliseconds (ms) all invalid trials were removed and the mean of the best three trials was used for analysis. One-way ANOVA was conducted to investigate whether there were statistically significant differences among groups.

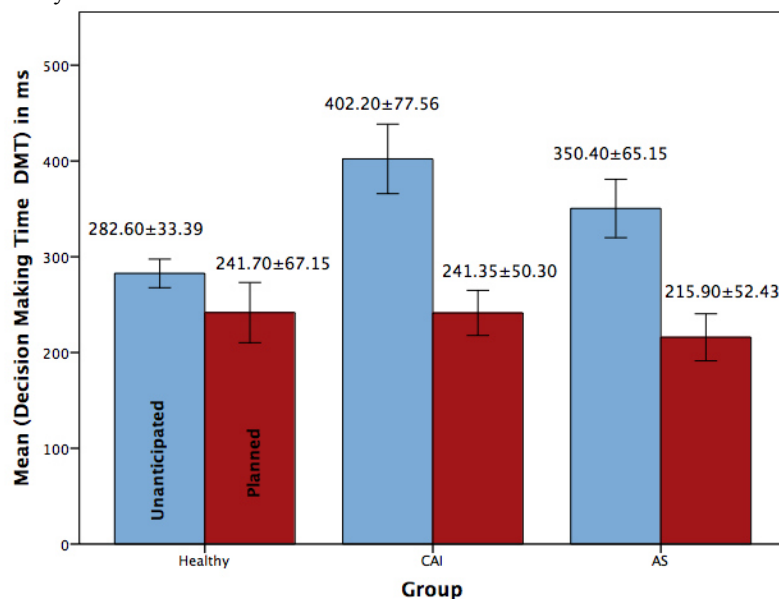
Table 7-4 outlines the result of all groups for the DMT and TT in milliseconds (ms). The result shows a significant difference between groups during UFT in only DMT ($F = 19.13$, $p = 0.001$). Post-hoc analysis revealed that the healthy group (Mean \pm SD 282.60 \pm 33.39) demonstrated faster time in decision making than both other groups. This time was longer in the CAI (Mean \pm SD 402.20 \pm 77.56) than the AS group. The difference in TT, in contrast, was found not significant between groups ($F = 2.53$, $p = 0.088$). During the PFT cutting manoeuvre the result shows no significant differences between groups in either DMT ($F = 1.34$, $p = 0.27$) or TT ($F = 1.55$, $p = 0.22$). Figures 7-1 and 7-2 show that the DMT and TT in the planned test were faster than in the unanticipated test in all groups.

Table 7-4: Functional performance during unanticipated functional test (UFT) and planned functional test (PFT) (comparison between groups in the cross-sectional study)

Outcome measure ↓	AS M \pm SD (CV%)	CAI M \pm SD (CV%)	Healthy (H) M \pm SD (CV%)	ANOVA	Bonferroni, Effect Size
<i>Unanticipated functional test (UFT)</i>					
DMT (ms)	350.40 \pm 65.15 (18.6%)	402.20 \pm 77.56 (19.3%)	282.60 \pm 33.39 (11.8%)	$F=19.13$ $p=0.001^*$	H vs. AS $p=.003^*$ EF = 1.3 H vs. CAI $p=.001^*$ EF = 2 CAI vs. AS $p=.03^*$ EF = .72
TT (ms)	1375.7 \pm 97.2 (7%)	1447.1 \pm 131 (9%)	1449.7 \pm 123.2 (8.5%)	$F=2.53$ $p=0.088$	H vs. AS EF = .66 H vs. CAI EF = .02 CAI vs. AS EF = .61
<i>Planned functional test (PFT)</i>					
DMT (ms)	215.90 \pm 52.43 (24.3%)	241.35 \pm 50.30 (20.8%)	241.70 \pm 67.15 (27.8%)	$F=1.34$ $p=0.27$	H vs. AS EF = .43 H vs. CAI EF = .006 CAI vs. AS EF = .49
TT (ms)	1208.40 \pm 130 (10.7%)	1153.70 \pm 86 (7.4%)	1180 \pm 70 (5.9%)	$F=1.55$ $p=0.22$	H vs. AS EF = .27 H vs. CAI EF = .33 CAI vs. AS EF = .49

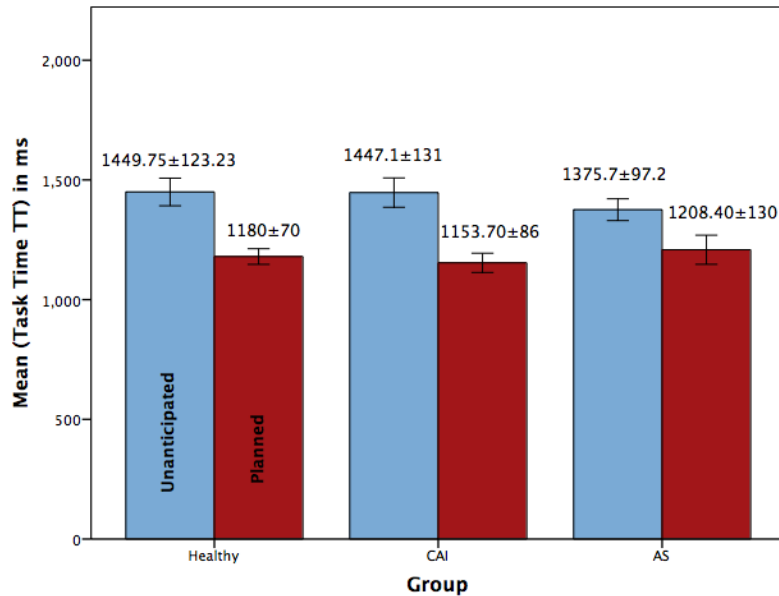
DMT= Decision Making Time; TT= Task Time, ms= milliseconds. M \pm SD= Mean \pm Standard deviation; ANOVA= analysis of variance; EF= Effect size. *Denotes significant at $p<0.05$

Figure 7-1: Comparison between unanticipated and planned functional tests for DMT in the cross-sectional study



Results presented in **mean ± standard deviation**, The unanticipated functional test is indicated by the **light blue bar** and the planned functional test is indicated by the **red bar**.

Figure 7-2: Comparison between unanticipated and planned functional tests for TT in the cross-sectional study



Results presented in **mean ± standard deviation**, The unanticipated functional test is indicated by the **light blue bar** and the planned functional test is indicated by the **red bar**.

II: Measure of functional performance during the deep vertical jump (DVJ):

In the DVJ, the flight time and contact time were generated using the vector mat system, the flight time was then converted to jump height in centimetres, as described in the methods chapter. Three trials on each ankle were evaluated and recorded as Injured and Non-Injured for AS and CAI groups and Skilled and Non-Skilled leg for the healthy group.

Table 7-5 show the results of contact time (CT) and jump height (JH) for all groups. No significant differences in CT and JH were displayed between groups. Table 7-6 shows the result of the comparison between ankles; a significant difference was found only in JH between injured and non-injured ankles for AS ($t = -4.62$, $p = 0.001$) and CAI ($t = -2.11$, $p = 0.048$) groups. The difference was not significant in either CT or JH between the skilled and non-skilled leg for the healthy group ($t = 0.79$ $p = 0.43$) and ($t = 1.4$ $p = 0.179$).

Table 7-5: Functional performance data during during the deep vertical jump (DVJ) (comparison between groups in the cross-sectional study)

Outcome measure ↓	AS M±SD	CAI M±SD	Healthy M±SD	ANOVA	Bonferroni
<i>Injured (skilled in healthy)</i>					
CT (ms)	452.85±102.9	427.3±78.4	420.85±143	F= 0.46 p= 0.63	H vs. AS EF = 0.25 H vs. CAI EF = 0.056 CAI vs. AS EF = 0.28
JH (cm)	5.5±1.70	5.8±1.83	6.5±1.73	F=1.96 p=0.15	H vs. AS EF = 0.58 H vs. CAI EF = 0.39 CAI vs. AS EF = 0.17
<i>Non-injured (Non-skilled in healthy)</i>					
CT (ms)	426.3±89.12	436.8±127.19	413.2±138.49	F= 0.194 p= 0.82	H vs. AS EF = 0.11 H vs. CAI EF = 0.18 CAI vs. AS EF = 0.095
JH (cm)	6.95±1.73	6.75±2.55	6±1.77	F=1.188 p= 0.31	H vs. AS EF = 0.54 H vs. CAI EF = 0.34 CAI vs. AS EF = 0.09

CT= contact time; JH= jump height; cm= centimetre; ms= milliseconds; ANOVA= analysis of variance; M±SD= Mean ± Standard deviation; EF= Effect size; N/A= not applicable. *Denotes significant at p<0.05

Table 7-6: Functional performance data during during the deep vertical jump (DVJ) (comparison between ankles in the cross-sectional study)

Group ↓	Injured (M±SD)	Non-Injured (M±SD)	M-diff±SD	t	Sig	Effect size
CT (ms)						
AS	452.85±102.9	426.3±89.12	26.55±66.9	1.77	0.092	0.27
CAI	427.3±78.43	436.8±127.2	-9.5±108.5	-0.39	0.70	0.09
Healthy	420.85±143	413±138.5	7.65±43.2	0.79	0.43	0.055
JH (cm)						
AS	5.55±1.7	6.95±1.73	1.4±1.35	-4.46	0.001*	0.81
CAI	5.8±1.82	6.75±2.55	0.95±2	-2.11	0.048*	0.43
Healthy	6.55±1.70	6±1.77	0.55±1.76	1.4	0.179	0.31

CT= contact time; JH= jump height; cm= centimetre; ms= milliseconds; M±SD= mean±standard deviation; t= Paired t test; (M-diff±SD)= mean difference±standard deviation. *Denotes significant at p<0.05

III. Electromyography data

EMG data were collected throughout the entire unanticipated functional test, as described previously in the methods chapter. Due to the challenges and difficulty in identifying acceptable trials were used for analysis in the current study, only 17 subjects in the AS, 15 subjects in the CAI and 14 subjects in the healthy group involved in this analysis.

Table 7-7 outlines the result of all groups for the TTP (ms) of the tibialis anterior (TA), peroneus longus (PL) and gastrocnemius lateralis (GAS). No significant differences were found in the TTP between groups for any of the three muscles. The values for the TTP showed that every muscle in each group scored the highest activity after foot contact (Table 7-7). However, the three muscles recorded showed different patterns in each group. The TTP for each muscle in each group occurred in a different order. In the AS and healthy groups, the PL first scored the highest value followed by GAS then TA. In the CAI group, the GAS first scored the highest value then the PL and TA at the same time.

Table 7-7: EMG data during the unanticipated functional test (comparison between groups in the cross-sectional study)

Time to Peak ↓	AS M±SD	CAI M±SD	Healthy M±SD	ANOVA	Bonferroni
Tibialis Anterior (TA)	118.06±85.63	127.92±70.52	139.15±78.06	F= 0.27 p= 0.76	H Vs. AS EF = .25 H Vs. CAI EF = .15 CAI Vs. AS EF = .12
Peroneus Longus (PL)	84±74.84	127.42±100	102.7±104.22	F= 0.87 p= 0.42	H Vs. AS EF = .20 H Vs. CAI EF = .24 CAI Vs. AS EF = .49
Gastrocnemius (GAS)	115.24±94.60	89.06±79.29	135.61±61.34	F= 1.21 p= 0.30	H Vs. AS EF = .25 H Vs. CAI EF = .65 CAI Vs. AS EF = .30

M±SD= mean±standard deviation; ANOVA= analysis of variance; EF= Effect size; N/A= not applicable; *Denotes significant at p<0.05

7.2.3.2 Secondary outcome parameters

I. Self-reported assessment

In the self-reported assessment, subjects were assessed using (1) The Foot and Ankle Disability Index (FADI), which contains two components: one assesses activities of daily living (FADI-ADL %) and the other is essential to sporting activities (FADI-Sport %) and (2) The chronic ankle instability scale (CAIS %). The FADI-ADL % and FADI-Sport % are scored separately as percentages, where 100% represents a higher level of physical performance, while a low percentage (%) on CAIS indicates a high level of physical performance. The healthy subjects were not asked to complete these self-reported assessments, as the inclusion criteria for this group allowed for the assumption of a maximum score, implying no restriction on activities of daily living or of sports such as running and changing direction etc.; therefore, in the comparison of groups a maximum score was given to healthy subjects (FADI-ADL = 100%, FSDI-

Sport = 100% and CAIS = 0%). One-way ANOVA was conducted to investigate whether there were statistically significant differences among groups.

Table 7-8 outlines the result of all groups, showing that there was a statistically significant difference in FADI-ADL %, FADI-Sport % and CAIS % score between groups ($F = 13.22$, $p = 0.00$; $F = 59.41$, $p = 0.00$; and $F = 104.88$, $p = 0.00$, respectively). Post-hoc analysis revealed that the CAI and AS groups demonstrated a significant lower score than healthy subjects using FADI-ADL % and FADI-Sport % and a higher score (worse) using CAIS %. Although there were significant differences between AS and CAI groups using both FADI-ADL % and FADI-Sport % scores, the difference was not significant between both groups using CAIS % score.

Table 7-8: Self-reported assessment (comparison between groups in the cross-sectional study)

	AS (M±SD)	CAI (M±SD)	Healthy (M±SD)	ANOVA	Bonferroni
FADI-ADL%**	95.1±4.18	97.5±3.12	100**±.00	F=13.22 p=0.00*	H>AS p=.001* H>CAI p=.034* CAI>AS p=.043*
FADI-Sport%**	78.9±7	91.1±8	100±.00	F=59.41 p=0.00*	H>AS p=.001* H>CAI p=.001* CAI>AS p=.001*
CAIS%***	37.7±11.4	33.02±10.6	.000***±.00	F=104.88 p=0.00*	H<AS p=.001* H<CAI p=.001* CAI<AS p=.319

ANOVA= analysis of variance; M±SD= mean±standard deviation; **Higher scores indicate higher level of physical performance; ***lower scores indicate greater higher level of physical performance. *Denotes significant at $p<0.05$

II. Ankle-dorsiflexion range of motion (dfROM)

The dfROM was measured for both ankles in all subjects using the weight-bearing lunge test, as described in the methods chapter. Table 7-9 outlines the result of dfROM in all groups. A significant difference in injured ankle in AS and CAI and skilled leg in healthy subjects ($F=16.06$ $p = 0.00$) was found between groups. Post-hoc analysis revealed that the CAI group (Mean \pm SD 11.19 \pm 2.01) demonstrated a non-significant difference value result ($p = 0.32$) when compared with the AS group (Mean \pm SD 10.17 \pm 2.51), whereas the healthy group (13.61 \pm 1.12) reported a significant best dfROM compared to AS and CAI ($p = 0.00$, $p = 0.001$).

A comparison of dfROM value between injured and non-injured ankles in AS and CAI groups and between skilled and non-skilled leg in healthy group were presented in Table 7-10. Injured ankles were significant lower compared with non-injured ankles in AS and CAI groups ($t=-6.55$ $p=0.00$, $t=-5.31$ $p=0.00$). Whereas a non significant difference was observed between skilled and non-skilled leg in healthy group ($t=1.88$ $p= 0.075$ (difference Mean \pm SD 0.35 \pm 0.83))

Table 7-9: Dorsiflexion range of motion (dfROM) comparison between groups in the cross-sectional study

	AS (M±SD)	CAI (M±SD)	Healthy (M±SD)	ANOVA	Bonferroni, EF
Injured or skilled leg	10.17±2.51	11.19±2.01	13.61±1.12	F=16.06 p=0.00*	H>AS p=0.001* EF= 1.77 H>CAI p=0.001* EF= 1.5 CAI>AS p=0.32 EF= 0.45
Non-injured	12.67± 1.51	12.85±1.43	13.26±1.49	F= .836 p=0.44	H vs.AS EF= 0.4 H vs. CAI EF= 0.3 CAI vs.AS EF= 0.12

dfROM= Dorsiflexion range of motion; **ANOVA**= analysis of variance; (M±SD)= mean±standard division; **EF**= Effect size. *Denotes significant at p<0.05

Table 7-10: Dorsiflexion range of motion (dfROM) comparison between ankles in the cross-sectional study

	dfROM (Injured) (M±SD)	dfROM (Non- injured) (M±SD)	Paired <i>t</i>	Effect size
AS	10.17±2.51	12.67±1.51	t=-6.55 p=0.00* (-2.49±1.7)	1.2
CAI	11.19±2.01	12.85±1.43	t=-5.31 p=0.00* (-1.66±1.4)	0.95
Healthy	13.61±1.12	13.26±1.49	t=1.88 p=.075 (0.35±0.83)	0.26

dfROM= Dorsiflexion range of motion; (M±SD)= mean±standard division *Denotes significant at p<0.05

III. Isokinetic strength data

Table 7-11 presents isokinetic strength data of injured ankle in AS and CAI groups and the skilled leg in the healthy group. The results are presented as peak torque (PT) and normalised peak torque to each subject's body weight (PT/BW) for concentric (Con) and eccentric (Ecc) contractions of both the right and left ankle and for inverter (Inv) and evertor (Eve) muscles. The results show that a significant difference between

groups was only found for inversion in Con-PT/BW ($F = 6.32$; $p = 0.003$) and Ecc-PT/BW ($F = 5.52$, $p = 0.006$). Post-hoc analysis revealed that there was only a difference between the healthy and AS groups, as demonstrated by a p-value of 0.002 and 0.005, respectively. Table 7-12 presented isokinetic strength data of non-injured ankle in AS and CAI groups and the non-skilled leg in the healthy group. The results show that no significant difference in any variable was observed between groups.

A comparison of strength value of injured and non-injured ankles in AS and CAI groups and between skilled and non-skilled leg in the healthy group were presented in Table 7-13. For the healthy group the results show that no significant difference in any variable was observed between the skilled and non-skilled leg. For the AS group the result shows that a significant difference was found only in inversion movement using Ecc-PT/BW, as demonstrated by $t = -2.13$ and $p = 0.046$. For the CAI group, the result shows that a significant difference in inversion using Con-PT ($t = -2.47$, $p = 0.023$) and Con-PT/BW ($t = -2.38$, $p = 0.028$) and in eversion using Ecc-PT ($t = -2.21$, $p = 0.039$) and Ecc-PT/BW ($t = -2.36$, $p = 0.029$) was found between ankles.

Table 7-11: Isokinetic strength data, comparison between groups (Injured ankle) in the cross-sectional study

	AS (M±SD)	CAI (M±SD)	Healthy (M±SD)	ANOVA	Bonferroni, EF
Inversion (Injured)					
Con-PT	33.65±8.4	34.40±7.1	38.50±6.2	F=2.53 p=.089	H vs.AS EF= .65 H vs. CAI EF= .61 CAI vs.AS EF= .1
Con-PT/BW%	45.93±10.24	50.65±11.12	57.11±8.36	F=6.32 p=.003*	H>AS p=0.002* EF= 1.2 H>CAI p=0.136 EF= .65 CAI>AS p=0.421 EF=.44
Ecc-PT	34.55±8.1	35.25±7.1	38.95±7.09	F=2.0 p=.144	H vs.AS EF= .58 H vs. CAI EF= .52 CAI vs.AS EF= .092
Ecc-PT/BW %	46.95 ± 8.4	51.99±11.92	57.84 ± 10.48	F=5.52 p= .006*	H>AS p=0.005* EF= 1.15 H>CAI p=0.24 EF= .52 CAI>AS P=0.39 EF= .49
Eversion (Injured)					
Con-PT	33±6.64	32.85±8.78	33.70±7.54	F=.069 p=.93	H vs.AS EF= .099 H vs. CAI EF= .1 CAI vs.AS EF= .019
Con-PT/BW%	45.39±9.60	47.7±11.29	49±9	F= .675 p=.51	H vs.AS EF= .38 H vs. CAI EF= .13 CAI vs.AS EF= .22
Ecc-PT	35.25±7.1	34.70±8.31	36.25±7.8	F=.204 p=.81	H vs.AS EF= .13 H vs. CAI EF= .19 CAI vs.AS EF= .071
Ecc-PT/BW %	48.24±8.72	50.64±10.96	52.92±10.67	F=1.05 p=.35	H vs.AS EF= .48 H vs. CAI EF= .21 CAI vs.AS EF= .24

Con-PT= Concentric Peak Torque; **Ecc-PT**= Eccentric Peak Torque **Con-PT/BW**= Concentric Peak Torque/body-weight; **Ecc-PT/BW**= Eccentric Peak Torque; **ANOVA**= analysis of variance; **(M±SD)**= mean±standard deviation; **EF**= Effect size. *Denotes significant at p<0.05.

Table 7-12: Isokinetic strength data, comparison between groups (Non-injured ankle) in the cross-sectional study.

	AS (M±SD)	CAI (M±SD)	Healthy (M±SD)	ANOVA	Bonferroni
Inversion (non-Injured)					
Con-PT	37.80±7.1	37.15±4.9	35.50±8.9	F=.539 p=.58	N/A
Con-PT/BW	52.2±11.2	54.3±5.9	52.2±13.8	F=.261 p=.77	N/A
Ecc-PT	38.5±7.7	37.6±7	38±9.8	F=.060 p=.94	N/A
Ecc-PT/BW	53.07±10.9	55.11±9.1	56.3±13.8	F=.405 p=.67	N/A
Eversion (non-Injured)					
Con-PT	33.05±5.5	34.15±5.8	31±5.7	F=1.6 p=.21	N/A
Con-PT/BW	45.5±7.7	50.3±9.66	46.18±8.6	F= 1.8 p=.17	N/A
Ecc-PT	37.50±6	37.30±6.1	33.85±6.6	F= 2.1 p=.12	N/A
Ecc-PT/BW	51.7±8.8	54.6±8.6	50.3±9.2	F=1.2 p=.29	N/A

Con-PT= Concentric Peak Torque; **Ecc-PT**= Eccentric Peak Torque **Con-PT/BW**= Concentric Peak Torque/body-weight; **Ecc-PT/BW**= Eccentric Peak Torque; **ANOVA**= analysis of variance; **(M±SD)**= mean±standard deviation *Denotes significant at p<0.05.

Table 7-13: Isokinetic strength data, comparison between ankles in each group in the cross-sectional study

Inversion	AS		CAI		Healthy	
	M±SD	Paired <i>t</i> EF	M±SD	Paired <i>t</i> EF	M±SD	Paired <i>t</i> EF
Con-PT (Injured) Vs. (NON Injured)	4.15±9.91	t=-1.87 p=.077 EF=.53	2.75±4.97	t=-2.47 p=.023* EF=.45	3.00±12.46	t=1.076 p=.29 EF=.39
Con-PT/BW (Injured) Vs. (NON Injured)	6.27±13.92	t=-2.01 p=.058 EF=.58	3.69±6.93	t=-2.38 p=.028* EF=.41	4.91±17.79	t=1.23 p=.23 EF=.43
Ecc-PT (Injured) Vs. (NON Injured)	-4±9.13	t=-1.96 p=.065 EF=.50	2.40±5.26	t=-2.03 p=.056 EF=.25	.95±6.05	t=.701 p=.49 EF=.11
Ecc-PT /BW (Injured) Vs. (NON Injured)	6.11±12.8	t=-2.13 p=.046* EF=.63	3.11±7.94	t=-1.75 p=.096 EF=.29	1.54±8.77	t=.787 p=.44 EF=.12
Eversion	M±SD	Paired <i>t</i> EF	M±SD	Paired <i>t</i> EF	M±SD	Paired <i>t</i> EF
Con-PT (Injured) Vs. (NON Injured)	.050±4.64	t=-.048 p=.962 EF=.008	1.3±6.97	t=-.834 p=.41 EF=.17	2.70±9.86	t=1.22 p=.23 EF=.40
Con-PT/BW (Injured) Vs. (NON Injured)	.091±6.63	t=-.062 p=.951 EF=.012	2.61±10.33	t=-1.13 p=.27 EF=.25	2.85±10.67	t=1.19 p=.24 EF=.32
Ecc-PT (Injured) Vs. (NON Injured)	2.25±5.92	t=-1.7 p=.105 EF=.34	2.60±5.24	t=-2.21 p=.039* EF=.35	2.40±11.04	t=.972 p=.34 EF=.33
Ecc-PT /BW (Injured) Vs. (NON Injured)	3.44±8.22	t=-1.87 p=.076 EF=.39	4.02±7.61	t=-2.36 p=.029* EF=.40	2.62±12.68	t=.924 p=.36 EF=.26

Con-PT= Concentric Peak Torque; **Ecc-PT**= Eccentric Peak Torque **Con-PT/BW**= Concentric Peak Torque/body-weight; **Ecc-PT/BW**= Eccentric Peak Torque. ; (M±SD)= Mean difference ± Standard deviation; **EF**= Effect size. *Denotes significant at p<0.05

7.2.4 Correlation between selected parameters

Correlations were computed to evaluate if there was any relationship between the selected parameters. Because approach speed and muscle strength were expected to influence the functional tasks, the correlations examined were 1) Approach speed and DMT and TT during the unanticipated functional test (UFT) and planned functional test, 2) Muscle strength data and DMT, TT, CT and JH. Additionally, groups' performance in the functional task was evaluated for correlation with the self-reported assessment.

Table 7-14 shows that during the UFT, the approach speed was correlated with only TT in AS and CAI groups ($r = -0.51$, $p = 0.020$, $r = -0.49$, $p = 0.025$), whereas during the planned functional test the correlation was observed only between approach speed and TT in the AS group ($r = -0.49$, $p = 0.026$).

Table 7-14: Correlation between approach speed (A-Speed) and DMT and TT in the cross-sectional study

	AS	CA	Healthy
<i>Unanticipated functional test (UFT)</i>			
DMT Vs. A-Speed	$r = 0.053$ $p = 0.82$	$r = 0.34$ $p = 0.14$	$r = 0.35$ $p = 0.12$
TT Vs. A-Speed	$r = -0.51$ $p = 0.020^*$	$r = -0.49$ $p = 0.025^*$	$r = -0.26$ $p = 0.25$
<i>Planned functional test (PFT)</i>			
DMT Vs. A-Speed	$r = -0.25$ $p = 0.27$	$r = -0.005$ $p = 0.98$	$r = -0.43$ $p = 0.055$
TT Vs. A-Speed	$r = -0.49$ $p = 0.026^*$	$r = -0.36$ $p = 0.11$	$r = 0.17$ $p = 0.47$

A-Speed= Approach Speed; **DMT**= Decision Making Time; **TT**= Task Time. * Denotes significant correlation at $p < 0.05$

Table 7-15 shows that muscle strength was not correlated with any functional performance test in the AS group. For the CAI group the significant correlation was between the jump height and inversion (Con-PT $r = 0.52$, $p = 0.018$) and between contact time and eversion (Con-PT $r = 0.45$, $p = 0.046$; Ecc-PT $r = 0.49$, $p = 0.027$; and Ecc-PT/BW $r = 0.44$, $p = 0.05$). For the healthy group a significant correlation was found in inversion between U-TT and (Ecc-PT $r = 0.44$, $p = 0.05$) and between JH and (Con-PT/BW $r = -0.47$, $p = 0.035$), whereas in eversion movement there was a significant correlation between JH and (Con-PT $r = 0.67$, $p = .001$; Con-PT/BW $r = 0.44$, $p = 0.048$; Ecc-PT $r = 0.64$, $p = 0.002$).

Table 7-15: correlation between muscles strength data and DMT, TT, CT and JH in the cross-sectional study

	AS group				CAI group				Healthy group			
	Concentric PT	Concentric PT/BW	Eccentric PT	Eccentric PT/BW	Concentric PT	Concentric PT/BW	Eccentric PT	Eccentric PT/BW	Concentric PT	Concentric PT/BW	Eccentric PT	Eccentric PT/BW
INVERSION (Injured ankle)								INVERSION (Skilled leg)				
U-DMT	r =.38 p =.094	r =.29 p =.21	r =.23 p =.33	r =.14 p =.55	r =-.32 p =.89	r =-.041 p =.86	r =-.14 p =.54	r =-.13 p =.57	r =.089 p =.71	r =-.14 p =.53	r =.38 p =.095	r =.20 p =.38
U -TT	r =.052 p =.83	r =.15 p =.50	r =.13 p =.57	r =.26 p =.27	r =-.22 p =.33	r =-.051 p =.83	r =-.16 p =.49	r =.025 p =.91	r =.18 p =.43	r =.15 p =.50	r =.44 p =.05*	r =.41 p =.071
P-DMT	r =.068 p =.77	r =-.025 p =.91	r =.078 p =.74	r =-.042 p =.86	r =.23 p =.33	r =.21 p =.36	r =.21 p =.35	r =.18 p =.43	r =.158 p =.50	r =.052 p =.82	r =.138 p =.56	r =.035 p =.88
P-TT	r =.025 p =.91	r =.018 p =.94	r =.020 p =.93	r =-.006 p =.97	r =-.32 p =.17	r =-.01 p =.96	r =-.32 p =.16	r =.01 p =.96	r =.25 p =.28	r =.18 p =.43	r =.32 p =.16	r =.27 p =.25
CT	r =-.15 p =.52	r =-.39 p =.088	r =.067 p =.77	r =-.17 p =.47	r =.25 p =.28	r =.14 p =.54	r =.24 p =.29	r =.12 p =.59	r =.21 p =.35	r =.39 p =.083	r =-.12 p =.61	r =.015 p =.95
JH	r =.14 p =.53	r =.32 p =.17	r =.13 p =.57	r =.40 p =.081	r =.52 p =.018*	r =.43 p =.056	r =.36 p =.11	r =.26 p =.26	r =-.27 p =.25	r =-.47 p =.035*	r =-.12 p =.58	r =-.26 p =.25
EVERSION (Injured ankle)								EVERSION (Skilled leg)				
U-DMT	r =.090 p =.70	r =-.034 p =.88	r =.23 p =.32	r =.12 p =.59	r =.095 p =.69	r =.086 p =.72	r =.198 p =.4	r =.20 p =.37	r =.12 p =.59	r =.25 p =.27	r =.075 p =.75	r =.18 p =.42
U-TT	r =-.003 p =.98	r =.063 p =.79	r =-.010 p =.96	r =.084 p =.72	r =-.34 p =.14	r =-.21 p =.36	r =-.41 p =.067	r =-.288 p =.21	r =-.13 p =.56	r =-.22 p =.35	r =-.24 p =.29	r =-.33 p =.15
P-DMT	r =.18 p =.44	r =.019 p =.94	r =.27 p =.24	r =.133 p =.57	r =.15 p =.51	r =.20 p =.39	r =.10 p =.65	r =.13 p =.57	r =-.28 p =.23	r =-.16 p =.48	r =-.28 p =.23	r =-.14 p =.55
P-TT	r =-.071 p =.76	r =-.099 p =.67	r =-.040 p =.86	r =-.065 p =.78	r =-.29 p =.20	r =-.079 p =.74	r =-.31 p =.17	r =-.077 p =.74	r =-.073 p =.76	r =.14 p =.53	r =-.12 p =.61	r =.085 p =.72
CT	r =.14 p =.53	r =-.06 p =.80	r =.13 p =.58	r =-.095 p =.69	r =.45 p =.046*	r =.42 p =.064	r =.49 p =.027*	r =.44 p =.05*	r =-.41 p =.067	r =-.29 p =.21	r =-.40 p =.079	r =-.24 p =.29
JH	r =-.15 p =.52	r =.059 p =.80	r =-.14 p =.56	r =.071 p =.766	r =.28 p =.22	r =.31 p =.18	r =.32 p =.16	r =.33 p =.14	r =.67 p =.001*	r =.44 p =.048*	r =.64 p =.002*	r =.35 p =.12

PT= Peak Torque; PT/BW= Peak Torque/body-weight; DMT= Decision Making Time; TT= Task Time (U= unanticipated, P= Planned); CT= Contact time; JH= Jump Height. * denotes significant correlation at p<0.05

Table 7-16 shows that only the performance of the AS group in JH was correlated with their assessment in FADI-ADL ($r = -0.47$, $p = 0.036$). For the CAI group a significant correlation was found between unanticipated functional performance (DMT and TT) and FADI-Sport score ($r = 0.53$, $p = 0.016$; $r = -0.47$, $p = 0.035$).

Table 7-16: correlation between Self-reported assessment and DMT and TT in the cross-sectional study

Measurements	Vs.	FADI-ADL%		FADI-Sport %		CAIS%	
		AS	CAI	AS	CAI	AS	CAI
Unanticipated functional test	DMT	$r = .16$ $p = .50$	$r = .20$ $p = .39$	$r = .19$ $p = .40$	$r = .53$ $p = .016^*$	$r = .28$ $p = .21$	$r = -.35$ $p = .13$
	TT	$r = -.21$ $p = .35$	$r = -.057$ $p = .81$	$r = .11$ $p = .62$	$r = -.47$ $p = .035^*$	$r = .15$ $p = .52$	$r = .09$ $p = .70$
Planned functional test	DMT	$r = -.06$ $p = .80$	$r = -.199$ $p = .40$	$r = .17$ $p = .46$	$r = .084$ $p = .72$	$r = -.066$ $p = .78$	$r = .24$ $p = .29$
	TT	$r = -.24$ $p = .29$	$r = .28$ $p = .22$	$r = -.097$ $p = .68$	$r = .25$ $p = .28$	$r = .185$ $p = .43$	$r = -.30$ $p = .19$
Deep vertical jump (DVJ)	JH	$r = -.47$ $p = .036^*$	$r = -.13$ $p = .58$	$r = .17$ $p = .47$	$r = .079$ $p = .74$	$r = -.031$ $p = .89$	$r = .19$ $p = .41$
	CT	$r = .14$ $p = .55$	$r = .15$ $p = .50$	$r = .14$ $p = .54$	$r = .36$ $p = .11$	$r = .11$ $p = .62$	$r = .10$ $p = .66$

DMT= Decision Making Time; TT= Task Time (U= unanticipated, P= Planned); CT= Contact time; JH= Jump Height. * Denotes significant correlation at $p < 0.05$

Table 7-17 shows that contact time CT was correlated with JH only in AS for the non-injured ankle and in the healthy group for the non-skilled leg. However, a trend toward significance was noted in the CAI group with the injured ankle ($r = 0.43$, $p = 0.059$).

Table 7-17: Correlation between Jump height and contact time in the cross-sectional study

	AS	CAI	Healthy
JH Vs. CT (injured)	r= -0.20 p= 0.37	r= 0.43 p= 0.059	r= -0.33 p= 0.15
JH Vs. CT (non-injured)	r= -0.67 p= 0.001*	r= -0.26 p= 0.26	r= -0.59 p= 0.005*

CT= Contact time; JH= Jump Height; * Denotes significant correlation at p<0.05

Table 7-18 shows that DMT was correlated with TT in planned condition in the AS group (r = 0.48, p = 0.03) and in an unanticipated condition in the CAI group (r = -0.45, p = 0.045). A non-significant correlation was noted in the healthy group in both conditions. Table 7-19 shows that DMT was correlated with time to peak of peroneus longus (PL) only in the CAI group.

Table 7-18: Correlation between DMT and TT in the cross-sectional study

	AS	CAI	Healthy
DMT Vs. TT (unanticipated)	r= -0.25 p= 0.28	r= -0.45 p= 0.045*	r= -0.18 p= 0.43
DMT Vs. TT (Planned)	r= 0.48 p= 0.03*	r= -0.34 p= 0.14	r= 0.05 p= 0.82

DMT= Decision Making Time; TT= Task Time; * Denotes significant correlation at p<0.05

Table 7-19: Correlation between muscle (Time to Peak) and DMT in the cross-sectional study

	AS	CAI	Healthy
<i>Unanticipated functional test (UFT)</i>			
DMT Vs. TTP Tibialis Anterior (TA)	r= 0.051 p= 0.86	r= -0.27 p= 0.32	r= 0.19 p= 0.45
DMT Vs. TTP Peroneus Longus (PL)	r= 0.18 p= 0.53	r= 0.81 p= 0.001*	r= -0.11 p= 0.96
DMT Vs. TTP Gastrocnemius (GAS)	r= -0.10 p= 0.73	r= -0.10 p= 0.071	r= -0.03 p= 0.89

TTP= Time to Peak; DMT= Decision Making Time. * Denotes significant correlation at p<0.05

7.3 Result related to the longitudinal study

The aim of this study was to investigate the progress of subjects in the AS group over 6 months plus a final self-reported follow-up at least 12 months after the onset of injury. This study was also aimed to identify predictor of functional recovery by investigating which of the functional parameters measured at baseline contribute to the functional outcome score using self-reported assessment at 3 parts time (baseline, 3-month and 12-month). Of the 20 subjects from AS group who were assessed at the initial visit (baseline), 10 subjects completed the 2nd visit and only 4 subjects completed the 3rd visit. Due to insufficient numbers at the 3rd visit, these data were not used to perform any statistical analysis. The final self-reported follow-up was sent and collected from all subjects who completed the initial visit (n = 20). Only 12 subjects responded to this final self-reported functional assessment..

In this section demographic data for all subjects included in this study will be presented first, followed by a visits comparison, which will be presented similar to the cross-sectional study and divided into two sections: primary and secondary outcome parameters. The final part in this section presents result of investigating predictor of functional recovery. All significant levels have been highlighted with an asterisk.

7.3.1 Demographic Data

Of the original 20 subjects in the AS group, only 10 subjects completed the 2nd visit and included in this study. Table 7-20 presents descriptive statistics for the characteristics of all subjects included in this study and the CAI and healthy groups used in the cross-sectional study. The age, weight and height ranges for participating subjects in both visits were 19–36 years, 59.5–90 kilograms (kg) and 169–186 centimetres (cm). The levels of sporting activity of the subjects were presented according to Noyes et al. (1989). However, sport levels I and II were used to describe the duration of participants' activity (4–7 days/week and 1–3 days/weeks, respectively).

Table 7-20: Demographic characteristics of subjects who participated in the longitudinal study

	AS (1 st and 2nd visit) M±SD	CAI M±SD	Healthy M±SD
N	10	20	20
Age (year)	26.20 ± 6.73 (19 – 36)	27.05 ± 6.58 (19 – 41)	30.55 ± 6.57 (20 – 44)
Weight (kg)	75.60 ± 10 (59.5 – 90)	68.75 ± 8.86 (53 – 87)	69.99 ± 10.85 (50 -90)
Height (cm)	175.15 ± 5.68 (169 – 186)	172.15 ± 5.69 (158 – 180)	172.60 ± 7.90 (157 – 190)
Activity Level	Level I= 6 Level II= 4	Level I= 13 Level II= 7	Level I= 9 Level II= 11

7.3.2 Comparison between visits related to the outcome parameters

To investigate the progress of subjects in the AS group, data of subjects who completed the 2nd visit (n=10) were compared statistically with their result at the 1st visit. The mean and standard deviation of each outcome were presented in charts and used for descriptive analysis for both visits compared with healthy and CAI groups.

The Kolmogorov–Smirnov test, histogram and Q-Q plots of each variable were checked for normality. All variables appeared sufficiently normal to meet the t-test assumptions. Paired t-test was conducted to investigate whether there were statistically significant differences between the AS 1st visit and AS 2nd visit. Between visits comparisons were considered significant if $p < 0.05$.

7.3.2.1 Primary outcome parameters

I. Measure of functional performance during unanticipated functional test (UFT) and planned functional test (PFT)

Table 7-21 outlines the performance results during UFT using DMT and TT. As reported earlier in the cross-sectional study, a significant difference in DMT between AS and healthy and CAI groups was found ($F = 19.13$ $p = 0.001$). Subjects in the AS group at the 2nd visit demonstrated a significant better score for DMT (faster) when compared with their results at the 1st visit with mean value difference of 74.2 ms ($t = 2.98$ $p = 0.015$). The DMT also demonstrated an overall improved score (mean \pm SD 260.7 \pm 36.17), reaching a just better than healthy mean score (mean \pm SD 282.60 \pm 33.39)

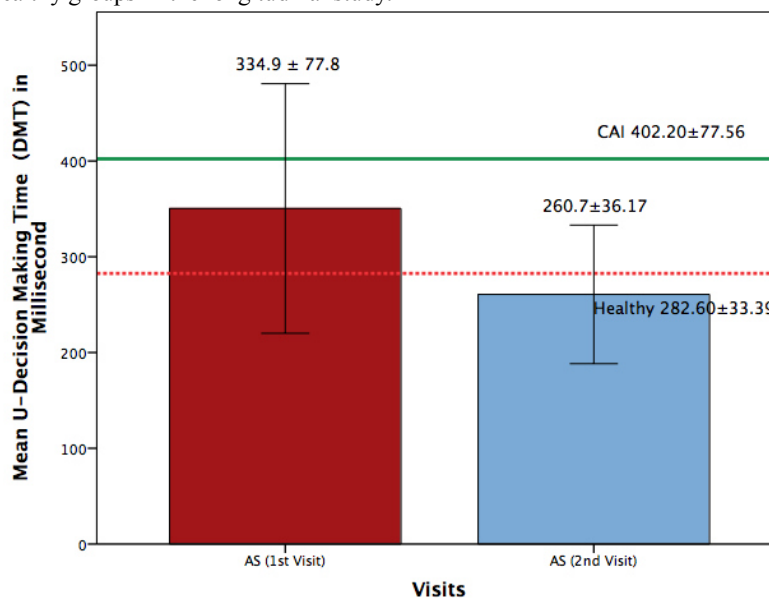
as illustrated in Figure 7-3. Although the AS group at the 1st visit demonstrated faster TT than both the healthy and the CAI group, the AS subjects demonstrated an overall improved score (faster) at the 2nd visit with significant differences between the 1st and 2nd visit, 119.5 (t=2.87 p=0.018) reaching a just better than both the healthy and the CAI group as illustrated in Figure 7-4.

Table 7-21: Comparison between the 1st and 2nd visits in U-DMT and U-TT in the longitudinal study

	AS (1 st Visit) M±SD	AS (2 nd Visit) M±SD	1 st and 2 nd Visits comparison t-test (p)	CAI M±SD	Healthy M±SD
U-DMT (ms)	334.9 ± 77.8	260.7 ± 36.17	t=2.98 p=0.015*	402.20±77.56	282.60±33.39
U-TT (ms)	1382.5 ± 121.38	1263 ± 92.17	t=2.87 p=0.018*	1447.1±131	1449.75±123.23

DMT= Decision Making Time; **TT**= Task Time; **U**= unanticipated; **ms**= milliseconds. **M±SD**= mean±standard deviation; **t-test** = Paired t-test. *Denotes significant at p<0.05

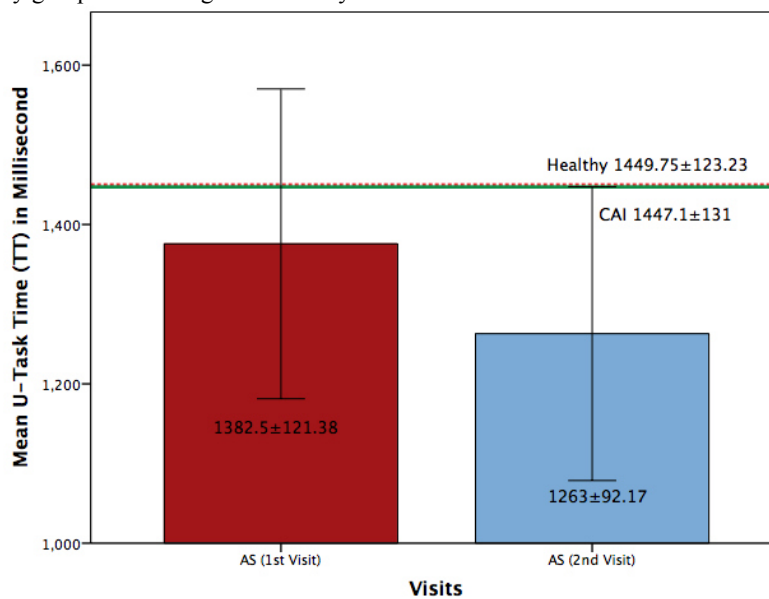
Figure 7-3: Mean U-DMT and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from the healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

Figure 7-4: Mean U-TT and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

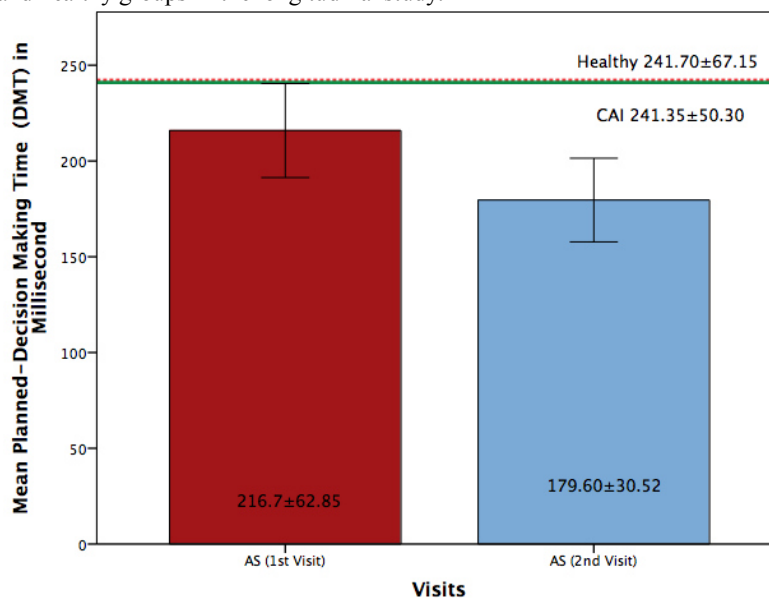
Table 7-22 outlines the performance results during PFT using DMT and TT. As reported earlier in the cross-sectional study the direction of the difference changed during PFT. The AS group was faster in DMT than the healthy group at both visits as illustrated in Figure 7-5. Subjects in the AS group at the 2nd visit demonstrated a better score for DMT (faster) when compared with the 1st visit with mean value difference of 37.1 ms but not significant ($t=1.38$ $p=0.19$). The TT during PFT demonstrated an overall improved score at the 2nd visit (mean \pm SD 1128.40 \pm 86.54), reaching a just better than healthy mean score (mean \pm SD 1180 \pm 70) with no significant differences ($t=1.30$ $p=0.22$) with mean difference of 63.3 ms, compared with the 1st visit as illustrated in Figure 7-6.

Table 7-22: Comparison between the 1st and 2nd visits in Planned-DMT and Planned-TT in the longitudinal study.

	AS (1 st Visit) M \pm SD	AS (2 nd Visit) M \pm SD	1 st and 2 nd Visits comparison t-test (p)	CAI M \pm SD	Healthy M \pm SD
Planned-DMT (ms)	216.7 \pm 62.85	179.60 \pm 30.52	$t=1.38$ $p=0.19$	241.35 \pm 50.30	241.70 \pm 67.15
Planned-TT (ms)	1191.70 \pm 130.9	1128.40 \pm 86.54	$t=1.30$ $p=0.22$	1153.70 \pm 86	1180 \pm 70

DMT= Decision Making Time; TT= Task Time; ms= milliseconds. M \pm SD= mean \pm standard deviation; t-test = Paired t-test.
*Denotes significant at $p<0.05$

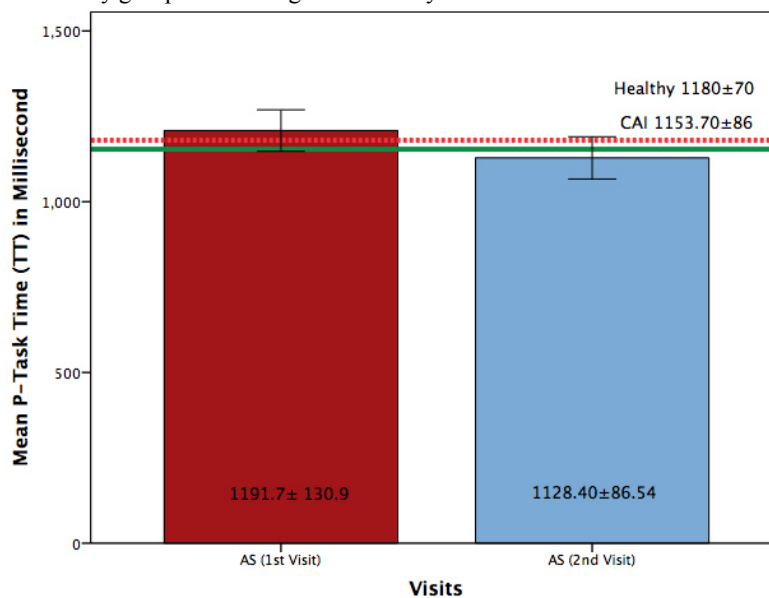
Figure 7-5: Mean Planned-DMT and standard deviation for the AS group at 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from the healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

Figure 7-6: Mean Planned-TT and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

II. Measure of functional performance during the deep vertical jump (DVJ):

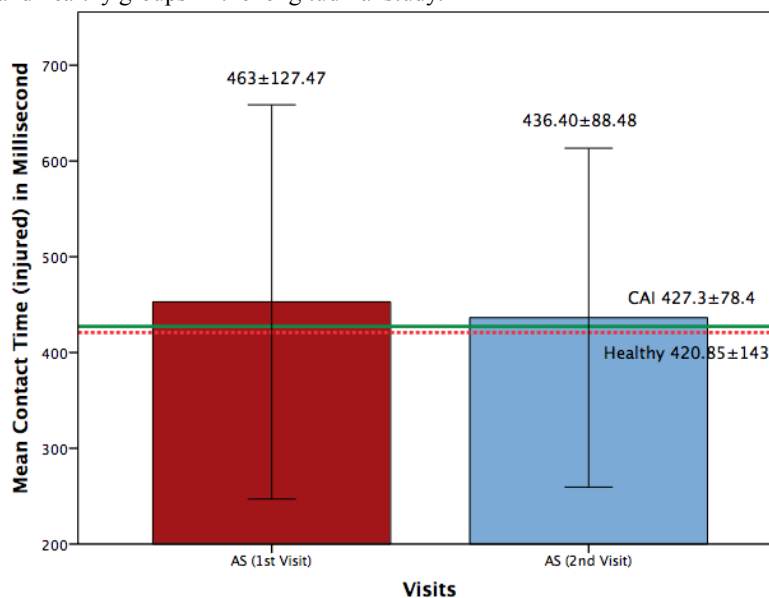
The AS subjects at the 2nd visit had scored better for jump height, with a significant difference when compared with the result of the 1st visit with a mean difference of 1.68 cm ($t=-2.85$ $p=0.019$). The AS subjects demonstrated an overall improved in jump score (higher) during the 2nd visit, reaching above both the healthy and CAI groups, as illustrated in Figure 7-8. Although the AS subjects at the 2nd visit scored a better contact time (short time) with a mean difference of 26.6 ms, this difference was not statistically significant ($t=0.78$ $p=0.45$).

Table 7-23: Comparison between the 1st and 2nd visits in JH and CT in the longitudinal study

	AS (1 st Visit) M±SD	AS (2 nd Visit) M±SD	1 st and 2 nd Visits comparison t-test (p)	CAI M±SD	Healthy M±SD
JH (cm)	5.10 ±1.58	6.78 ± 1.43	$t=-2.85$ $p=0.019^*$	5.8±1.83	6.5±1.70
CT (ms)	463 ± 127.47	436.40 ± 88.48	$t=0.78$ $p=0.45$	427.3±78.4	420.85±143

CT= contact time; JH= jump height; cm= centimetre; ms= milliseconds; t-test = Paired t-test; M±SD= mean±standard deviation *Denotes significant at $p<0.05$

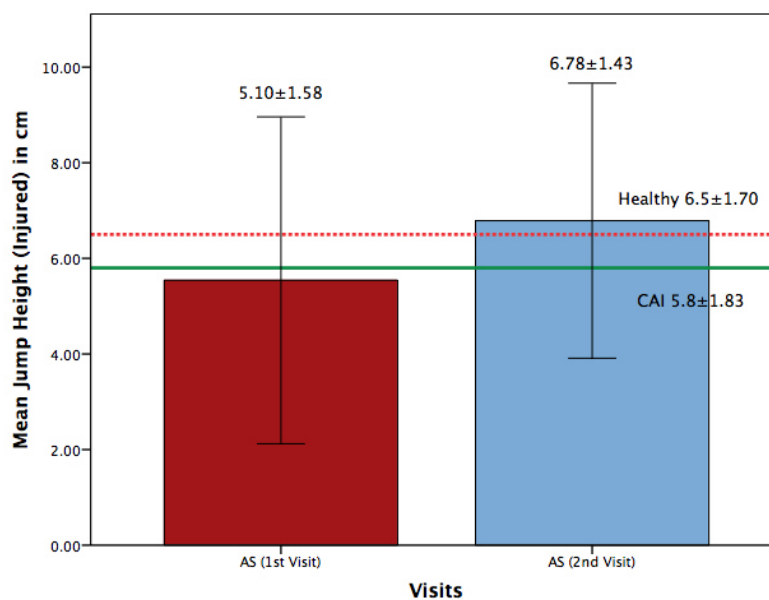
Figure 7-7: Mean contact time and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

Figure 7-8: Mean jump height and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

Table 7-24 shows the result of the comparison between ankles during the 2nd visit. The difference was not significant in either CT or JH between injured and non-injured ankles for AS group at 2nd visit ($t = -2.16$ $p = 0.059$) and ($t = 1.38$ $p = 0.19$) respectively.

Table 7-24: Functional performance data during the deep vertical jump (DVJ) (comparison between ankles in the longitudinal study)

	Injured (M±SD)	Non-Injured (M±SD)	M-diff±SD	Paired <i>t</i>	Sig	Effect size
CT (ms)						
AS 2 nd visit	436.4±88.48	505±152.48	68.6±100.43	-2.16	0.059	0.55
JH (cm)						
AS 2 nd visit	6.78±1.43	6.20±1.39	0.58±1.34	1.38	0.19	0.41

CT= contact time; JH= jump height; cm= centimetre; ms= milliseconds; M±SD= mean±standard deviation; (M-diff±SD)= mean difference±standard deviation. *Denotes significant at $p < 0.05$

III. Electromyography data

Due to the challenges and difficulty in identifying acceptable trials were used for analysis in the current study, only 8 subjects in the AS at 2nd visit compared with 10 subjects in the AS at 1st visit. For descriptive analysis data, this data were compared with data of 15 subjects in the CAI and 14 subjects in the healthy group. Table 7-25 outlines the result of both visits and other groups for the TTP (ms) of the tibialis anterior (TA), peroneus longus (PL) and gastrocnemius lateralis (GAS). No significant differences were found in the TTP between the AS at 1st and 2nd visits for any of the three muscles. The values for the TTP showed that every muscle in each group scored the highest activity after foot contact.

Table 7-25: Comparison between the 1st and 2nd visits in EMG data in the longitudinal study.

Time to Peak (ms) ↓	AS 1 st visit M±SD	AS 2 nd visit M±SD	CAI M±SD	Healthy M±SD	1 st and 2 nd Visits comparison t-test (p)
Tibialis Anterior (TA)	138.83±85.55	101±77.38	127.92±70.52	139.15±78.06	t= .84 p= .42
Peroneus Longus (PL)	79±93.75	140.37±48.22	127.42±100	102.7±104.22	t= -1.44p=.19
Gastrocnemius GAS	129.68±89.66	155.65±38.44	89.06±79.29	135.61±61.34	t=-.70 p=.50

ms= milliseconds. M±SD= mean±standard deviation; t-test = Paired t-test. *Denotes significant at p<0.05

7.3.2.2 Secondary outcome parameters

I. Self-reported assessment

This section present results of participants' self-reported assessment: (1) The Foot and Ankle Disability Index (FADI) contains two components: one assesses activities of daily living (FADI-ADL %) and the other is essential to sporting activities (FADI-Sport %) and (2) The chronic ankle instability scale (CAIS %). The FADI-ADL % and FADI-Sport % are scored separately as percentages, where 100% represents a higher level of physical performance, while a low percentage (%) on CAIS indicates a high level of physical performance. Paired t-test was conducted to investigate whether there were statistically significant differences between the AS 1st visit and AS 2nd visit.

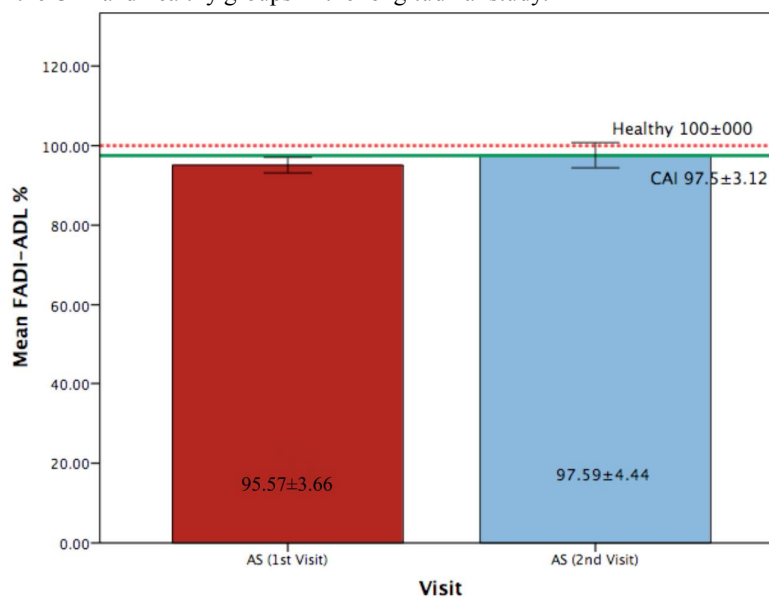
Table 7-26 outlines the mean and standard deviation of self-reported assessment and the difference between the 1st and 2nd visits. Analysis revealed that the subjects in the AS group at the 2nd visit showed a significant difference (better score) only in CAIS % from the 1st visit with a mean difference of 15.29% ($t= 2.87$ $p=0.018$) as illustrated in Figure 7-9, 7-10 and 7-11.

Table 7-26: Comparison between the 1st and 2nd visits in Self-reported assessment in the longitudinal study.

	AS (1 st Visit) M±SD	AS (2 nd Visit) M±SD	1 st and 2 nd Visits comparison t-test (p)	CAI M±SD	Healthy M±SD
FADI-ADL %	95.57±3.66	97.59±4.44	$t=-1.98$ $p=0.079$	97.5±3.12	100**±0.00
FADI-Sport %	81.56±7.43	87.5±12.32	$t=-1.38$ $p=0.19$	91.1±8	100**±0.00
CAIS %	36.71±15.12	21.42±16.77	$t= 2.87$ $p=0.018^*$	33.02±10.6	0.00***±0.00

FADI-ADL %= Foot and Ankle Disability Index (activities of daily living); **FADI-Sport %**= Foot and Ankle Disability Index (Sport); **CAIS%**= The chronic ankle instability scale; **M±SD**= mean±standard deviation; **t-test** = Paired t-test; *Denotes significant at $p<0.05$

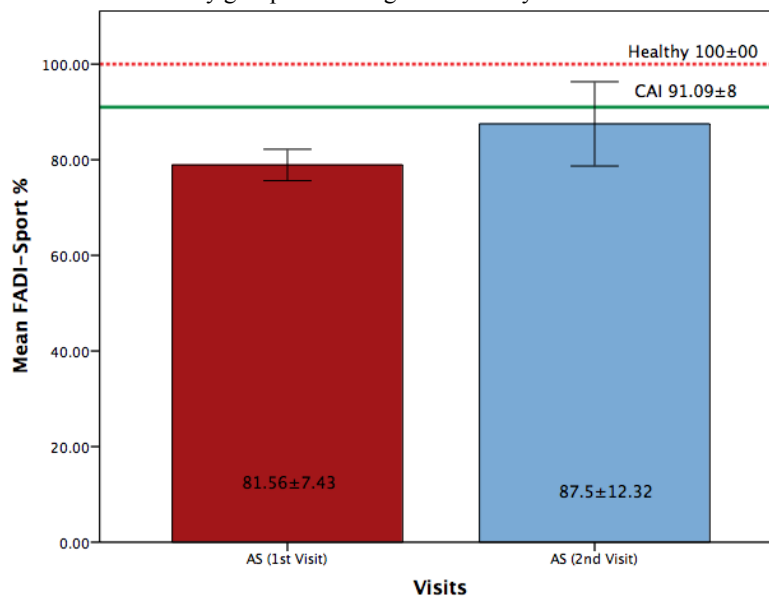
Figure 7-9: Mean FADI-ADL % and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

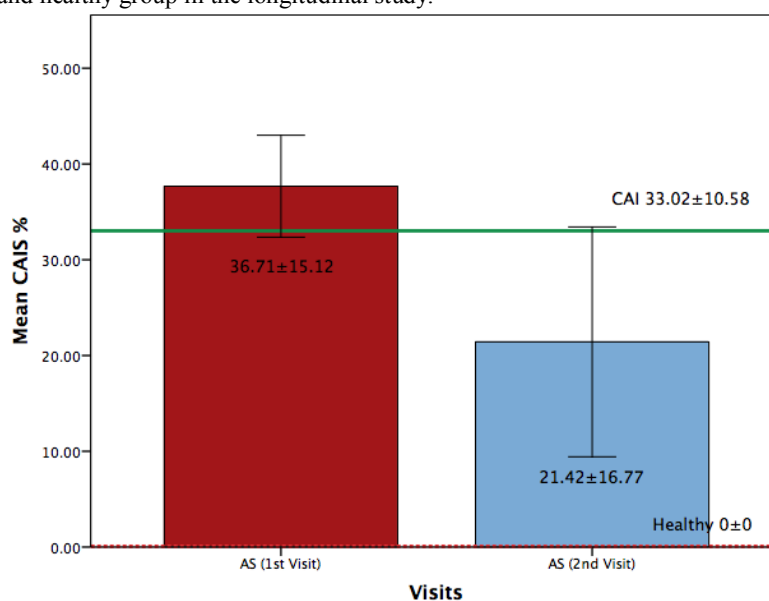
Figure 7-10: Mean FADI-Sport % and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy group in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

Figure 7-11: Mean CAIS % and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy group in the longitudinal study.



Results presented in **mean±standard deviation**,

The reference value derived from healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the solid green line (M±SD)**

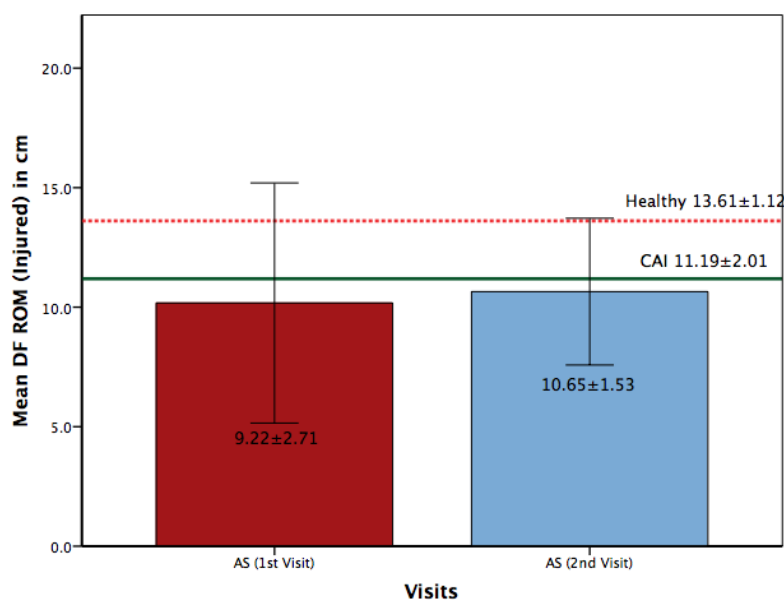
II. Ankle-dorsiflexion range of motion (dfROM)

Table 7-27 shows the results of dfROM for the AS group during the 1st and 2nd visit and in comparison with CAI and healthy groups. The results show that subjects in the AS group at the 2nd visit had better but no significant difference in dfROM compared with the 1st visit, with only a mean difference of 1.43cm ($t=-1.88$ $p=0.093$). The AS subjects demonstrated similar results at the 2nd visit, scoring below (worse) both the healthy and CAI groups as illustrated in Figure 7-12.

Table 7-27: Comparison between the 1st and 2nd visits in dfROM in the longitudinal study..

	AS (1 st Visit) M±SD	AS (2 nd Visit) M±SD	1 st and 2 nd Visits comparison t-test (p)	CAI M±SD	Healthy M±SD
dfROM (cm)	9.22 ± 2.71	10.65 ± 1.53	t=-1.88 p=0.093	11.19 ±2.01	13.61 ±1.12

dfROM= Dorsiflexion range of motion; **cm**= centimetre; **M-diff (p)**= mean difference (p value); **t-test** = Paired t-test.
*Denotes significant at p<0.05

Figure 7-12: Mean dfROM and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy group in the longitudinal study.

Results presented in **mean±standard deviation**,

The reference value derived from the healthy group is indicated by the **dotted red line (M±SD)** and the value derived from the CAI group is indicated by the **solid green line (M±SD)**

III. Isokinetic strength data

Table 7-28 shows the results of isokinetic strength data of injured ankle for the AS group during the 1st and 2nd visit and in comparison with CAI and healthy groups..

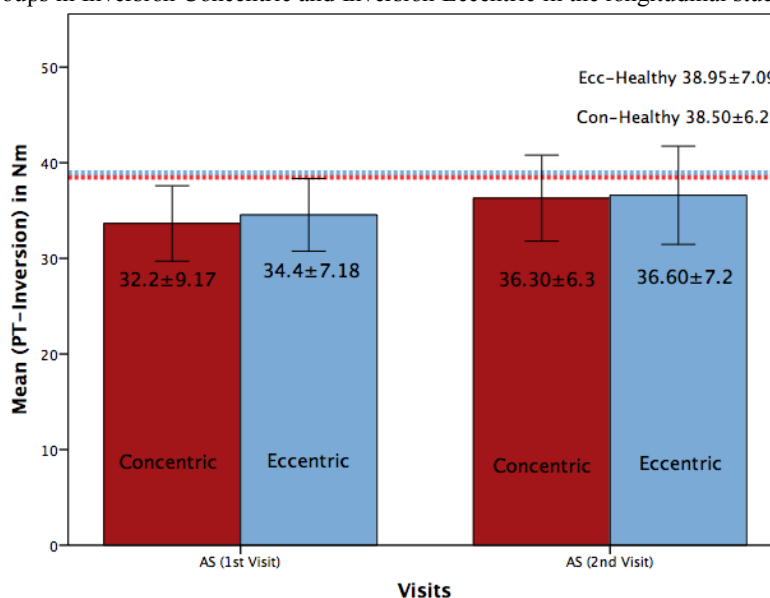
While there is no significant difference in the AS group between 1st and 2nd visits, there are overall improvements, particularly in inversion as illustrated in Figure 7-13, 7-14, 7-15 and 7-16.

Table 7-28: Isokinetic strength data in the longitudinal study, comparison between the AS group at the 1st and 2nd visit.

	AS 1st (M±SD)	AS 2nd (M±SD)	CAI (M±SD)	Healthy (M±SD)	1 st and 2 nd Visits comparison t-test (p) (95% CI)
Inversion (Injured)					
Con-PT	32.20±9.17	36.30±6.3	34.40±7.1	38.50±6.2	t=-2.07 p=.068
Con-PT/BW %	42.26±10.56	48.62±9.98	50.65±11.12	57.11±8.36	t=-1.56 p=.15
Ecc-PT	34.40±7.18	36.60±7.2	35.25±7.1	38.95±7.09	t=-1.06 p=.31
Ecc-PT/BW %	45.22± 7.75	48.92±10.32	51.99±11.92	57.84±10.48	t=-.92 p=.38,
Eversion (Injured)					
Con-PT	33.50±6.51	32.50±3.53	32.85±8.78	33.70±7.54	t=.58 p=.57
Con-PT/BW %	43.9±5.78	43.33±4.65	47.7±11.29	49±9	t=.22 p=.83
Ecc-PT	35.30±7.79	35.10±3.7	34.70±8.31	36.25±7.8	t=.092 p=.92
Ecc-PT/BW %	46.18±6.95	46.76±4.73	50.64±10.96	52.92±10.67	t=-.22 p=.82

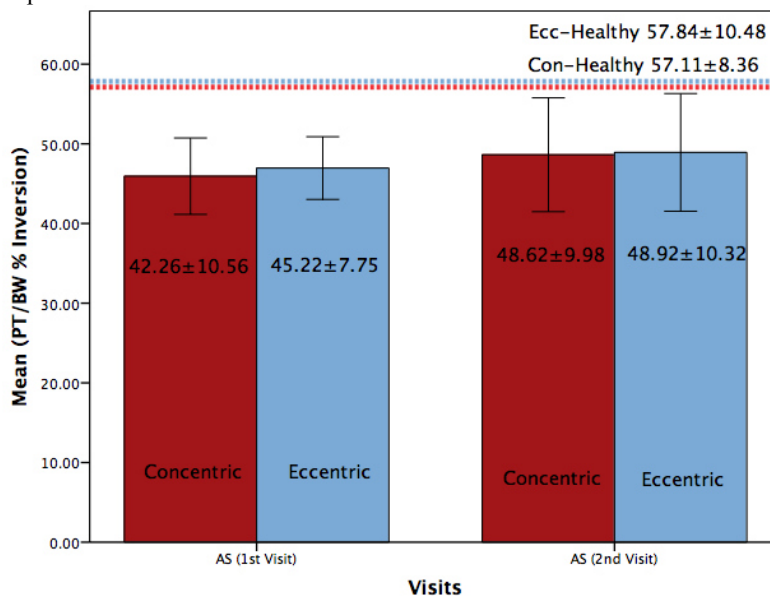
Con-PT= Concentric Peak Torque; **Ecc-PT**= Eccentric Peak Torque **Con-PT/BW**= Concentric Peak Torque/body-weight; **Ecc-PT/BW**= Eccentric Peak Torque; **t-test** = Independent t-test; **CI**= the 95% Confidence Interval; **(M±SD)**= mean±standard deviation *Denotes significant at p<0.05.

Figure 7-13: Mean and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in Inversion Concentric and Inversion Eccentric in the longitudinal study.



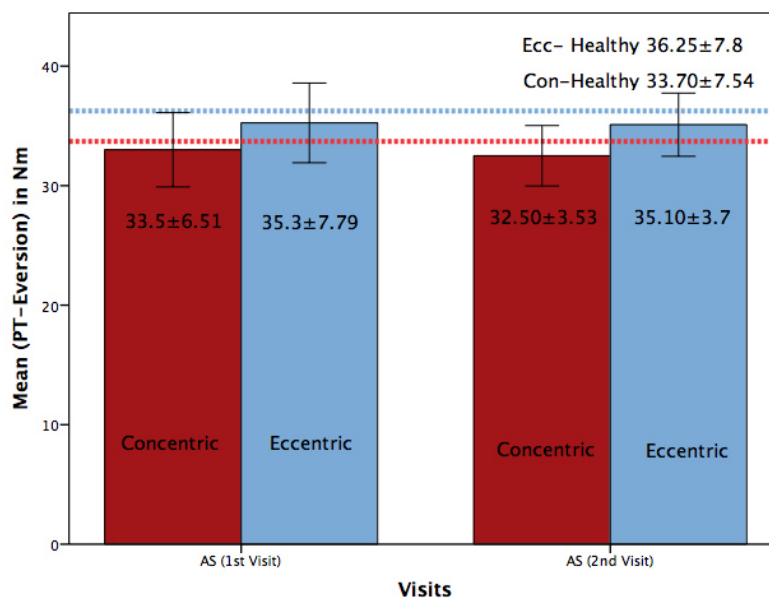
Results presented in **mean ± standard deviation**, The reference value derived from the healthy group is indicated by **the dotted red line (M ± SD)** and the value derived from the CAI group is indicated by **the dotted blue line (M ± SD)**

Figure 7-14: Mean and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in Inversion Concentric PT/BW % and Eccentric PT/BW %.



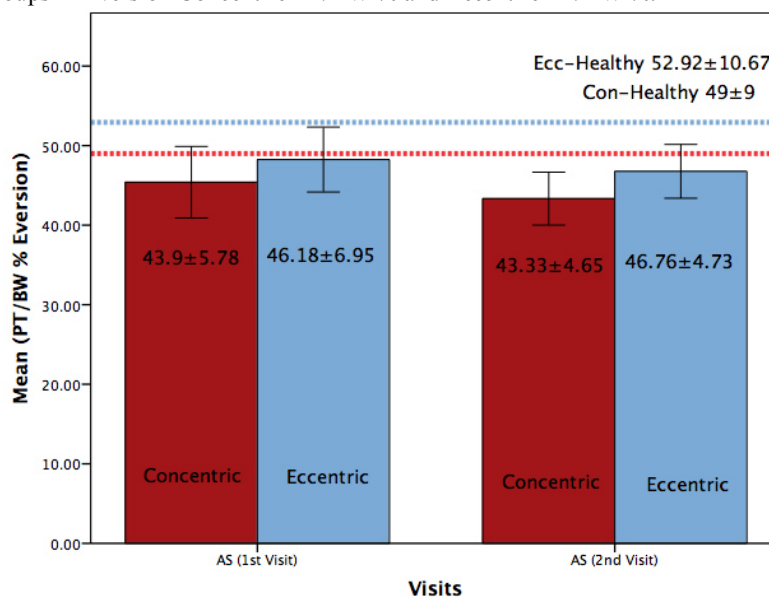
Results presented in **mean ± standard deviation**. The reference value derived from the healthy group is indicated by **the dotted red line (M ± SD)** and the value derived from the CAI group is indicated by **the dotted blue line (M ± SD)**

Figure 7-15: Mean and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in Eversion Concentric and Eversion Eccentric PT.



Results presented in **mean±standard deviation**. The reference value derived from the healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the dotted blue line (M±SD)**

Figure 7-16: Mean and standard deviation for the AS group at the 1st and 2nd visit compared with the CAI and healthy groups in Eversion Concentric PT/BW % and Eccentric PT/BW %.



Results presented in **mean± standard deviation**. The reference value derived from the healthy group is indicated by **the dotted red line (M±SD)** and the value derived from the CAI group is indicated by **the dotted blue line (M±SD)**

7.3.3 Descriptive analysis of the final self-reported assessment at 12-month

This section present results of participants' self-reported assessment at 12-month compared with results at 3-month and baseline: (1) FADI-ADL %, (2) FADI-Sport % and (3) CAIS %. The final self-reported follow-up was sent and collected from all subjects who completed the initial visit (n = 20).

Table 7-29 shows the mean and standard deviation of self-reported assessment data for the AS group at 3 parts (baseline, 3-month and 12-month). Of the 20 subjects from AS group who were assessed at the baseline (41.59 ± 10.7 days), 10 subjects completed the 2nd visit (3-month) and Only 12 subjects responded to the final self-reported functional assessment (12-month).

Table 7-29: Descriptive data of self-reported assessment

	Baseline n=20 (M±SD)	3-month n=10 (M±SD)	12-month n=12 (M±SD)
FADI-ADL%**	95.1±4.18	95.5±3.66	99.5±0.65
FADI-Sport%**	77.5±7.9	78.75±9.85	96±3.26
CAIS%***	37.67±11.4	36.71±15.12	7±4.20

FADI-ADL %= Foot and Ankle Disability Index (activities of daily living); **FADI-Sport %**= Foot and Ankle Disability Index (Sport); **CAIS%**= The chronic ankle instability scale; **M±SD**= mean±standard deviation.

7.3.4 Predictors of functional recovery

The aim of this section was to identify potential recovery predictor by investigating which of the functional outcome measured at baseline contribute to the functional status using self-reported assessment at 3 parts time. In attempting to identify the functional recovery predictors, correlations analysis were computed and divided into 3 parts to evaluate if there was any relationship between the self-reported functional assessment (FADI-ADL%, FADI-Sport % and CAIS%) and results of functional performance.

Functional data of all subjects recruited at baseline (n=20) including: DMT and TT during unanticipated functional test, JH and CT during deep vertical jump and weight-bearing dorsiflexion (dfROM) were used to determine predictors of their results in self-reported function at baseline (part 1) using (FADI-ADL%, FADI-Sport % and CAIS%). In part 2 similar functional data at baseline of 10 subjects recruited at the 2nd visit were used to determine predictors of their results in self-reported function at 3-month using (FADI-ADL%, FADI-Sport % and CAIS%). In part 3 functional data were obtained from the baseline results of 12 subjects who responded to the final 12-month and used to determine predictors of their results in self-reported function at 12-month using (FADI-ADL%, FADI-Sport % and CAIS%).

7.3.4.1 Correlation between selected parameters and self-reported assessment

Table 7-30 shows that only the performance in JH was correlated with FADI-ADL ($r = -0.47$, $p = 0.036$) in part 1, whereas there were no significant associations found in part 2 between outcome measures at baseline and functional status at (3-month) using scores

of (FADI-ADL%, FADI-Sport % and CAIS%) as illustrated in Table 7-31.

Table 7-32 shows that Eversion Con-PT, Eversion Con-PT/BW and Eversion Ecc-PT/BW were significant correlated with FADI-Sport % at (12-month) $r = .61$ $p = .03$, $r = .67$ $p = .015$ and $r = .68$ $p = .014$ respectively.

Table 7-30: Correlation between performance parameters at baseline and self-reported assessment at baseline

Performance at baseline (n=20)	Self-reported assessment at (baseline) (n=20)		
	FADI-ADL%	FADI-Sport %	CAIS%
U-DMT	$r = .14$ $p = .55$	$r = .17$ $p = .45$	$r = -.27$ $p = .24$
U-TT	$r = -.19$ $p = .41$	$r = -.013$ $p = .95$	$r = -.16$ $p = .47$
JH	$r = -.47$ $p = .036^*$	$r = .13$ $p = .56$	$r = -.031$ $p = .89$
CT	$r = .14$ $p = .55$	$r = -.24$ $p = .3$	$r = .117$ $p = .62$
dfROM	$r = -.018$ $p = .93$	$r = -.18$ $p = .42$	$r = .087$ $p = .71$
Inversion Con-PT	$r = .014$ $p = .95$	$r = .25$ $p = .27$	$r = .22$ $p = .35$
Inversion Con-PT/BW	$r = -.083$ $p = .72$	$r = .28$ $p = .23$	$r = .176$ $p = .45$
Inversion Ecc-PT	$r = -.11$ $p = .63$	$r = .026$ $p = .91$	$r = .14$ $p = .53$
Inversion Ecc-PT/BW	$r = -.30$ $p = .19$	$r = .034$ $p = .88$	$r = .097$ $p = .68$
Eversion Con-PT	$r = .051$ $p = .83$	$r = .23$ $p = .31$	$r = .170$ $p = .47$
Eversion Con-PT/BW	$r = -.064$ $p = .78$	$r = .20$ $p = .38$	$r = .104$ $p = .66$
Eversion Ecc-PT	$r = .15$ $p = .50$	$r = .28$ $p = .23$	$r = .053$ $p = .82$
Eversion Ecc-PT/BW	$r = .042$ $p = .86$	$r = .31$ $p = .18$	$r = -.023$ $p = .92$

Table 7-31 Correlation between performance at baseline and self-reported assessment at 3-month

Performance at baseline (n=10)	Self-reported assessment at (3 months) (n=10)		
	FADI-ADL%	FADI-Sport %	CAIS%
U-DMT	r =.49 p=.14	r =.41 p=.23	r =-.19 p=.58
U-TT	r =-.15 p=.67	r =-.38 p=.26	r =-.24 p=.50
JH	r =-.40 p=.25	r =.15 p=.67	r =.10 p=.78
CT	r =.20 p=.57	r =-.16 p=.65	r =.06 p=.86
dfROM	r =.35 p=.32	r =-.26 p=.46	r =.20 p=.57
Inversion Con-PT	r =.084 p=.81	r =.148 p=.68	r =.41 p=.22
Inversion Con-PT/BW	r =-.011 p=.97	r =.156 p=.66	r =.22 p=.53
Inversion Ecc-PT	r =-.010 p=.97	r =-.16 p=.65	r =.45 p=.182
Inversion Ecc-PT/BW	r =-.15 p=.67	r =-.17 p=.62	r =.19 p=.58
Eversion Con-PT	r =.27 p=.43	r =.016 p=.96	r =.16 p=.65
Eversion Con-PT/BW	r =.24 p=.50	r =.067 p=.85	r =-.25 p=.47
Eversion Ecc-PT	r =.36 p=.29	r =.061 p=.86	r =.12 p=.74
Eversion Ecc-PT/BW	r =.377 p=.28	r =.113 p=.75	r =-.25 p=.48

Table 7-32: Correlation between performance at baseline and self-reported assessment at 12-month

Performance at baseline (n=12)	Self-assessment at (12-month) (n=12)		
	FADI-ADL%	FADI-Sport %	CAIS%
U-DMT	r =.22 p=.47	r =.41 p=.18	r =-.46 p=.12
U-TT	r =-.25 p=.42	r =-.24 p=.45	r =.087 p=.78
JH	r =-.35 p=.25	r =-.081 p=.80	r =.057 p=.86
CT	r =-.12 p=.70	r =.19 p=.55	r =-.037 p=.91
dfROM	r =.23 p=.46	r =-.27 p=.38	r =.26 p=.41
Inversion Con-PT	r =-.26 p=.41	r =.02 p=.94	r =-.11 p=.71
Inversion Con-PT/BW	r =-.32 p=.3	r =-.07 p=.81	r =-.55 p=.86
Inversion Ecc-PT	r =-.23 p=.46	r =-.009 p=.97	r =.037 p=.90
Inversion Ecc-PT/BW	r =-.32 p=.30	r =-.15 p=.64	r =.14 p=.65
Eversion Con-PT	r =-.004 p=.99	r =.61 p=.03*	r =-.41 p=.18
Eversion Con-PT/BW	r =-.5 p=.88	r =.67 p=.015*	r =-.45 p=.13
Eversion Ecc-PT	r =.20 p=.52	r =.57 p=.052	r =-.34 p=.266
Eversion Ecc-PT/BW	r =.23 p=.45	r =.68 p=.014*	r =-.40 p=.188

CHAPTER 8 : DISCUSSION

This chapter is presented in two main parts that reflect the structure of the results chapter of the main studies, including a cross-sectional study and a longitudinal study. Recommendations for clinical practice, limitations and directions for future research are also presented and discussed in this chapter. The main objective of these studies was to explore the functional performance and neuromuscular control of subjects with a history of ankle sprain under unanticipated conditions. Therefore, there were two main hypotheses. Firstly, the knowledge gained by using this condition in functional assessment for subjects with a history of ankle sprain would provide more appropriate information about an individual's recovery than under conditions allowing preplanning. Secondly, the deficiency in neuromuscular control for subjects with a history of ankle sprain would be clearer under conditions requiring decision-making. Consequently, it would help in the development of more appropriate treatment aiming at reducing the risk of recurrent ankle sprain. Further details about the aims are presented in Chapter 4.

8.1 Discussion related to the cross-sectional study

This part will discuss the findings of the cross-sectional study that investigated whether there were any statistically significant differences between individuals following acute ankle sprains (AS), individuals who complain about recurrent incidence of ankle sprains (CAI) and individuals with stable ankles who have never experienced a sprain (healthy). This study included parameters related to functional performance, muscle activity, self-reported functional assessment, assessment of range of motion and muscle strength assessment.

8.1.1 Measures of functional performance during unanticipated functional test (UFT) and planned functional test (PFT)

In the current study the Decision Making Time (DMT) and Task Time (TT) in milliseconds (ms) were measured using the vector mat system under two conditions: 1) Unanticipated and 2) Planned functional test. The main findings were that the difference between groups was significant only under unanticipated conditions in DMT ($F=19.13$ $p=0.001$), effect sizes ranged from 0.72 to 2. The healthy group demonstrated faster decision making times (282.60ms) compared with the AS group (350.40ms) and CAI group (402.20ms) under unanticipated conditions. The result of DMT supports the first hypothesis of the current study in functional performance under unanticipated conditions.

The result showed that there was a longer DMT in the CAI group compared with the AS group ($p = 0.03$) suggesting less self-confidence under this condition in CAI subjects. This may also present a delay in the muscles to produce action due to motor control deficiency; the EMG of muscle activity will be discussed in next section. Longer decision times in this group could also be interpreted as a compensating strategy within the motor control system in an attempt to prevent recurrent ankle sprain, which allows adding more time for stability and potentially reduce the stress on the ankle joint under unanticipated conditions.

However, within the same condition (unanticipated) there was no significant difference in the time taken to complete the task (TT) between groups indicating that individuals with history of ankle sprain are not likely to have clear impairment when they are investigated only by TT. The contradiction in findings across the two parameters could be because, despite instructions, some subjects slowed down once they had made their direction decision and stepped off the decision mat, whilst others continued through the test area to the final mat. This difference is reflected in the reliability data for TT compared to DMT. Therefore future measurements around functional tasks should consider collecting both DMT and TT.

On the other hand, the difference between groups under planned conditions was not significant in both DMT and TT ($F = 1.34$ $p = 0.27$) and ($F = 1.55$ $p = 0.22$), effect sizes ranged from 0.006 to 0.49. Both functional tests in the current study involve changing direction and lateral movement, which was suggested by researchers when investigating functional performance in people with a history of ankle sprain. Due to the fact that

these tests were performed based on their ability to stress the lateral aspect of the ankle joint and to simulate the mechanisms that may bring about feelings of instability, it was expected that AS and CAI would require longer DMT and TT in both conditions. However, this view was not supported by the current study as the healthy subjects under planned conditions had slower DMT than AS subjects (241.70ms 215.90ms) respectively and longer TT than CAI subjects (1180ms, 1153.70ms) respectively. This supported the hypothesis that incorporating an unanticipated condition into functional tests could also provide more appropriate information about an individual's ability to cope with returning to previous sporting activity. This result was similar to the result reported in preliminary studies (Study 3, Chapter 5), whereas the AS group was faster and better (TT = 13.22 sec) than the healthy group (14.19 sec) in performing planned task (T-drill test). This suggested that with planned tasks, the subject has more time to develop a strategy to complete the task whilst compensating for an ankle that may be functionally unstable. During unanticipated tasks, longer decision times could be interpreted as a compensating strategy aimed adding more time for stability. This agreement in findings in the preliminary studies and current study may be attributed to the sensitivity of DMT under unanticipated conditions.

To determine whether the approach speed has provided a significant contribution to the performance in each group or whether the difference in DMT is a result of other factors a correlation was performed. While the approach speed during this test was statistically equivalent among groups at (AS = 4.75 ± 0.59 ms, CAI = 4.69 ± 0.59 ms, Healthy = 4.65 ± 0.52 ms), the approach speed was correlated with only TT in AS and CAI groups during the unanticipated test ($r = -0.51$ $p = 0.020$, $r = -0.49$ $p = 0.025$ respectively).

Whereas during the planned functional test the correlation was observed only in the AS group ($r = -0.49$ $p = 0.026$). The lack of association between the approach speed and DMT supports that the performance in DMT is a result of a more complex motor process within the neuromuscular control system. This finding adds further evidence to ankle studies by investigation of DMT under unanticipated conditions; however, it does offer some insight into the function of an individual's ability to cope with returning to previous sporting activity. Therefore, the important message from this finding is to include unanticipated condition into the functional test to simulate conditions seen during sport activity. The current study also concluded that the DMT demonstrated fair to substantial reliability within-session during the unanticipated test, which suggests also that the performance may potentially useful outcome measure.

Muscle strength was also suggested to influence functional performance (Young et al. 2002). Although, no significant associations were found in the current study between DMT and muscle strength, the healthy subjects who demonstrated faster time (282.60ms) in DMT compared with the other groups also demonstrated better muscle strength but there was no significant difference between groups. This will be discussed later in more detail. However, this small difference could provide an explanation of why this group performed better in DMT and could be clinically important.

The subject's movement pattern during the unanticipated test was reviewed using the video recording, and different approaches have been identified throughout the trials. This gives an important indication of pattern variability; therefore, variability was presented. The AS and CAI groups, under unanticipated conditions, were also presented

by a greater variability for DMT compared with the healthy group as evidenced by coefficient of variation (CV% = 18.6%, 19.3% and 11.8%) respectively. Thus, this variability may be explained by the learning effect developed during assessment and how it directly relates to the unanticipated test. Both groups may experience difficulty in dealing with this test, which suggests that both groups have an impaired ability to maintain their performance when placed under unanticipated condition. On the other hand, TT presented with less variability CV% compared with DMT in (AS = 7%, CAI = 9% and Healthy = 8.5%). Thus, DMT presents the most variability during this functional test, which could also support the importance of including the DMT in functional performance.

These results indicated that DMT could predict performance under unanticipated conditions. The reason is that the planned condition may lie in the simplicity of the functional performance test. Comparisons with other studies were not possible as no other research used similar methods in ankle analysis. However, a different approach was used in unplanned tasks to investigate the neuromuscular control in individuals with CAI, mainly by using a device that would introduce a sudden inversion during standing, walking and jumping tests (Gutierrez et al. 2012; Gehring et al. 2013). Some studies reported that participants with CAI try to protect their ankle by demonstrating a greater plantar-flexed position or by activating early the PL muscles. Limitation of the approach in these studies could be due to participants knowing that the protocol during assessment is designed to supinate the ankle.

To date, research on unanticipated condition is commonly included in studies related to

the knee joint and has focused primarily on biomechanics and muscle activities. These studies found that the risk of noncontact injury in the knee joint was increased when changing direction was unanticipated compared with planned condition as a result of increased valgus angle and moments (Hyun Kim 2014; Weinhandl 2013; Houck 2006; Houck 2007; Weinhandl 2013; Besier 2000; Besier 2003; Ford 2005). In addition, individuals in unanticipated tasks showed a limitation in initiating appropriate proactive adjustments of lower extremity muscles. The result in the current study is in accordance with the positive results in these studies that utilised unanticipated tests.

Similar positive findings were also reported in other studies in the healthy sporting population (Farrow et al. 2005; Duvnjak-Zaknich et al. 2011; Henry et al. 2011). These studies showed that the unanticipated test has the ability to discriminate between players' skill. Researchers in these studies evaluated DMT to predict functional performance. They used life-sized players image projected onto a screen placed in front of the subject as the external stimulus. Subjects were required to physically react to the movements of the projected image. In these studies video footage (50Hz) was used to identify the time for decision making. Frame-by-frame (within ± 20 ms) video recording was then used to generate data for analysis and DMT was defined in each trial from stimulus point and the first lateral movement of the foot that initiates the change of direction. DMT was found to be significantly shorter for the highly skilled players than for the lesser-skilled players.

DMT was found to be significantly correlated with TT during unanticipated condition in the CAI group ($r = -0.45$ $p = 0.045$) and during planned conditions in AS group ($r = 0.48$

$p = 0.03$). This result was similar to the result reported in preliminary studies (Study 2, Chapter 5), whereas the DMT was significantly associated with the TT ($r = 0.774$, $P = 0.00$), indicating that the DMT can reflect performance variance in the task time. Non-significant correlation was noted in the healthy group during both conditions. Young and Willey (2010) investigated the relationship between total time of the task and DMT and tested time by using a tester who initiates side-step movements to provide a stimulus for participants to change direction. Thirty-one male semi-professional Australian Rules football players were recruited in this study. The DMT was defined as the time when the examiner planted his foot to the time the participant planted his foot to respond in changing direction. The response movement was defined as the time when the participant planted his foot in changing direction to the instant of running. The greatest relationship existed between DMT and the total time ($r = 0.77$) rather than response time ($r = 0.59$), indicating that the decision-making was most responsible for the variance in the total time. However, there was no significant relationship between DMT and response time ($r = 0.03$ $p = 0.88$). This is consistent with findings of previous research indicating that the decision-making component significantly contributes to reactive agility (Farrow et al. 2005; Gabbett & Benton 2009). While this form of reactive stimulus has some validity by applying a better sport scenario and also investigating the DM responses by requiring players to react physically, some researchers argue that using a 2-dimensional stimulus is still unable to present participants with a real sport scenario to measure decision-making time. Therefore, other researchers started using a different stimulus (Sheppard et al. 2006; Gabbett et al. 2008; Gabbett & Benton 2009; Veale et al. 2010). The participants in these studies were required to respond to movements by a human tester who performed one of four

possible scenarios. The four possible scenarios were presented in a random order that was different for each participant: (1) Step forward with the right foot and change direction to the left. (2) Step forward with the left foot and change direction to the right. (3) Step forward with the right foot, then left and change direction to the right. (4) Step forward with the left foot, then right and change direction to the left. DMT was identified within ± 5 ms for each trial using a high-speed video camera and defined as the time difference between the first definitive foot contact initiating the movement of the investigator in the final direction he moved his body, and the first definitive foot contact initiating the response of the player. The analysis of the data by using high-speed video footage in these studies allows for more precise identification of movement during the reactive agility test compared with previous studies. However, limitation of this method relies on the examiner's technique, as it is difficult to standardise this technique throughout the study. In addition, this method will be difficult to apply in another study with similar examiner's movements, which may give different results. In the current study provide a simple and valid approaches to measure functional performance in an unanticipated condition.

8.1.2 Measure of functional performance during deep vertical jump (DVJ):

The contact time (CT) and jump height (JH) were measured using the vector mat system during a deep vertical jump (DVJ) as described in the methods chapter. Three trials on each ankle were evaluated for each subject. The link between contact time and jump height has been studied in research explained by stretch-shortening cycle (SSC) functioning to produce high jump in a short amount of time. Two hypotheses were set

and tested related to the JH and CT. The result of JH and CT did not support the first hypothesis of the current study in functional performance. No significant differences were found between groups in JH and CT ($p = 0.15$ and $p = 0.63$) respectively. Similar findings were reported in other studies that used a variety of jump tests including triple-crossover hop, figure-of-8 hop, side hop, single hop, single-limb hurdle test, multiple hops in zigzag pattern, square hop and hop for distance. Some of these tests did not produce significant differences by comparing the performance between injured and uninjured limbs (Munn et al. 2002; Eechaute et al. 2008) or by comparing these injured limbs with healthy subjects (Eechaute et al. 2008; Buchanan et al. 2008; Wikstrom et al. 2009). Some authors believe that as several of these tests were done primarily in the sagittal plane direction and did not place stress on the lateral aspect of the ankle joint, this was why these studies did not find functional differences (2005 Docherty). In another study the triple-crossover hop for distance was also not sensitive enough to predicate functional differences among 16 subjects (Munn et al. 2002). However, this view was not supported by the results of the current study during a cutting manoeuvre as reported in the previous section. The planned condition was suggested as a reason for not finding functional differences.

While the interaction did not reach significance during DVJ, the healthy subjects had a better JH than the AS group by 1 cm and the CAI group by 0.7 cm, which could be clinically meaningful. Therefore, JH and CT were further analysed by comparison between each injured and non-injured ankle in the AS and the CAI groups and between skilled and non-skilled legs in the healthy group. A significant difference was found only between injured and non-injured ankles in JH for the AS and CAI groups ($t = -4.62$

$p = 0.001$) and ($t = -2.11$ $p = 0.048$) respectively. This result supports the fourth hypothesis in current study that is injured ankle in subject with history of ankle sprain would have significant difference in jump height, than non-injured ankle.

The variety of physical activity ability could explain the results when looking between groups and then when looked within subject JH this confounding variable was removed. However, it should be noted that all subjects in the current study were engaged in physical activity during recruitment into the study defined as being performed at least 1-3 days (30-90 min) per week of cardiovascular, resistance training and sports-related activity. Only subjects on Level 1 (4-7 days/week) and Level 2 (1-3 days/week) were included as it was thought that those will be most representative of the sporting population who were involved in team or competitive sports at recreational level. Being more attuned to sport and subsequently similar movements, it was also thought that these subjects would be less likely to affect the results through a learning effect. The difference of JH between ankles in the AS group was 1.4cm (effect size = 0.81) and in the CAI group 0.95cm (effect size = 0.43). The results did not discriminate between ankles (skilled and non-skilled leg) in healthy subjects for either parameter CT and JH ($t = 0.79$ $p = 0.43$) and ($t = 1.4$ $p = 0.179$) respectively. This result indicates that JH by utilising deep vertical or counter-movement jump should continue to be used when investigating the functional performance of individuals with a history of ankle sprain. However, it should be noted that the time spent on the ground before jumping was measured in the current study, so each subject was required to keep contact time short while jumping higher. This could influence a subject in the AS and CAI group to jump less using their injured ankle compared with their unaffected ankle. There is a belief that

reduced ability to generate fast muscle production during high-speed movement in individuals with CAI is a possible cause of instability and increases the risk of re-sprains compared to healthy people.

Therefore, motor production in relation to the velocity could provide a better indication of individual performance during functional activities than measured jump height only, which explains the reported difference between ankles in the current study. Further analysis was performed by investigating the correlation between CT and JH in each ankle of all groups. However, a trend toward significance was noted in the CAI group with the injured ankle ($r = 0.43$ $p = 0.059$).

There is no significant relationship between JH and muscle strength in AS and the healthy group indicating that the strength of ankle muscles was not a predictor for the performance of jump height. However, in CAI the muscle strength was significant with JH as demonstrated by concentric PT (inversion $r = 0.52$ $p = 0.018$) and eversion concentric and eccentric PT ($r = 0.45$ $p = 0.046$ and $r = 0.49$ $p = 0.027$).

8.1.3 Electromyography data

Time to peak (TTP) of muscle activity during the unanticipated functional test was collected as described previously in the method chapter. The TTP was defined as the time between the highest peak of EMG burst and the reference of foot contact within the time window. The negative values (-) presented activation prior to foot contact and positive values (+) presented activation after foot contact. The main findings related to

the EMG did not support the second hypothesis as no significant differences were found between groups while performing unanticipated cutting manoeuvres in TTP for the tibialis anterior (TA) peroneus longus (PL) and gastrocnemius lateralis (GAS). However, it is clear that the AS group scored the highest activity of the PL muscle earlier (84ms) than the healthy (102.7ms) and the CAI groups (127.24ms). These results are in agreement with those of previous studies that focused on the onset time of PL muscles as a defence mechanism during inversion movement in people with CAI (Vaes 2002; Eechaute 2009; Konradsen and Ravn 1990; Caulfield et al. 2004; Delahunt et al. 2006b; Suda & Sacco 2009). Quicker activation of PL muscles in these studies is explained as a protective motor strategy in individuals with a history of ankle sprain. This strategy results in a less planter-flexed position during foot contact, which provides more stability and prevents further injury.

However, the values of TTP in the current study showed that every muscle in each group scored the highest activity after the foot contact. This may potentially be explained as due to the unanticipated approach and speed used in the current study. Previous studies used planned conditions in their investigation, in which participants were aware that the trial would involve perturbation. Unplanned tasks were recently used to investigate the neuromuscular control in individuals with CAI during standing, walking and jumping tests (Gehring et al. 2013; Gutierrez et al. 2012). While these tasks were unplanned, causing some difficulty for the participants to predict the action, limitations still exist within the approach used in these tests. The results obtained from these studies could be due to participants knowing that the protocol during these assessments is designed to supinate the ankle. Therefore, participants were trying to

protect their ankle by activating their muscles before landing. Gutierrez et al. (2012) assessed muscle activity (EMG area) during drop-jump testing using a supinating device placed over a force plate. Participants in the ankle instability group showed a significant increase in PL muscles at 200ms before landing. Another limitation is that the device designed for assessment took time, allowing additional time for participants to predict the movement and react appropriately.

It should be noted that the CAI group in the current study had a different strategy than that reported in previous studies. The TTP of PL muscle in CAI took longer by 43.42ms compared with AS (effect size = 0.49) and by 24.72ms with the healthy group (effect size = 0.24). While these did not reach a significant difference, this could predispose them to suffer ankle instability.

An interesting finding in the current study was that TTP of PL muscle in CAI demonstrated a significant positive association with DMT performance in CAI subjects. This indicates that slower DMT performance, as reported in the previous section, could be a result of a motor control deficit, affecting the activity of PL muscles. Another interesting finding in the current study was that the three muscles studied showed different patterns, and the peak EMG burst occurred in a different order in each group. In the AS and healthy group, the peak of PL was scored first followed by GAS then TA. In the CAI group the GAS was first to score the peak value then the PL and TA at the same time. The peak of GAS in the CAI group may have increased the plantar flexion position of the foot at foot contact moment. This could be a strategy in those with CAI to develop enough power for propulsion to move the leg off the ground. Foot

positioning and angle of ankle joint at period of foot contact were investigated and presented in different studies. Cheng-Feng Lin (2011) evaluated the ankle position during running tasks and CAI subjects showed a greater inverted ankle of the affected ankle. Another study used 3-D video motion analysis and detected 6 - 7° greater inversion positioning by comparing 25 subjects with CAI and 25 healthy subjects during the 100ms pre- to 200ms post-foot contact (Monaghan et al. 2006). Similar results were reported in another study during walking on a treadmill (Delahunt 2006). In single leg downward jumps Delahunt et al. (2006b) found that FI subjects had a more inverted position of the ankle joint compared to healthy individuals between time periods from 200ms – 95ms pre-IC. They also had a less dorsiflexed position of the ankle joint during the time period from 90ms – 200ms post-IC. Less dorsiflexion of the ankle during landing was also found in another study in CAI participants (Brown et al. 2008). Another study found that a CAI stepping down task during continued walking demonstrated a greater plantar-flexed position compared with those with a history of ankle sprain without instability and the healthy group, which could place the individual in a high-risk position (Dundas et al. 2014). A less plantar-flexed position was also reported in another study in participants with acute ankle sprain during walking at heel strike moment (Doherty et al. 2015b), and during drop vertical jump test in subject six month post ankle sprain injury (Doherty et al. 2015a). These findings could be a strategy in participants with history of ankle sprain because of a deficit in motor control to prepare the joint in advance of movement and to protect the ligaments.

8.1.4 Self-reported functional assessment

In self-reported functional assessment subjects were assessed using: (1) The Foot and Ankle Disability Index (FADI), including two components, one assesses activities of daily living (FADI-ADL%) and the other is essential to sporting activities (FADI-Sport%) and (2) The Chronic Ankle Instability Scale (CAIS%). Both are found to be valid and reliable tools for assessing limitations in patients with CAI (Hale and Hertel 2005; Eechaute et al. 2008). The FADI-ADL% and FADI-Sport% are scored separately as percentages, with 100% representing a higher level of physical performance, while the low percentage in CAIS indicates a high level of physical performance. The healthy subjects were not asked to complete these self-reported functional assessments as the inclusion criteria for this group could allow assumption of a maximum score, implying no restriction in activities of daily living or sports such as running, change of direction etc.; therefore, in comparison between groups a maximum score was scored for healthy subjects (FADI-ADL = 100%, FSDI-Sport = 100% and CAIS = 0%).

The results in the current study showed a statistically significant difference in FADI-ADL%, FADI-Sport% and CAIS% score between groups ($F = 13.22$ $p = 0.00$, $F = 59.41$ $p = 0.00$ and $F = 104.88$ $p = 0.00$) respectively. Post-hoc revealed that the CAI and AS groups demonstrated a significant lower score than healthy subjects using FADI-ADL% (CAI = 97.5% and AS = 95.1%) and FADI-Sport% (CAI = 91.1% and AS = 78.9%) and higher score (worse) using CAIS% (CAI = 33.02% and AS = 37.7%).

Although there were significant differences between AS and CAI groups using both FADI-ADL%, FADI-Sport% scores, the difference was not significant between both

groups using CAIS% score. These findings suggest that the CAIS% is more responsive to functional performance in the CAI population than both FADI-ADL%, FADI-Sport%.

Cut-off scores have been used in some studies to identify subjects with CAI with scores of $\leq 90\%$ on the FADI and $\leq 75\%$ on the FADI-Sport (McKeon and Hertel 2008a; McKeon et al. 2008b). In another study CAI subjects scored 88.7% for FADI and 74.8% for FADI-Sport (Hubbard et al. 2007). Similarly, Brown et al. (2008) reported mechanical instability group means of FADI = 89.1% and FADI-Sport = 76.6% and functional instability group means of FADI = 94.2% and FADI-Sport = 81.5%. The scores were higher in another study, with average scores of 92.9% for FADI and 84.2% for FADI-Sport (Marshall et al. 2009). Similar scores were reported by Wikstrom et al. (2009) with mean scores of 95.2% for FADI and 92.9% for the FADI-Sport. The results of the current study for CAI score were 95.1% for FADI and 78.9% for FADI-Sport and 97.5% for FADI and 91.1% for FADI-Sport in AS and CAI groups respectively. These scores were higher than those in previous studies.

A significant correlation was found between FADI-Sport% score and DMT and TT under unanticipated conditions of CAI subjects ($r = 0.53$ $p = 0.016$, $r = -.47$ $p = 0.035$). This correlation indicates that subjects in the CAI group who scored higher on FADI-sport (higher level of physical performance) tended to have less time in DMT and TT under unanticipated conditions. Another significant correlation was found between FADI-ADL% score and jump height of AS subjects ($r = -.47$ $p = 0.036$). The lack of correlation may be due to the different purposes of these scales. Although the FADI-

ADL addresses activities of daily living, the FADI-Sport asks about higher-level activities. Commonly, CAI subjects are associated with deficits during sport activity, whereas the completion of low-level tasks is not problematic. Therefore, the lack of association between the FADI results among subjects with CAI is consistent with many clinical presentations of CAI. This result suggests that questionnaires that have little relevance to ankle function or to the patient's physical level could give inappropriate results.

8.1.5 Ankle-dorsiflexion range of motion (dfROM)

Limitation of dfROM has been identified as a contributing factor for individuals with chronic ankle instability (Collins and Vicenzino 2004; Hertel 2000). This allows for abnormal movement during physical activity, which may stress the tissues around the ankle to produce compensation movement in order to maintain the function. Consequently, this will put the individual at risk of re-injury (Hubbard and Hertel 2006). The link between limitation of dorsiflexion and ankle sprain is further supported by a systematic review by De Noronha et al. (2006). In the present study the dfROM was measured using a weight-bearing lunge using the knee-to-wall principle. This test was performed using a protocol previously described by Hoch and McKeon (2011) and Konor et al. (2012). The knee-to-wall principle also shows the ability to measure the change after a mobilisation intervention programme and the ability to distinguish between individuals with chronic ankle instability and the healthy.

Two hypotheses were set and tested related to the dfROM. The result supported the

third hypothesis of the current study in measuring dfROM. The result showed that a significant difference was found between groups in injured ankle in AS and CAI and skilled leg in healthy subjects ($F = 16.06$ $p = 0.00$). Post-hoc revealed that the CAI group (Mean \pm SD 11.19 ± 2.01) demonstrated a non-significant difference value result ($p = 0.32$) when compared with AS (Mean \pm SD 10.17 ± 2.51) (effect size = 0.45), whereas the healthy group (13.61 ± 1.12) reported significantly better dfROM compared to AS ($p = 0.001$ effect size = 1.77) and CAI ($p = 0.001$ effect size = 1.5).

The mean score for the CAI group (11.19 ± 2.01 cm) is higher than other studies that used the same knee-to-wall principle. In a study by Hoch et al. (2012a) the mean of DF in CAI subjects was (Mean \pm SD 10.73 ± 3.44) compared with healthy subjects (Mean \pm SD 12.47 ± 2.51). However, this was similar to the mean score in the AS group in the current study (10.17cm). In other studies CAI subjects reported a value of 9.03 ± 2.33 (Hoch et al. 2015) and a value of 9.08 ± 2.46 on WBLT dorsiflexion ROM (Terada et al. 2014). Additionally, no significant difference was found between AS and CAI ($p = 0.32$). This finding suggests that individuals who suffer repeated ankle sprains are likely to experience limitation similar to those who have initial ankle sprain.

The dfROM were further analysed by comparison between injured and non-injured ankles in AS and CAI groups and between skilled and non-skilled legs in the healthy group. The result supported the fourth hypothesis of the current study in measuring dfROM. Significant differences were found between injured and non-injured ankles in AS with mean difference of 2.49cm ($p = 0.00$, effect size = 1.2) and in CAI groups with mean difference of 1.66cm ($p = 0.00$, effect size = 0.95). Whereas a non-significant

difference was observed between skilled and non-skilled legs in the healthy group with mean difference of 0.35 ($p = 0.075$, effect size = 0.12)

8.1.6 Isokinetic strength data

In regards to the CAI, the strength of ankle muscles has been widely investigated, mostly by evaluating the deficit in evertor and invertor muscles (Yavuz Yildiz 2003; Hartsell 1999; Leanderson 1999; Kaminski 1999; Rottigni 1991; Willems 2002; Bernier 1997). A variety of methods have been used to assess ankle muscles in subjects with a history of ankle sprain. An isokinetic dynamometer provides a better assessment and is defined as an electromechanical tool that can provide objective values of an isokinetic muscle action for joints (Nitschke 1992). The reliability of measuring ankle muscles using an isokinetic dynamometer method was reported in different studies and varied from (ICC 0.69 to 0.98) (Kaminski et al. 1995; De Noronha and Junior 2004; Sekir et al. 2008). However, It has been used widely with different movement direction, contraction mode and also variety of speed. Therefore, variety in methods may explain the inconsistent results among the studies related to strength in individuals with CAI using the isokinetic dynamometer. While some studies have revealed strength differences between healthy and CAI individuals (Tropp 1986; Wilkerson 1997; Hartsell 1999; Willems 2002; Pontaga 2004; Yavuz Yildiz 2003), other studies found no significant difference (Negahban 2013; Fox et al. 2008; Munn 2002; Kaminski 1999; Bernier 1997).

In the current study, isokinetic testing of the ankle invertor and evertor muscles was

performed at a velocity of 120°/s for both ankles in eccentric and concentric contractions, using Kin.Com® 125E Plus (Chattanooga Group Inc., Hixson, Tennessee, USA) using software version 5.30. The results presented as peak torque (PT) and normalised PT to each subject's body weight (PT/BW). More details can be found in the methods chapter.

Two hypotheses were set and tested related to the strength assessment, which was that subjects with history of ankle sprain would demonstrate significant strength difference in ankle invertor and evertor muscles in contrast to healthy subjects and between ankles. The findings of the current study did not fully support these hypotheses. The results show that a significant difference between groups was only found for inversion in Con-PT/BW and Ecc-PT/BW between healthy and AS groups as demonstrated by Bonferroni test and p value of 0.002 and 0.005 respectively. However, pain-avoidance behaviour and discomfort are important, especially when dealing with patients with acute musculoskeletal injury resulting in poor performance, which could be a reason for those following acute ankle sprain (AS group) to present with low muscle strength value. Consequently, this result may not add new information by finding a difference between AS and healthy groups.

However, this result is equivalent to another study by Wikerson (1997), who found that invertor and evertor muscle strength is significantly lower for subjects with acute ankle sprain (n = 15) when matched with subjects having symptoms of CAI (n = 15). Subjects in the acute group were recruited from 6 to 14 days post-injury and that was based on assuming that the activity of walking was normal without discomfort. The deficits were

significant and more in the invertor muscles than evartor and at the 30°/s than 120°/s angular velocity. Another study found that the peak torque was significantly lower only when using body weight to normalize the data and suggested using it for better comparison (Willems 2002). The authors in this study recruited 87 subjects and analysed 174 ankles divided into four groups. The control group consisted of 53 subjects. The instability group included 10 subjects who had a history of more than three lateral ankle sprains with a sensation of giving way. Group three consisted of 17 subjects (20 ankles) with a history of one to three ankle sprains in the previous two years without any instability complaints. The fourth group consisted of 8 subjects (8 ankles) with one to three ankle sprains three to five years before and no complaints. Significant differences were found between the instability group and other groups for eversion strength/body weight for both concentric and eccentric condition at 30°/s than 120°/s angular velocity when researchers had normalised the value of peak torque by body weight. No significant differences were reported when using peak torque, inversion-to-eversion strength ratio or eccentric-to-concentric strength ratio.

In the current study muscle strength was further analysed by comparing injured and non-injured ankles in AS and CAI groups and between skilled and non-skilled legs in the healthy group. For the healthy group the results show that no significant difference was observed between two legs in all variables. For the AS group the results show that a significant difference was found only in inversion movement using Ecc-PT /BW as demonstrated by $t = -2.13$ $p = 0.046$. For the CAI group the results show that a significant difference was found between ankles in inversion using Con-PT ($t = -2.47$ $p = 0.023$), Con-PT/BW ($t = -2.38$ $p = 0.028$) and in eversion using Ecc-PT ($t = -2.21$ $p =$

0.039), Ecc-PT/BW ($t = -2.36$ $p = 0.029$).

No consistency is evident among the studies that used participants with CAI investigating the strength of ankle muscles. Because of this inconsistency, and the results of the current study, it is difficult to provide strong support of the weakness in ankle muscles as a main factor in ankle instability. While there was no statistically significant difference between groups in the current study, the healthy group reported higher strength than CAI and AS groups in all scores, which could be clinically meaningful. However, the assessment of muscles performances in functional manner that available on deep vertical or counter-movement jump could provide a better indication of how muscle performs when investigating the recovery of individuals with a history of ankle sprain. This also could be more acceptable clinically than measured muscles strength independently using isokinetic dynamometers. This explained by the stretch-shortening cycle (SSC) functioning in which eccentric and concentric muscle actions occur (Chmielewski et al. 2006). The fast SSC means that an athlete can use the most muscle-tendon units to move fast.

8.2 Discussion related to the longitudinal study

This section will discuss the findings of the longitudinal study. The aim of this study was to investigate the progress of subjects in the AS group over six months plus a final self-reported follow-up at least 12 months after the onset of injury. No studies used a similar timeframe for follow up in a similar functional assessment of individuals after acute ankle sprains. This study included parameters related to functional performance, muscle activity, self-reported functional assessment, assessment of range of motion and muscle strength assessment. These will be discussed similarly to the cross-section study and divided into two sections: primary and secondary outcome parameters. Of the 20 subjects from the AS group who were assessed at the initial visit, 10 subjects completed the second visit and only four subjects completed the third visit. Due to insufficient numbers at the third visit, these data were not used to perform any statistical analysis.

This section also will discuss the finding of the correlation analysis between selected parameters at baseline and self-reported assessment at 3 parts time (baseline, 3-month and 12-month). This was aimed to identify which of the functional outcome measured at baseline contribute to the self-reported assessment. The final self-reported follow-up was sent to all subjects who completed the initial visit ($n = 20$). Only 12 subjects responded to this final self-reported assessment.

8.2.1 Measure of functional performance during unanticipated functional test (UFT) and planned functional test (PFT)

In the current study the DMT and TT in milliseconds (ms) were measured using the vector mat system similar to the cross-sectional study under two conditions: 1) Unanticipated and 2) Planned functional tests. As reported earlier in the cross-sectional study a significant difference in DMT between AS and healthy and CAI groups was found ($F = 19.13$ $p=0.001$). The main findings in the longitudinal study were that the subjects in the AS group at the second visit demonstrated a significantly better score for DMT under unanticipated conditions. They had faster DMT by 74.2ms when compared with the first visit ($t = 2.98$ $p = 0.015$). The DMT also demonstrated an overall improved mean score of 260.7ms, reaching a just better than healthy mean score of 282.60ms. Although the AS group at the 1st visit demonstrated faster TT than both the healthy and the CAI group, the AS subjects demonstrated an overall improved score (faster) at the 2nd visit with significant differences between the 1st and 2nd visit, 119.5ms ($t=2.87$ $p=0.018$). During the planned condition subjects at the 2nd visit demonstrated a better score for DMT (faster) when compared with the 1st visit with mean value difference of 37.1 ms but not significant ($t=1.38$ $p=0.19$). The TT demonstrated an overall improved score at the 2nd visit (mean \pm SD 1128.40 \pm 86.54), reaching a just better than healthy mean score (mean \pm SD 1180 \pm 70) with no significant differences ($t=1.30$ $p=0.22$) with mean difference of 63.3 ms, compared with the 1st visit

This result supports the first hypothesis of the current study in functional performance under unanticipated conditions. This is in agreement with findings in the cross-sectional

study, which adds further evidence to ankle studies by investigation of functional performance under unanticipated conditions; however, it does offer some insight into the function of an individual's ability to cope with returning to previous sporting activity. While AS subjects at the first visit were reported that they back to engaging in sport at recreational level within one month after injury, the evidence from this finding suggests that functional recovery on average in those subjects did not reach to be normal. There are no clear guidelines in the literature related to functional recovery in individuals with ankle sprains specially for sport population. Damaged ligaments mostly take 6-12 weeks for healing; early return to sport is commonly a problem in individuals with ankle sprains (Nelson et al. 2007; Hubbard 2008). This study suggests that a further research is required in this area aiming to reduce the current high re-injury. This could be achieved by implementing functional assessment such as unanticipated manoeuvres, which are manoeuvres thought to be more close to a sport scenario where the ankle sprain is a common injury.

8.2.2 Measure of functional performance during deep vertical jump (DVJ):

The contact time (CT) and jump height (JH) were measured using the vector mat system during deep vertical jump (DVJ), similar to the cross-sectional study. The results of JH support the first hypothesis of the current study in functional performance. In this study the AS subjects significantly had scored better for jump height at the second visit by 1.68 cm ($t=-2.85$ $p=0.019$). Also the AS subjects demonstrated an overall improved in jump score (higher) during the 2nd visit, reaching above both the healthy and CAI groups. Although the AS subjects at the 2nd visit scored a better contact time (short

time) with a mean difference of 26.6 ms, this difference was not statistically significant ($t=0.78$ $p=0.45$).

However, the improvement in the JH reported in this study is consistent with the result reported in the cross-sectional study, whereas, the AS group at the 1st visit showed a difference of 1.4cm between ankles in JH. The difference in JH between injured and non-injured ankles for AS group at 2nd visit was only 0.58cm. This difference was not significant in either CT or JH between injured and non-injured ankles for AS group at 2nd visit ($t = -2.16$ $p= 0.059$, Effect size = 0.55) and ($t = 1.38$ $p= 0.19$, Effect size = 0.41) respectively. Subsequently, the results of this study support the suggestion reported in the cross-sectional study, that jumping height is an important functional performance should be measured in the assessment of individuals with a history of ankle sprain. However, it should be noted that the time spent on the ground before jumping was measured in the current study, so each subject was required to keep contact time short while jumping higher.

8.2.3 Electromyography data

Due to the variability introduced in how the subjects carried out the unanticipated manoeuvres, which resulted in difficulties in identifying acceptable trials to use for analysis in the current study. Only data of 8 subjects in the AS at 2nd visit and 10 subjects in the AS at 1st visit, involved in this analysis. The result did not support the second hypothesis as no significant changes were found in TTP for the tibialis anterior (TA) peroneus longus (PL) and gastrocnemius lateralis (GAS) performing unanticipated

cutting manoeuvres.

No significant differences were found in the TTP between the AS at 2nd visit and 1st visits for any of the three muscles. The values for the TTP showed that every muscle in each visits scored the highest activity after foot contact. However, TTP of PL muscle in AS at the 2nd visit was longer (140 ± 48.22 ms) compared with AS at the 1st visit (79 ± 93.75 ms). Due to insufficient numbers of subjects included in this analysis, these results should be interpreted with caution. These results are in agreement with those of previous studies that focused on the onset time of PL muscles as a defence mechanism during inversion movement in people with CAI (Vaes 2002; Eechaute 2009; Konradsen and Ravn 1990; Caulfield et al. 2004; Delahunt et al. 2006b; Suda & Sacco 2009). Quicker activation of PL muscles in these studies is explained as a protective motor strategy in individuals with a history of ankle sprain.

8.2.4 Self-reported functional assessment

Self-reported assessments were analysed similar to the cross-sectional study using (1) the Foot and Ankle Disability Index (FADI), including two components, one assesses activities of daily living (FADI-ADL%) and the other is essential to sporting activities (FADI-Sport%) and (2) the Chronic Ankle Instability Scale (CAIS%). The subjects in the AS group at the 1st visit showed a better score only in CAIS % with a mean difference of 15.29% ($t= 2.87$ $p=0.018$). This results support the finding reported previously in the cross-sectional study that questionnaires that have little relevance to

ankle function or to the patient's physical level could give inappropriate results.

8.2.5 Ankle-dorsiflexion range of motion (dfROM)

In the present study the dfROM was measured using a weight-bearing lunge using the knee-to-wall principle (WBLT) similar to the cross-sectional study. The WBLT also has the ability to measure the change after a mobilisation intervention programme and the ability to distinguish between CAI and healthy individuals (Marrón-Gómez et al 2015, Hoch et al. 2012a, Hoch et al. 2012b). The third hypothesis of the current study was that AS would demonstrate changes in dorsiflexion ROM compared to the first visit. This was not supported in the current study, which showed that subjects in the AS group at the 2nd visit had better but no significant difference in dfROM compared with the 1st visit, with only a mean difference of 1.43cm ($t=-1.88$ $p=0.093$). The AS subjects demonstrated similar results at the 2nd visit, scoring below (worse) both the healthy and CAI groups. This supports the view that dfROM is not a strong predictor related to functional performance.

8.2.6 Isokinetic strength data

In the current study, isokinetic testing of the ankle invertor and evtor muscles was performed similar to the cross-sectional study. The results were presented as peak torque (PT) and normalised PT for each subject's body weight (PT/BW). More details can be found in the methods chapter. While there is no significant difference in the AS group between first and second visits, there are overall improvements, particularly in

inversion. This finding from the current study does not support the third hypothesis. The lack of significant improvement in the muscle strength can be explained by the small sample.

8.2.7 Predictors of functional recovery

The aim of this section was to identify functional recovery predictor by investigating which of the functional performance outcome measured at baseline contribute to the functional scores using self-reported assessment at 3 parts time. In attempting to identify the functional recovery predictors, correlations analysis were computed and divided into 3 parts to evaluate if there was any relationship between the self-reported functional assessment (FADI-ADL%, FADI-Sport % and CAIS%) and results of functional performance outcome.

Only the performance of JH evaluated at baseline can predict the functional outcome score at 1-month following injury using FADI-ADL ($r = -0.47$, $p = 0.036$). This result supports the finding of cross-sectional study where the healthy subjects had a better JH than the AS group by 1 cm and the CAI group by 0.7 cm, which could be clinically meaningful. Therefore, JH were further analysed by comparison between each injured and non-injured ankle in the AS and the CAI groups and between skilled and non-skilled legs in the healthy group. A significant difference was found only between injured and non-injured ankles in JH for the AS and CAI groups ($t = -4.62$ $p = 0.001$) and ($t = -2.11$ $p = 0.048$) respectively. This result indicates that JH by utilising deep vertical or counter-movement jump should continue to be used when investigating the

functional performance of individuals with a history of ankle sprain. Similar results were reported by Doherty et al (2016) found that inability to perform single leg drop landing and vertical jump at 2-week time point was predictor of CAI at the 12-month.

Further, there were no performance at baseline predict of functional statuses at 3 months. The analyses for correlation showed also that muscle strength including: Eversion Con-PT, Eversion Con-PT/BW and Eversion Ecc-PT/BW collected at baseline can predict the functional outcome at 12-month using FADI-Sport %.

The lack of association could be related to the small number of subjects included in the analyses. However, it should be noted that recovery outcome used in the current study was based on subjective assessments, which seems appropriate for some patients. These subjective assessments may not completely reflect the complexity of the functional performance test used in the current study for example unanticipated functional test. Therefore, a large longitudinal research is needed to evaluate more functional performance test and use more objective assessment to define recovery in subject following ankle sprain. This could potentially provide clinicians with more appropriate information about an individual's recovery. Consequently, it would help in the development of more appropriate treatment aiming at reducing the risk of recurrent ankle sprain.

8.3 Clinical implications of the study

The results gained from this thesis have several clinical implications related to ankle sprain injuries and chronic instability associated with this injury. Investigation of functional performance under unanticipated cutting manoeuvre was developed in the current study; however, it does offer some insight into the function of an individual's ability to cope with returning to previous recreational sporting activity. Therefore, the important recommendation from this finding is to include an unanticipated condition or a reactive element into functional tests, to simulate conditions seen during sport activity. This study also suggests that planned conditions in functional tests that have been used commonly in the literature related to CAI are not providing enough information to clinicians to predict functional performance or motor control deficiency. Therefore, it is not enough to know how fast person can complete task to predict individual's functional ability.

Another clinical implication obtain from the current thesis is that the assessment of strength is not the most appropriate measure to use independently to predict return to pre-injury sport level. The functional performance available in countermovement or deep vertical jump could provide a better indication of how muscle performs during functional activities than measured strength independently using isokinetic dynamometers.

Early activity of PL muscles has been identified in the literature as a defence strategy during inversion movement in people with CAI (Vaes 2002; Eechaute 2009; Konradsen and Ravn 1990; Caulfield et al. 2004; Delahunt et al. 2006b; Suda & Sacco 2009). This strategy results in a less plantar-flexed position during foot contact, which provides more stability and prevents further injury. The current thesis represents one of the first studies to investigate muscle activity present during unanticipated manoeuvres, which are manoeuvres thought to be more close to a sport scenario where ankle sprain is a common injury. Similar unanticipated conditions were commonly included in studies related to the knee joint and it was found that the risk of noncontact injury in the knee joint was increased when changing direction was unanticipated compared with a planned condition as a result of increased valgus angle and moments (Hyun Kim 2014; Weinhandl 2013; Houck 2006; Houck 2007; Weinhandl 2013; Besier 2000; Besier 2003; Ford 2005). In addition, individuals during unanticipated tasks showed limitation in initiating appropriate proactive adjustments of lower extremity muscles. Similar positive findings were also reported in other studies in the healthy sporty population (Farrow et al. 2005; Duvnjak-Zaknich et al. 2011; Henry et al. 2011). These studies showed that the unanticipated test has the ability to discriminate between players' skill. The results in the current study are in accordance with the positive results in these studies that utilised unanticipated tests. This supported that functional performance relies on interaction of neuromuscular system in recruiting the appropriate muscle. Therefore, this suggests that DMT could be a useful clinical parameter and an effective method of assessing the suitability of individual to return to recreational sport level after ankle sprain injury.

8.4 Limitations of the study

Due to difficulties during recruitment, only 15 consents of permission-to-contact were received from the physiotherapy-screening unit in the Accident and Emergency department (A&E) at the University Hospital of Wales, Cardiff. Nine of those 15 potential subjects refused to participate or were not eligible for the study. The main reason for refusing to take part in this study was lack of time due to study or work commitments or because they were not interested in research. However, due to the long time spent on the waiting list a high number of patients with ankle sprains who were referred to the physiotherapy-screening unit failed to turn up for their appointments. An alternative plan was implemented to recruit subjects into this group via flyers posted in and around Cardiff University and e-mail announcements were also sent to staff and students in the department of the School of Healthcare Sciences. Sports teams competing for the university were also invited through e-mail and visited for the same purposes. Any injured individual who was interested in participating was contacted to determine their eligibility according to the criteria. A total of 11 subjects were recruited by this method. While this could be recognised as a different population, which is considered a potential bias in recruitment, only those subjects who visited and received medical diagnoses were included. All subjects were also similar in their demographics and level of sport activity. Additionally, a period of 4-8 weeks post-injury before conducting the first assessment to move safely back to normal activity was applied to all subjects in this group. Another limitation is that the identification of individuals in the CAI group involved reliance on self-report of history. Therefore, there were differences in onset time of the first ankle sprain. However, an effort was made to match subjects

between groups.

Another limitation of the study was also related to recruitment in Part 2. Loss of follow-up has been a problem in this study with the ankle sprain group, as subjects were free to withdraw from the trial at any time. The study was designed to assess each subject in the ankle sprain group at three stages post-injury. Each of the subjects was encouraged during the first visit in an attempt to minimise loss of follow-up, and reminder texts and telephone calls were made to those who were scheduled for follow-up. However, term-time and holidays were considered in the booking schedule for those subjects who were students. Of the 20 subjects included in the AS group in the first assessment, only 10 subjects were included in the first follow-up while the second follow-up was composed of only four subjects.

Investigating functional performances is not without limitation, especially in an unanticipated condition. One of the major problems in the current study is the high degree of variability throughout the unanticipated functional test. Subjects were instructed to change direction in a manner that felt more natural and comfortable to them. Therefore, foot placement and cutting techniques were not monitored and controlled during the test, which introduced variability in the data. In the current study only approach speed was statistically equivalent among groups, subjects were instructed to react to the stimulus in a manner that felt natural to them. This was thought to be more close to a sport scenario where ankle sprain is a common injury. All trials were checked on video clips by the researcher (the PhD student) and then by the second assessor using criteria as explained in the method chapter. This was undertaken to avoid

a selection bias. However, the second assessor was blind to the subject group. It was clear by observing the video recordings that there was high variability in how subjects carried out the tasks in order to successfully perform the manoeuvres. The best three trials that were checked and recorded as acceptable were used for analysis. There are some limitations in identifying the variability due to camera speed, which made it more difficult to detect differences.

While EMG could provide information, there are some limitations, especially during dynamic activity such as cutting manoeuvres. Crosstalk has been reported to be a problem when investigating muscle activity. This could be a problem associated with the protocol used in onset muscle activation (Guidetti 1996). However, this problem is minimised when the peak time identification is used. However, to maximise the signal while avoiding crosstalk, electrodes were placed on both legs in accordance with the guidelines suggested by the European recommendations for surface electromyography (Hermens et al. 2000). In particular, each electrode was positioned during contraction over the belly of the muscle. For the EMG process all trials were firstly checked using video recordings. There were some limitations in identifying the foot contact moment due to the camera speed used. However, a footswitch was used to overcome this limitation and identify an accurate foot contact moment.

8.5 Future research

The findings from the current study provide a foundation for future research related to ankle sprain and targeting reducing the incidence of recurrent injury and developing chronic ankle sprain. This study adds further evidence to ankle studies by investigation of functional performance under unanticipated conditions; however, it does offer some insight into the function of an individual's ability to cope with returning to previous recreational sporting activity. These findings can also be used to design a rehabilitation-training programme aimed at reducing the current high re-injury rate. Therefore, future research can be carried out to determine the change after this programme.

Different performance strategies have been notice within subject trials. This gives an important indication of pattern variability, which may result because of deficits in motor control. The variability may be explained by the learning effect developed during assessment. Some subjects may experience difficulty in dealing with this test, which suggests that they have a reduced ability to maintain their performance when placed under unanticipated conditions. Variability under unanticipated cutting manoeuvres related to CAI has not been addressed in the literature. Therefore, future research should focus on analysis of functional movement, which may also enhance the current understanding of ankle sprain injuries.

CHAPTER 9 : CONCLUSION

The main objective of this thesis was to explore the functional performance and the neuromuscular control of subjects with a history of ankle sprain under unanticipated conditions. Therefore, this study involved two main hypotheses: Firstly, the knowledge gained by using this condition in functional assessment for people with a history of ankle sprain would provide more appropriate information about an individual's recovery than under conditions allowing preplanning. Secondly, the deficiency in neuromuscular control for subjects with a history of ankle sprain would be clearer under conditions requiring decision-making. Consequently, it would help in the development of more appropriate treatment aiming at reducing the risk of recurrent ankle sprain.

There is evidence to suggest that using unanticipated conditions in functional performance tests could provide important performance outcomes such as decision-making time (DMT) and muscle activation patterns. This could potentially provide researchers with a clear insight related to impaired function in CAI. This may also help in reducing the incidence of recurrence by the development the more appropriate treatment and rehabilitation protocols. However, this approach by a functional performance test has not been the subject of much research for subjects with a history of ankle sprain.

Results presented in part 1 of this study supported that assessing functional performance under unanticipated conditions in patients with lower limb injury, such as ankle sprain,

may be more appropriate to predict functional recovery. It also demonstrated that parameter including DMT using unanticipated condition is a useful outcome that predicts performance in subject with history of ankle sprain. In addition, the vector mat system is a simple, reliable and valid tool that could eventually allow for a functional performance to be applied and analysed clinically with less expensive equipment or time consuming. However, the current study was performed on individual at recreational sport level. Further research is needed using this approach to measure the functional performance after ankle sprain in elite athletes population to predict return to pre-injury sport level.

The results in the cross-sectional study provide further evidence that jump height using deep vertical or counter-movement jump should continue to be used when investigating the functional performance of individuals with a history of ankle sprain. However, it should be noted that the time spent on the ground before jumping was measured in the current study, so each subject was required to keep contact time short while jumping higher, which explains the reported difference between ankles in the current study. This supports that strength performance in relation to the velocity could provide a better indication of individual performance during functional activities than measured jump height only or measured strength independently using isokinetic dynamometers.

Investigating Time to peak (TTP) of muscle activity during the unanticipated functional test was collected in the current study. The main finding related to muscle activity was the values of TTP showed that every muscle in each group scored the highest activity after the foot contact. This may potentially be explained as due to the unanticipated

approach and speed used in the current study. However, it is clear that the AS group activated the PL muscle earlier than the healthy and the CAI groups with no significant differences.

An interesting finding in the current study was that TTP of PL muscle in CAI demonstrated a significant positive association with DMT performance in CAI subjects. This indicates that slower DMT performance could be a result of a motor control deficit, affecting the activity of PL muscles. Another interesting finding in the current study was that the three muscles studied showed different patterns, and the peak EMG burst occurred in a different order in each group. In the AS and healthy group, the peak of PL was scored first followed by GAS then TA. In the CAI group the GAS was first to score the peak value then the PL and TA at the same time. The peak of GAS in the CAI group may have increased the plantar flexion position of the foot at foot contact moment. This could be a strategy in those with CAI to develop enough power for propulsion to move the leg off the ground.

The main aim in the longitudinal study was to investigate the functional progress of subjects in the AS group over 6 months. Only 10 subjects completed the 2nd visit and only 4 subjects completed the 3rd visit. The subjects in the AS group at the 2nd visit at 3 months post injury performed better and faster DMT by 89.70 ms when compared with the 1st visit under unanticipated condition. The DMT also demonstrated an overall improved score of 260.7 ms, reaching a just better than healthy score of 282.60 ms with no significant differences.

In this study the AS subjects also improved during jump task, at the 2nd visit those subjects had scored higher jump by 1.24 cm compared with the 1st visit. Although, this difference was not statistically significant, the AS group at the 2nd visit scored better jump than healthy and CAI group. The change of 1.24 cm reported in this study in JH could be clinically meaningful. The results of this study support the suggestion reported in part 1 that jumping height is an important functional performance and should be measured in the assessment of individual with history of ankle sprain. Subjects were required to keep contact time short while jumping higher. This does offer some insight into the function of individual's ability to cope with returning to previous sporting activity. Subjects had better contact time (short time) by 16.45 ms at the 2nd visits. An advantage of the methods utilised in the current study is the simple equipment which can applied for both clinical and sport.

REFERENCES

- Amaral De Noronha, M. and Borges Jr., N.G. (2004). Lateral ankle sprain: isokinetic test reliability and comparison between invertors and evertors. *Clin Biomech (Bristol, Avon)* 19, pp. 868–71.
- Aragón, L.F. (2000). Evaluation of Four Vertical Jump Tests: Methodology, Reliability, Validity, and Accuracy. *Measurement in Physical Education and Exercise Science* 4(4), pp. 215–228.
- Araújo, D., Davids, K. and Serpa, S. (2005). An ecological approach to expertise effects in decision-making in a simulated sailing regatta. *Psychology of Sport and Exercise* 6(6), pp. 671–692.
- Arnold, B.L., De La Motte, S., Linens, S. and Ross, S.E. (2009). Ankle instability is associated with balance impairments: A meta-analysis. *Medicine and Science in Sports and Exercise* 41(5), pp. 1048–1062.
- Asmussen, E. and Bonde-Petersen, F. (1974). Storage of elastic energy in skeletal muscles in man. *Acta physiologica Scandinavica* 91(3), pp. 385–392.
- Bennell, K.L., Talbot, R.C., Wajswelner, H., Techovanich, W., Kelly, D.H. and Hall, A.J. (1998). Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *The Australian journal of physiotherapy* 44(3), pp. 175–180.
- Bennett, J.G. and Stauber, W.T. (1986). Evaluation and treatment of anterior knee pain using eccentric exercise. *Med Sci Sports Exerc* 18(5), pp. 526–530.
- Bernier, J.N., Perrin, D.H. and Rijke, A. (1997). Effect of unilateral functional instability of the ankle on postural sway and inversion and eversion strength. *Journal of Athletic Training* 32(3), pp. 226–232.
- Besier, T.F., Lloyd, D.G. and Ackland, T.R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Med Sci Sports Exerc* 35(1), pp. 119–127.
- Besier, T.F., Lloyd, D.G., Ackland, T.R. and Cochrane, J.L. (2001). Anticipatory effects on knee joint loading during running and cutting maneuvers. *Med Sci Sports Exerc* 33(7), pp. 1176–1181.
- Beynon, B.D., Murphy, D.F. and Alosa, D.M. (2002). Predictive Factors for Lateral Ankle Sprains: A Literature Review. *J Athl Train* 37, pp. 376–380.
- Biedert, R.M. (2000). Contribution of the three levels of nervous system motor control: Spinal cord, lower brain, and cerebral cortex. In: *Proprioception and neuromuscular control in joint stability*. Champaign Illinois: McGraw-Hill., pp. 23–31.

- Bonnel, F., Toullec, E., Mabit, C. and Tourné, Y. (2010). Chronic ankle instability: Biomechanics and pathomechanics of ligaments injury and associated lesions. *Orthopaedics and Traumatology: Surgery and Research* 96(4), pp. 424–432.
- Bosien, W.R., Staples, O.S. and Russell, S.W. (1955). Residual disability following acute ankle sprains. *J Bone Joint Surg Am* 37-A(6), pp. 1237–1243.
- Boyle, J. and Negus, V. (1998). Joint position sense in the recurrently sprained ankle. *Australian Journal of Physiotherapy* 44(3), pp. 159–163.
- Bozkurt, M. and Doral, M.N. (2006). Anatomic Factors and Biomechanics in Ankle Instability. *Foot and Ankle Clinics* 11(3), pp. 451–463.
- Bridgman, S.A., Clement, D., Downing, A., Walley, G., Phair, I. and Maffulli, N. (2003). Population based epidemiology of ankle sprains attending accident and emergency units in the West Midlands of England, and a survey of UK practice for severe ankle sprains. *Emerg Med J* 20(6), pp. 508–510.
- Brink, H., Van der Walt, C. & Van Rensburg, G. (2006) *Fundamentals of research methodology for health care professionals*. 2nd Edition. Cape Town: Juta.
- Brown, C., Padua, D., Marshall, S.W. and Guskiewicz, K. (2008). Individuals with mechanical ankle instability exhibit different motion patterns than those with functional ankle instability and ankle sprain copers. *Clin Biomech (Bristol, Avon)* 23(6), pp. 822–831.
- Brown, C., Ross, S., Mynark, R. and Guskiewicz, K. (2004). Assessing Functional Ankle Instability With Joint Position Sense, Time to Stabilization, and Electromyography. *J Sport Rehabil*, pp. 122–134.
- Brown, C.N., Rosen, A.B. and Ko, J. (2015). Ankle ligament laxity and stiffness in chronic ankle instability. *Foot & ankle international* 36(5), pp. 565–72.
- Bruton, A., Conway, J.H. and Holgate, S.T. (2000). Reliability: What is it, and how is it measured? *Physiotherapy* 86(2), pp. 94–99.
- Buchanan, A.S., Docherty, C.L. and Schrader, J. (2008). Functional performance testing in participants with functional ankle instability and in a Healthy Control Group. *Journal of Athletic Training* 43(4), pp. 342–346.
- Caffrey, E., Docherty, C.L., Schrader, J. and Klossner, J. (2009). The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. *J Orthop Sports Phys Ther* 39(11), pp. 799–806.
- Caulfield, B., Crammond, T., O’Sullivan, A., Reynolds, S. and Ward, T. (2004). Altered Ankle-Muscle Activation During Jump Landing in Participants With Functional Instability of the Ankle Joint. *J Sport Rehabil* 13(3), pp. 189–200.

- Caulfield, B. and Garrett, M. (2004). Changes in ground reaction force during jump landing in subjects with functional instability of the ankle joint. In: *Clin Biomech (Bristol, Avon)*. Elsevier Ltd, pp. 617–621.
- Chan, K.W., Ding, B.C. and Mroczek, K.J. (2011). Acute and chronic lateral ankle instability in the athlete. *Bulletin of the NYU Hospital for Joint Diseases* 69(1), pp. 17–26.
- Chmielewski, T.L., Myer, G.D., Kauffman, D. and Tillman, S.M. (2006). Plyometric exercise in the rehabilitation of athletes: physiological responses and clinical application. *The Journal of orthopaedic and sports physical therapy* 36(5), pp. 308–319.
- Collins, N., Teys, P. and Vicenzino, B. (2004). The initial effects of a Mulligan's mobilization with movement technique on dorsiflexion and pain in subacute ankle sprains. *Manual Therapy* 9(2), pp. 77–82.
- Cooke, M.W., Lamb, S.E., Marsh, J. and Dale, J. (2003). A survey of current consultant practice of treatment of severe ankle sprains in emergency departments in the United Kingdom. *Emerg Med J* 20(6), pp. 505–507.
- Cordova, M.L. and Armstrong, C.W. (1996). Reliability of ground reaction forces during a vertical jump: implications for functional strength assessment. *Journal of athletic training* 31(4), pp. 342–345.
- Criswell, E. (2011). *Cram's Introduction to Surface Electromyography*. 2nd ed.
- Croy, T., Saliba, S.A., Saliba, E., Anderson, M.W. and Hertel, J. (2012). Differences in lateral ankle laxity measured via stress ultrasonography in individuals with chronic ankle instability, ankle sprain copers, and healthy individuals. *The Journal of orthopaedic and sports physical therapy* 42(7), pp. 593–600.
- De Vaus, D. (2001). *Research Design in Social Research*. London: SAGE
- Delahunt, E. (2007). Neuromuscular contributions to functional instability of the ankle joint. *Journal of Bodywork and Movement Therapies* 11(3), pp. 203–213.
- Delahunt, E., Coughlan, G.F., Caulfield, B., Nightingale, E.J., Lin, C. and Hiller, C.E. (2010). Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Medicine and science in sports and exercise* 42(11), pp. 2106–21.
- Delahunt, E., Monaghan, K. and Caulfield, B. (2006a). Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. *Am J Sports Med* 34(12), pp. 1970–6 ST
- Delahunt, E., Monaghan, K. and Caulfield, B. (2006b). Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the

- ankle joint during a single leg drop jump. *Journal of Orthopaedic Research* 24(10), pp. 1991–2000.
- Delahunt, E., Monaghan, K. and Caulfield, B. (2007). Ankle function during hopping in subjects with functional instability of the ankle joint. In: *Scand J Med Sci Sports*. pp. 641–8 ST.
- Denegar, C. and Miller III, S. (2002). Can chronic ankle instability be prevented? Rethinking management of lateral ankle sprains. *Journal of Athletic Training* 37(4), pp. 430–435.
- Dicks, M., Button, C. and Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Atten Percept Psychophys* 72(3), pp. 706–720.
- Docherty, C.L., Arnold, B.L., Gansneder, B.M., Hurwitz, S. and Gieck, J. (2005). Functional-Performance Deficits in Volunteers With Functional Ankle Instability. *J Athl Train* 40(1), pp. 30–34.
- Docherty, C.L., Gansneder, B.M., Arnold, B.L. and Hurwitz, S.R. (2006). Development and reliability of the ankle instability instrument. *Journal of Athletic Training* 41(2), pp. 154–158.
- Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J. and Delahunt, E. (2015a). Locomotive biomechanics in persons with chronic ankle instability and lateral ankle sprain copers. *Journal of Science and Medicine in Sport* 15.
- Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J. and Delahunt, E. (2016). Recovery From a First-Time Lateral Ankle Sprain and the Predictors of Chronic Ankle Instability: A Prospective Cohort Analysis. *The American Journal of Sports Medicine* 44(4), pp. 995–1003.
- Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J. and Delahunt, E. (2015b). Lower extremity function during gait in participants with first time acute lateral ankle sprain compared to controls. *Journal of Electromyography and Kinesiology* 25(1), pp. 182–192.
- Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., Sweeney, K., Patterson, M.R. and Delahunt, E. (2015c). Coordination and symmetry patterns during the drop vertical jump, 6-months after first-time lateral ankle sprain. *Journal of orthopaedic research* 33(10), pp. 1537–44.
- Doherty, C., Delahunt, E., Caulfield, B., Hertel, J., Ryan, J. and Bleakley, C. (2014). The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. *Sports Med* 44(1), pp. 123–140.
- Domsic, R.T. and Saltzman, C.L. (1998). Ankle osteoarthritis scale. *Foot Ankle Int* 19(7), pp. 466–471.

- Donahue, M., Simon, J. and Docherty, C. (2012). Reliability and validity of a new questionnaire created to establish the presence of functional ankle instability: the IdFAI. *Athletic Training and Sports Health Care* 5, pp. 38–43.
- Donahue, M., Simon, J., Docherty, C. (2011). Critical review of self-reported functional ankle instability measures. *Foot and Ankle International* 32(12), pp. 1140–1146.
- Drake, R., Vogl, W. and Mitchell, A. (2005). *Gray's Anatomy for Students*. Philadelphia: Elsevier.
- Dundas, M.A., Gutierrez, G.M. and Pozzi, F. (2014). Neuromuscular control during stepping down in continuous gait in individuals with and without ankle instability. *J Sports Sci* 32(10), pp. 926–933.
- Duvnjak-Zaknich, D.M., Dawson, B.T., Wallman, K.E. and Henry, G. (2011). Effect of caffeine on reactive agility time when fresh and fatigued. *Medicine and Science in Sports and Exercise* 43(8), pp. 1523–1530.
- Eechaute, C., Vaes, P., Van Aerschot, L., Asman, S. and Duquet, W. (2007). The clinimetric qualities of patient-assessed instruments for measuring chronic ankle instability: A systematic review. *BMC Musculoskeletal Disorders* 8, p. 6 ST.
- Eechaute, C., Vaes, P. and Duquet, W. (2008a). Functional performance deficits in patients with CAI: Validity of the multiple hop test. *Clinical Journal of Sport Medicine* 18(2), pp. 124–9 ST.
- Eechaute, C., Vaes, P. and Duquet, W. (2008b). The chronic ankle instability scale: Clinimetric properties of a multidimensional, patient-assessed instrument. *Physical Therapy in Sport* 9(2), pp. 57–66.
- Eechaute, C., Vaes, P., Duquet, W. and Van Gheluwe, B. (2009). Reliability and discriminative validity of sudden ankle inversion measurements in patients with chronic ankle instability. *Gait Posture* 30(1), pp. 1–82.
- Elliott, A.C. and Woodward, W.A. (2010). *SAS Essentials: A guide to mastering SAS for research*. 1st ed. Jossey-Bass.
- Enoka, R.M. (2008). *Neuromechanics of human movement*. 4th Ed. Human Kinetics.
- Enoksen, E., Tønnessen, E. and Shalfawi, S. (2009). Validity and reliability of the Newtest Powertimer 300-series testing system. *Journal of sports sciences* 27(1), pp. 77–84.
- Farrow, D., Young, W. and Bruce, L. (2005). The development of a test of reactive agility for netball: a new methodology. *J Sci Med Sport* 8(1), pp. 52–60.
- Feger, M.A., Donovan, L., Hart, J.M. and Hertel, J. (2014). Lower extremity muscle activation during functional exercises in patients with and without chronic ankle

- instability. *PM & R : the journal of injury, function, and rehabilitation* 6(7), pp. 602–11.
- Ferrell, W.R., Gandevia, S.C. and McCloskey, D.I. (1987). The role of joint receptors in human kinaesthesia when intramuscular receptors cannot contribute. *The Journal of physiology* 386, pp. 63–71.
- Feuerbach, J.W., Grabiner, M.D., Koh, T.J. and Weiker, G.G. (1994). Effect of an ankle orthosis and ankle ligament anesthesia on ankle joint proprioception. *The American journal of sports medicine* 22(2), pp. 223–229.
- Fitzgerald, G.K., Lephart, S.M., Hwang, J.H. and Wainner, R.S. (2001). Hop tests as predictors of dynamic knee stability. *The Journal of orthopaedic and sports physical therapy* 31(10), pp. 588–597.
- Fitzpatrick, R., Rogers, D.K. and McCloskey, D.I. (1994). Stable human standing with lower-limb muscle afferents providing the only sensory input. *The Journal of physiology* 480 (Pt 2(1994), pp. 395–403.
- Fong, D., Ha, S., Mok, K., Chan, C. and Chan, K. (2012). Kinematics Analysis of Ankle Inversion Ligamentous Sprain Injuries in Sports: Five Cases From Televised Tennis Competitions. *The American Journal of Sports Medicine* 40(11), pp. 2627–2632.
- Fong, D.T.-P., Hong, Y., Shima, Y., Krosshaug, T., Yung, P.S.-H. and Chan, K.-M. (2009). Biomechanics of supination ankle sprain: a case report of an accidental injury event in the laboratory. *American Orthopaedic Society for Sports Medicine* 37(4), pp. 822–827.
- Fong, D.T., Hong, Y., Chan, L.K., Yung, P.S. and Chan, K.M. (2007). A systematic review on ankle injury and ankle sprain in sports. *Sports Med* 37(1), pp. 73–94.
- Ford, K.R., Myer, G.D., Toms, H.E. and Hewett, T.E. (2005). Gender differences in the kinematics of unanticipated cutting in young athletes. *Med Sci Sports Exerc* 37(1), pp. 124–129.
- Fox, J., Docherty, C.L., Schrader, J. and Applegate, T. (2008). Eccentric plantar-flexor torque deficits in participants with functional ankle instability. *J Athl Train* 43(1), pp. 51–54.
- Freeman, M. a and Wyke, B. (1967). The innervation of the knee joint. An anatomical and histological study in the cat. *Journal of anatomy* 101(Pt 3), pp. 505–532.
- Freeman, M.A., Dean, M.R. and Hanham, I.W. (1965). The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br* 47(4), pp. 678–685.
- Friel, K., McLean, N., Myers, C. and Caceres, M. (2006). Ipsilateral hip abductor weakness after inversion ankle sprain. *Journal of Athletic Training* 41(1), pp. 74–78.
- Gabbett, T. and Benton, D. (2009). Reactive agility of rugby league players. *J Sci Med*

Sport 12(1), pp. 212–214.

Gabbett, T.J., Kelly, J.N. and Sheppard, J.M. (2008). Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 22(1), pp. 174–181.

Gaebler, C., Kukla, C., Breitenseher, M.J., Nellas, Z.J., Mittlboeck, M., Trattnig, S. and Vecsei, V. (1997). Diagnosis of lateral ankle ligament injuries. Comparison between talar tilt, MRI and operative findings in 112 athletes. *Acta Orthop Scand* 68, pp. 286–90.

García-López, J., Peleteiro, J., Rodríguez-Marroyo, J.A., Morante, J.C., Herrero, J.A. and Villa, J.G. (2005). The validation of a new method that measures contact and flight times during vertical jump. *International journal of sports medicine* 26(4), pp. 294–302.

Gehring, D., Faschian, K., Lauber, B., Lohrer, H., Nauck, T. and Gollhofer, A. (2014). Mechanical instability destabilises the ankle joint directly in the ankle-sprain mechanism. *British journal of sports medicine* 48(5), pp. 377–382.

Goodwin, G.M., McCloskey, D.I. and Matthews, P.B. (1972). Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science (New York, N.Y.)* 175(28), pp. 1382–1384.

Gordon, J. and Ghez, C. (1991). Muscle receptors and spinal reflexes: the stretch reflex. In: Kandel, E. et al. eds. *Principles of Neural Science*. 3rd ed. New York, NY: Elsevier Science, pp. 564–580.

Gribble, P.A., Delahunt, E., Bleakley, C., Caulfield, B., Docherty, C.L., Fourchet, F., Fong, D., Hertel, J., Hiller, C., Kaminski, T.W., McKeon, P.O., Refshauge, K.M., van der Wees, P., Vicenzino, B. and Wikstrom, E.A. (2013). Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the International Ankle Consortium. *The Journal of orthopaedic and sports physical therapy* 43(8), pp. 585–591.

Gribble, P.A., Robinson, R.H., P.A., G. and R.H., R. (2009). An examination of ankle, knee, and hip torque production in individuals with chronic ankle instability. *J Strength Cond Res* 23(2), pp. 395–400.

Guidetti, L., Rivellini, G. and Figura, F. (1996). EMG patterns during running: Intra- and inter-individual variability. *Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology* 6(1), pp. 37–48.

Gutierrez, G.M., Kaminski, T.W. and Douex, A.T. (2009). Neuromuscular Control and Ankle Instability. *PM and R* 1(4), pp. 359–365.

Gutierrez, G.M., Knight, C.A., Swanik, C.B., Royer, T., Manal, K., Caulfield, B. and Kaminski, T.W. (2012). Examining neuromuscular control during landings on a supinating platform in persons with and without ankle instability. *The American journal of sports medicine* 40(1), pp. 193–201.

- Hale, S. a and Hertel, J. (2005). Reliability and Sensitivity of the Foot and Ankle Disability Index in Subjects With Chronic Ankle Instability. *Journal of athletic training* 40(1), pp. 35–40.
- Hartsell, H.D. and Spaulding, S.J. (1999). Eccentric/concentric ratios at selected velocities for the invertor and evertor muscles of the chronically unstable ankle. *British Journal of Sports Medicine* 33(4), pp. 255–258.
- Henry, G., Dawson, B., Lay, B. and Young, W. (2011). Validity of a reactive agility test for Australian football. *Int J Sports Physiol Perform* 6(4), pp. 534–545.
- Hermens, H.J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology* 10(5), pp. 361–374.
- Hertel, J. (2000). Functional instability following lateral ankle sprain. *Sports Med* 29(5), pp. 361–71.
- Hertel, J. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *Journal of Athletic Training* 37(4), pp. 364–375.
- Hertel, J. (2008). Sensorimotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med* 27, pp. 353–70.
- Hertel, J., Braham, R.A., Hale, S.A. and Olmsted-Kramer, L.C. (2006). Simplifying the star excursion balance test: Analyses of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther* 36(3), pp. 131–7.
- Hertel, J., Kahler, D., Perrin, D. and Guskiewicz, K. (1996). Effect of lateral ankle joint anesthesia on center of balance, postural sway, and joint position sense. *J Sport Rehabil* 5, pp. 111–119.
- Hertel, J. and Olmsted-Kramer, C. (2007). Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait and Posture* 25(1), pp. 33–39.
- Hiller, C.E., Kilbreath, S.L. and Refshauge, K.M. (2011). Chronic ankle instability: evolution of the model. *J Athl Train* 46(2), pp. 133–141.
- Hiller, C.E., Refshauge, K.M., Bundy, A.C., Herbert, R.D., Kilbreath, S.L., CE, H., KM, R., AC, B., RD, H. and SL, K. (2006). The Cumberland Ankle Instability Tool: A Report of Validity and Reliability Testing. *Archives of Physical Medicine and Rehabilitation* 87(9), pp. 1235–1241.
- Hoch, M.C., Staton, G.S., Medina McKeon, J.M., Mattacola, C.G. and McKeon, P.O. (2012a). Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. *Journal of Science and Medicine in Sport* 15(6), pp. 574–579.

- Hoch, M.C., Andreatta, R.D., Mullineaux, D.R., English, R.A., Medina McKeon, J.M., Mattacola, C.G. and McKeon, P.O. (2012b). Two-week joint mobilization intervention improves self-reported function, range of motion, and dynamic balance in those with chronic ankle instability. *Journal of Orthopaedic Research* 30(11), pp. 1798–1804.
- Hoch, M.C., Farwell, K.E., Gaven, S.L. and Weinhandl, J.T. (2015). Weight-Bearing Dorsiflexion Range of Motion and Landing Biomechanics in Individuals With Chronic Ankle Instability. *Journal of athletic training* 50(8), pp. 833–9.
- Hopkins, J.T., Brown, T.N., Christensen, L. and Palmieri-Smith, R.M. (2009). Deficits in peroneal latency and electromechanical delay in patients with functional ankle instability. *Journal of Orthopaedic Research* 27(12), pp. 1541–1546.
- Houck, J.R., Duncan, A. and De Haven, K.E. (2006). Comparison of frontal plane trunk kinematics and hip and knee moments during anticipated and unanticipated walking and side step cutting tasks. *Gait and Posture* 24(3), pp. 314–322.
- Houck, J.R., De Haven, K.E. and Maloney, M. (2007). Influence of anticipation on movement patterns in subjects with ACL deficiency classified as noncopers. *Journal of Orthopaedic and Sports Physical Therapy* 37(2), pp. 56–64.
- Hua, Y., Yang, Y., Chen, S. and Cai, Y. (2012). Ultrasound examination for the diagnosis of chronic anterior talofibular ligament injury. *Acta radiologica (Stockholm, Sweden : 1987)* 53(10), pp. 1142–1145.
- Hubbard, T., Kramer, L., Denegar, C. and Hertel, J. (2007a). Contributing factors to chronic ankle instability. *Foot & ankle international* 28(3), pp. 343–354.
- Hubbard, T.J., Kramer, L.C., Denegar, C.R. and Hertel, J. (2007b). Correlations among multiple measures of functional and mechanical instability in subjects with chronic ankle instability. *Journal of Athletic Training* 42(3), pp. 361–366.
- Hubbard, T.J. (2008). Ligament laxity following inversion injury with and without chronic ankle instability. *Foot and Ankle International* 29(3), pp. 305–311.
- Hubbard, T.J. and Hertel, J. (2006). Mechanical contributions to chronic lateral ankle instability. *Sports medicine* 36(3), pp. 263–77.
- Hubbard, T.J., Kaminski, T.W., Vander Griend, R.A. and Kovalski, J.E. (2004). Quantitative Assessment of Mechanical Laxity in the Functionally Unstable Ankle. *Medicine and Science in Sports and Exercise* 36(5), pp. 760–766.
- Hurley, M. V, Jones, D.W. and Newham, D.J. (1994). Arthrogenic quadriceps inhibition and rehabilitation of patients with extensive traumatic knee injuries. *Clin Sci (Lond)* 86(3), pp. 305–310.
- Jackson, D.W., Ashley, R.L. and Powell, J.W. (1974). Ankle sprains in young athletes. Relation of severity and disability. *Clin Orthop Relat Res* (101), pp. 201–215.

- Johansson, H., Pedersen, J. and Bergenheim, M. (2000). Peripheral afferents of the knee: their effects on central mechanisms regulating muscle stiffness, joint stability, and proprioception and coordination. In: *Proprioception and neuromuscular control in joint stability*. Champaign: Human Kinetics, pp. 5–22.
- Johnson, K.O. (2001). The roles and functions of cutaneous mechanoreceptors. *Current Opinion in Neurobiology* 11, pp. 455–461.
- Kaikkonen, A., Kannus, P. and Järvinen, M. (1994). A performance test protocol and scoring scale for the evaluation of ankle injuries. *Am J Sports Med* 22(4), pp. 462–469.
- Kaminski, B.T.W., Perrin, D.H., Mattacola, C.G., Szczerba, J.E. and Julie, N. (1995). The Reliability and Validity of Ankle Inversion and Eversion Torque Measurements From the Kin Com II Isokinetic Dynamometer. *Journal of Sport Rehabilitation* 4, pp. 210–218.
- Kaminski, T.W. and Hartsell, H.D. (2002). Factors Contributing to Chronic Ankle Instability: A Strength Perspective. *J Athl Train* 37(4), pp. 394–405.
- Kaminski, T.W., Perrin, D.H. and Gansneder, B.M. (1999). Eversion strength analysis of uninjured and functionally unstable ankles. *J Athl Train* 34(3), pp. 239–245.
- Kanamoto, T., Shiozaki, Y., Tanaka, Y., Yonetani, Y. and Horibe, S. (2014). The use of MRI in pre-operative evaluation of anterior talofibular ligament in chronic ankle instability. *Bone Joint Res* 3(8), pp. 241–245.
- Kandel, E.R., Schwartz, J.H. and Jessell, T.M. (2000). *Principles of Neural Science*.
- Khin-Myo-Hla, Ishii, T., Sakane, M. and Hayashi, K. (1999). Effect of anesthesia of the sinus tarsi on peroneal reaction time in patients with functional instability of the ankle. *Foot Ankle Int* 20(9), pp. 554–559.
- Kim, J.H., Lee, K.K., Kong, S.J., An, K.O., Jeong, J.H. and Lee, Y.S. (2014). Effect of Anticipation on Lower Extremity Biomechanics During Side- and Cross-Cutting Maneuvers in Young Soccer Players. *Am J Sports Med* 42(8), pp. 1985–1992.
- Kitaoka, H.B., Alexander, I.J., Adelaar, R.S., Nunley, J.A., Myerson, M.S. and Sanders, M. (1994). Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. *Foot Ankle Int* 15(7), pp. 349–353.
- Konor, M.M., Morton, S., Eckerson, J.M. and Grindstaff, T.L. (2012). Reliability of three measures of ankle dorsiflexion range of motion. *International journal of sports physical therapy* 7(3), pp. 279–87.
- Konradsen, L. and Magnusson, P. (2000). Increased inversion angle replication error in functional ankle instability. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA* 8(4), pp. 246–251.

- Konradsen, L., Olesen, S. and Hansen, H.M. (1998). Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *The American journal of sports medicine* 26(1), pp. 72–77.
- Konradsen, L., Peura, G., Beynnon, B. and Renström, P. (2005). Ankle eversion torque response to sudden ankle inversion Torque response in unbraced, braced, and pre-activated situations. *Journal of orthopaedic research: official publication of the Orthopaedic Research Society* 23(2), pp. 315–21.
- Konradsen, L. and Ravn, J.B. (1990). Ankle instability caused by prolonged peroneal reaction time. *Acta Orthop Scand* 61(5), pp. 388–90.
- Konradsen, L. and Ravn, J.B. (1991). Prolonged peroneal reaction time in ankle instability. *Int J Sports Med* 12(3), pp. 290–292.
- Konradsen, L., Ravn, J.B. and Sørensen, a I. (1993). Proprioception at the ankle: the effect of anaesthetic blockade of ligament receptors. *The Journal of bone and joint surgery. British volume* 75(3), pp. 433–436.
- Konradsen, L., Voigt, M. and Hojsgaard, C. (1997). Ankle inversion injuries. The role of the dynamic defense mechanism. *Am J Sports Med* 25(1), pp. 54–58.
- Kristianslund, E., Bahr, R. and Krosshaug, T. (2011). Kinematics and kinetics of an accidental lateral ankle sprain. *Journal of Biomechanics* 44(14), pp. 2576–2578.
- Krosshaug, T. and Bahr, R. (2005). A model-based image-matching technique for three-dimensional reconstruction of human motion from uncalibrated video sequences. *Journal of Biomechanics* 38(4), pp. 919–929.
- Landis, J.R. and Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics* 33(1), pp. 159–174.
- Larkins, C. and Snabb, T.E. (1999). Positive versus negative foot inclination for maximum height two-leg vertical jumps. *Clinical biomechanics (Bristol, Avon)* 14(5), pp. 321–8.
- Leanderson, J., Bergqvist, M., Rolf, C., Westblad, P., Wigelius-Roovers, S. and Wredmark, T. (1999). Early influence of an ankle sprain on objective measures of ankle joint function. A prospective randomised study of ankle brace treatment. *Knee surgery, sports traumatology, arthroscopy* 7(1), pp. 51–8.
- Lee, K.M., Chung, C.Y., Kwon, S.-S., Chung, M.K., Won, S.H., Lee, S.Y. and Park, M.S. (2013). Relationship between stress ankle radiographs and injured ligaments on MRI. *Skeletal radiology* 42(11), pp. 1537–42.
- Lee, K.T., Park, Y.U., Jegal, H., Park, J.W., Choi, J.P. and Kim, J.S. (2014). New

method of diagnosis for chronic ankle instability: Comparison of manual anterior drawer test, stress radiography and stress ultrasound. *Knee Surgery, Sports Traumatology, Arthroscopy* 22(7), pp. 1701–1707.

Lentell, G., Cashman, P., Shiimoto, K. and Spry, J. (1988). The effect of knee position on torque output during inversion and eversion movements at the ankle. *J Orthop Sports Phys Ther* 10(5), pp. 177–83.

Levin, O., Van Nevel, A., Malone, C., Van Deun, S., Duysens, J. and Staes, F. (2012). Sway activity and muscle recruitment order during transition from double to single-leg stance in subjects with chronic ankle instability. *Gait Posture* 36(3), pp. 546–551.

Levin, O., Vanwanseele, B., Thijsen, J.R.J., Helsen, W.F., Staes, F.F. and Duysens, J. (2015). Proactive and reactive neuromuscular control in subjects with chronic ankle instability: Evidence from a pilot study on landing. *Gait and Posture* 41(1), pp. 106–111.

Lin, C.-F., Chen, C.-Y. and Lin, C.-W. (2011). Dynamic ankle control in athletes with ankle instability during sports maneuvers. *The American journal of sports medicine* 39, pp. 2007–2015.

Linthorne, N.P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physiology* 69(11), pp. 1198–1204.

Lofvenberg, R., Karrholm, J., Sundelin, G. and Ahlgren, O. (1995). Prolonged reaction time in patients with chronic lateral instability of the ankle. *Am J Sports Med* 23(4), pp. 414–417.

Magill, R.A. (2011). *Motor Learning and Control: Concepts and Applications*. 9th ed. New York, NY: McGraw Hill.

Mann, G., Nysha, M., Constantini, N., Matan, Y., Renstrom, P. and Lynch, S. (2002). Mechanics of injury, clinical presentation, and staging. In: Nyska, M. and Mann, G. eds. *The Unstable Ankle*. Human Kinetics, pp. 54–60.

Marrón-Gómez, D., Rodríguez-Fernández, T.L. and Martín-Urrialde, J.A. (2015). The effect of two mobilization techniques on dorsiflexion in people with chronic ankle instability. *Physical Therapy in Sport* 16(1), pp. 10–15.

Marshall, P.W.M., McKee, A.D. and Murphy, B.A. (2009). Impaired trunk and ankle stability in subjects with functional ankle instability. *Medicine and Science in Sports and Exercise* 41(8), pp. 1549–1557.

Martin, R., Burdett, R. and Irrgang, J. (1999). Development of the Foot and Ankle Disability Index (FADI). *J Orthop Sports Phys Ther* 29, pp. A32–A33.

Martin, R.L., Irrgang, J.J., Burdett, R.G., Conti, S.F. and Van Swearingen, J.M. (2005). Evidence of validity for the Foot and Ankle Ability Measure (FAAM). *Foot & ankle*

international / American Orthopaedic Foot and Ankle Society [and] Swiss Foot and Ankle Society 26(11), pp. 968–983.

Matsusaka, N., Yokoyama, S., Tsurusaki, T., Inokuchi, S. and Okita, M. (2001). Effect of ankle disk training combined with tactile stimulation to the leg and foot on functional instability of the ankle. *Am J Sports Med* 29(1), pp. 25–30.

McCloskey, D.I., Cross, M.J., Honner, R. and Potter, E.K. (1983). Sensory effects of pulling or vibrating exposed tendons in man. *Brain : a journal of neurology* 106 (Pt 1), pp. 21–37.

McKeon, P.O. and Hertel, J. (2008a). Systematic Review of Postural Control and Lateral Ankle Instability , Part I : Can Deficits Be Detected. *Journal of Athletic Training* 293 43(3), pp. 293–304.

McKeon, P.O. and Hertel, J. (2008b). Systematic review of postural control and lateral ankle instability, part II: Is balance training clinically effective? *J Athl Train* 43(3), pp. 305–315.

McKeon, P.O., Ingersoll, C.D., Kerrigan, D.C., Saliba, E., Bennett, B.C. and Hertel, J. (2008). Balance training improves function and postural control in those with chronic ankle instability. *Medicine and Science in Sports and Exercise* 40(10), pp. 1810–1819.

McVey, E.D., Palmieri, R.M., Docherty, C.L., Zinder, S.M. and Ingersoll, C.D. (2005). Arthrogenic muscle inhibition in the leg muscles of subjects exhibiting functional ankle instability. *Foot and Ankle International* 26(12), pp. 1055–1061.

Moir, G.L. (2008). Three Different Methods of Calculating Vertical Jump Height from Force Platform Data in Men and Women. *Measurement in Physical Education and Exercise Science* 12(March 2015), pp. 207–218.

Monaghan, K., Delahunt, E. and Caulfield, B. (2006). Ankle function during gait in patients with chronic ankle instability compared to controls. *Clin Biomech (Bristol, Avon)* 21(2), pp. 168–174.

Monteleone, B.J., Ronsky, J.L., Meeuwisse, W.H. and Zernicke, R.F. (2014). Ankle Kinematics and Muscle Activity in Functional Ankle Instability. *Clinical Journal of Sport Medicine* 24(1), pp. 62–68.

Morrison, K. and Kaminski, T. (2007). Foot characteristics in association with inversion ankle injury. *Journal of Athletic Training* 42(1), pp. 135–142.

Munn, J., Beard, D., Refshauge, K. and Lee, R. (2002). Do functional-performance tests detect impairment in subjects with ankle instability? *Journal of Sport Rehabilitation* 11(1), pp. 40–50.

Munn, J., Beard, D.J., Refshauge, K.M. and Lee, R.Y. (2003). Eccentric muscle strength in functional ankle instability. *Medicine and Science in Sports and Exercise*

35(2), pp. 245–250.

Myers, J.B., Riemann, B.L., Hwang, J.-H., Fu, F.H. and Lephart, S.M. (2003). Effect of peripheral afferent alteration of the lateral ankle ligaments on dynamic stability. *The American journal of sports medicine* 31(4), pp. 498–506.

Naicker, M., McLean, M., Esterhuizen, T.M. and Peters-Futre, E.M. (2007). Poor peak dorsiflexor torque associated with incidence of ankle injury in elite field female hockey players. *J Sci Med Sport* 10(6), pp. 363–371.

Nakagawa, L. and Hoffman, M. (2004). Performance in Static, Dynamic, and Clinical Tests of Postural Control in Individuals With Recurrent Ankle Sprains. *Journal of Sport Rehabilitation* 13(3), pp. 255–268.

Negahban, H., Moradi-Bousari, A., Naghibi, S., Sarrafzadeh, J., Shaterzadeh-Yazdi, M.J., Goharpey, S., Etemadi, M., Mazaheri, M. and Feizi, A. (2013). The eccentric torque production capacity of the ankle, knee, and hip muscle groups in patients with unilateral chronic ankle instability. *Asian J Sports Med* 4(2), pp. 144–152.

Nelson, A.J., Collins, C.L., Yard, E.E., Fields, S.K. and Comstock, R.D. (2007). Ankle injuries among United States high school sports athletes, 2005-2006. *Journal of Athletic Training* 42(3), pp. 381–387.

Nitschke, J.E. (1992). Reliability of isokinetic torque measurements: A review of the literature. *The Australian journal of physiotherapy* 38(2), pp. 125–34.

Noyes, F., Barber, S. and Mangine, R. (1991). Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *American Journal Of Sports Medicine* 19(5), pp. 513–518.

Noyes, F.R., Barber, S.D. and Mooar, L.A. (1989). A rationale for assessing sports activity levels and limitations in knee disorders. *Clinical orthopaedics and related research* 246, pp. 238–49.

O'Connor, S.R., Bleakley, C.M., Tully, M.A. and McDonough, S.M. (2013). Predicting Functional Recovery after Acute Ankle Sprain. *PLoS ONE* 8(8).

Oliver, J.L. and Meyers, R.W. (2009). Reliability and generality of measures of acceleration, planned agility, and reactive agility. *Int J Sports Physiol Perform* 4(3), pp. 345–354.

Palmieri-Smith, R.M., Hopkins, J.T. and Brown, T.N. (2009). Peroneal activation deficits in persons with functional ankle instability. *The American journal of sports medicine* 37(5), pp. 982–8.

Parasher, R.K., Nagy, D.R., Em, A.L., Phillips, H.J. and Mc Donough, A.L. (2012). Clinical measurement of mechanical ankle instability. *Manual Therapy* 17(5), pp. 470–473.

- Pauole, K., Madole, K., Garhammer, J., Lacourse, M. and Rozenek, R. (2000). Reliability and validity of the T-test as a measure of agility, leg power, and leg speed in college-aged men and women. *The Journal of Strength and Conditioning Research* 14(4), pp. 443–450.
- Peters, J.W., Trevino, S.G. and Renstrom, P.A. (1991). Chronic lateral ankle instability. *Foot Ankle* 12(3), pp. 182–191.
- Pontaga, I. (2004). Ankle joint evertor-invertor muscle torque ratio decrease due to recurrent lateral ligament sprains. *Clin Biomech (Bristol, Avon)* 19(7), pp. 760–2.
- Portney, L.G. and Watkins, M.P. (2009). *Foundations of Clinical Research: Application to Practice*. 3rd ed. New Jersey: Pearson Education.
- Proske, U., Schaible, H.-G. and Schmidt, R.F. (1988). Joint receptors and kinaesthesia. *Experimental Brain Research* 72(2), pp. 219–224.
- Refshauge, K.M., Kilbreath, S.L. and Gandevia, S.C. (1998). Movement detection at the distal joint of the human thumb and fingers. *Experimental Brain Research* 122(1), pp. 85–92.
- Rice, D.A. and McNair, P.J. (2010). Quadriceps Arthroscopic Muscle Inhibition: Neural Mechanisms and Treatment Perspectives. *Seminars in Arthritis and Rheumatism* 40(3), pp. 250–266.
- Riemann, B.L. and Lephart, S.M. (2002). The sensorimotor system, part I: the physiologic basis of functional joint stability. *Journal of athletic training* 37(1), pp. 71–9.
- Riemann, B.L., Myers, J.B., Stone, D.A. and Lephart, S.M. (2004). Effect of lateral ankle ligament anesthesia on single-leg stance stability. *Medicine and Science in Sports and Exercise* 36(3), pp. 388–396.
- Rosen, A., Swanik, C., Thomas, S., Glutting, J., Knight, C. and Kaminski, T.W. (2013). Differences in lateral drop jumps from an unknown height among individuals with functional ankle instability. *Journal of athletic training* 48(6), pp. 773–781.
- Ross, S.E., Guskiewicz, K.M., Gross, M.T. and Yu, B. (2008). Assessment tools for identifying functional limitations associated with functional ankle instability. *Journal of athletic training* 43(1), pp. 44–50.
- Ryan, L. (1994). Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. *Australian Journal of Physiotherapy* 40(1), pp. 41–47.
- Saag, K.G., Saltzman, C.L., Brown, C.K. and Budiman-Mak, E. (1996). The Foot Function Index for measuring rheumatoid arthritis pain: evaluating side-to-side reliability. *Foot Ankle Int* 17(8), pp. 506–510.

- Safran, M.R., Benedetti, R.S., Bartolozzi 3rd, A.R. and Mandelbaum, B.R. (1999). Lateral ankle sprains: a comprehensive review: part 1: etiology, pathoanatomy, histopathogenesis, and diagnosis. *Medicine and Science in Sports and Exercise* 31(7 SUPPL.), pp. S429–37.
- Santello, M. and McDonagh, M.J. (1998). coordinatino of locomotion with voluntary movements in humans. *Experimental physiology* 83(31), pp. 857–874.
- Santilli, V., Frascarelli, M.A., Paoloni, M., Frascarelli, F., Camerota, F., De Natale, L. and De Santis, F. (2005). Peroneus longus muscle activation pattern during gait cycle in athletes affected by functional ankle instability: A surface electromyographic study. *Am J Sports Med* 33(8), pp. 1183–1187.
- Scanlan, A.T., Tucker, P.S. and Dalbo, V.J. (2015). The importance of open- and closed-skill agility for team selection of adult male basketball players. *The Journal of sports medicine and physical fitness* 55(5), pp. 390–396.
- Schmidt, R.A. and Lee, T.D. (2005). *Motor control and learning: A behavioral emphasis*.
- Sekir, U., Yildiz, Y., Hazneci, B., Ors, F., Saka, T. and Aydin, T. (2008). Reliability of a functional test battery evaluating functionality, proprioception, and strength in recreational athletes with functional ankle instability. *Eur J Phys Rehabil Med* 44(4), pp. 407–15.
- Sharma, N., Sharma, A. and Singh Sandhu, J. (2011). Functional performance testing in athletes with functional ankle instability. *Asian J Sports Med* 2(4), pp. 249–258.
- Sheppard, J.M., Young, W.B. and Doyle, T.L. (2006). An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *J Sci Med Sport* 9(4), pp. 342–349.
- Simon, J., Donahue, M. and Docherty, C. (2012). Development of the identification of functional ankle instability (IdFAI). *Foot and Ankle International* 33(9), pp. 755–763.
- Simon, J., Donahue, M. and Docherty, C.L. (2014). Critical review of self-reported functional ankle instability measures: A follow up. *Physical Therapy in Sport* 15(2), pp. 97–100.
- Stanfield, C.L. and Germann, W.J. (2008). *Principles of human physiology*. 3rd ed. San Francisco, CA: Pearson Education.
- Stiell, I.G., Greenberg, G.H., McKnight, R.D., Nair, R.C., McDowell, I. and Worthington, J.R. (1992). A study to develop clinical decision rules for the use of radiography in acute ankle injuries. *Ann Emerg Med* 21(4), pp. 384–390.
- Suda, E.Y., Amorim, C.F. and Sacco Ide, C. (2009). Influence of ankle functional instability on the ankle electromyography during landing after volleyball blocking. *J*

Electromyogr Kinesiol 19(2), pp. e84–e93.

Suda, E.Y. and Sacco, I.C. (2011). Altered leg muscle activity in volleyball players with functional ankle instability during a sideward lateral cutting movement. *Physical Therapy in Sport* 12(4), pp. 164–170.

Terada, M., Harkey, M.S., Wells, A.M., Pietrosimone, B.G. and Gribble, P.A. (2014). The influence of ankle dorsiflexion and self-reported patient outcomes on dynamic postural control in participants with chronic ankle instability. *Gait and Posture* 40(1), pp. 193–197.

Trč, T., Handl, M. and Havlas, V. (2010). The anterior talo-fibular ligament reconstruction in surgical treatment of chronic lateral ankle instability. *International Orthopaedics* 34(7), pp. 991–996.

Tropp, H. (1986). Pronator muscle weakness in functional instability of the ankle joint. *Int J Sports Med* 7, pp. 291–4.

Vaes, P., Duquet, W. and Van Gheluwe, B. (2002). Peroneal Reaction Times and Eversion Motor Response in Healthy and Unstable Ankles. *J Athl Train* 37(4), pp. 475–480.

Vaeyens, R., Lenoir, M., Williams, A.M. and Philippaerts, R.M. (2007). Mechanisms underpinning successful decision making in skilled youth soccer players: an analysis of visual search behaviors. *J Mot Behav* 39(5), pp. 395–408.

van Rijn, R.M., van Os, A.G., Bernsen, R.M.D., Luijsterburg, P. a, Koes, B.W. and Bierma-Zeinstra, S.M.A. (2008). What Is the Clinical Course of Acute Ankle Sprains? A Systematic Literature Review. *The American Journal of Medicine* 121(4), pp. 324–331.e7.

Veale, J.P., Pearce, A.J. and Carlson, J.S. (2010). Reliability and validity of a reactive agility test for Australian football. *International Journal of ...* 5(2), pp. 239–248.

Weinhandl, J.T., Earl-Boehm, J.E., Ebersole, K.T., Huddleston, W.E., Armstrong, B.S. and O'Connor, K.M. (2013). Anticipatory effects on anterior cruciate ligament loading during sidestep cutting. *Clin Biomech (Bristol, Avon)* 28(6), pp. 655–663.

Westlake, K.P., Wu, Y. and Culham, E.G. (2007). Sensory-specific balance training in older adults: effect on position, movement, and velocity sense at the ankle. *Physical therapy* 87(5), pp. 560–568.

Wexler, R.K. (1998). The injured ankle. *Am Fam Physician* 57(3), pp. 474–480.

Wikstrom, E.A., Arrigenna, M.A., Tillman, M.D. and Borsa, P.A. (2006). Dynamic postural stability in subjects with braced, functionally unstable ankles. *Journal of Athletic Training* 41(3), pp. 245–250.

- Wikstrom, E.A., Tillman, M.D., Chmielewski, T.L., Cauraugh, J.H., Naugle, K.E. and Borsa, P.A. (2009). Self-assessed disability and functional performance in individuals with and without ankle instability: A case control study. *Journal of Orthopaedic and Sports Physical Therapy* 39(6), pp. 458–467.
- Wikstrom, E.A., Tillman, M.D., Chmielewski, T.L., Cauraugh, J.H., Naugle, K.E. and Borsa, P.A. (2012). Discriminating between copers and people with chronic ankle instability. *Journal of athletic training* 47(2), pp. 136–142.
- Wilkerson, G.B., Pinerola, J.J. and Caturano, R.W. (1997). Invertor vs. evertor peak torque and power deficiencies associated with lateral ankle ligament injury. *Journal of Orthopaedic and Sports Physical Therapy* 26(2), pp. 78–86.
- Willems, T., Witvrouw, E., Verstuyft, J., Vaes, P., Clercq, D. De and De Clercq, D. (2002). Proprioception and Muscle Strength in Subjects With a History of Ankle Sprains and Chronic Instability. *Journal of Athletic Training* 37(4), pp. 487–493.
- Williams, G.N., Chmielewski, T., Rudolph, K., Buchanan, T.S. and Snyder-Mackler, L. (2001). Dynamic knee stability: current theory and implications for clinicians and scientists. *The Journal of orthopaedic and sports physical therapy* 31(10), pp. 546–566.
- Wilson, R.W. and Gansneder, B.M. (2000). Measures of functional limitation as predictors of disablement in athletes with acute ankle sprains. *The Journal of orthopaedic and sports physical therapy* 30(9), pp. 528–35.
- Winter, J. a, Allen, T.J. and Proske, U. (2005). Muscle spindle signals combine with the sense of effort to indicate limb position. *The Journal of physiology* 568(3), pp. 1035–1046.
- Wright, C.J., Arnold, B.L., Ross, S.E. and Linens, S.W. (2014). Recalibration and validation of the Cumberland ankle instability tool cutoff score for individuals with chronic ankle instability. *Archives of physical medicine and rehabilitation* 95(10), pp. 1853–1859.
- Yeung, M.S., Chan, K.M., So, C.H. and Yuan, W.Y. (1994). An epidemiological survey on ankle sprain. *British Journal of Sports Medicine* 28(2), pp. 112–116.
- Yildiz, Y., Aydin, T., Sekir, U., Hazneci, B., Komurcu, M. and Kalyon, T.A. (2003). Peak and end range eccentric evertor/concentric invertor muscle strength ratios in chronically unstable ankles: comparison with healthy individuals. *J Sports Sci Med* 2(3), pp. 70–76.
- Young, W.B., James, R. and Montgomery, I. (2002). Is muscle power related to running speed with changes of direction? *Journal of Sports Medicine and Physical Fitness* 42(3), pp. 282–288.

Young, W.B., MacDonald, C. and Flowers, M.A. (2001). Validity of double- and single-leg vertical jumps as tests of leg extensor muscle function. *Journal of strength and conditioning research* 15(1), pp. 6–11.

Young, W.B. and Willey, B. (2010). Analysis of a reactive agility field test. *J Sci Med Sport* 13(3), pp. 376–378.

APPENDIX A

Ankle Instability Instrument

Instructions

This form will be used to categorize your ankle instability. Please fill out the form completely. If you have any questions, please ask.

Y N

1. Have you ever sprained an ankle?

2. Have you ever seen a doctor for an ankle sprain?

If yes, How did the doctor categorize your most serious ankle sprain?

Mild (grade 1) Moderate (grade 2) Severe (grade 3)

3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?

If yes, In the most serious case, how long did you need to use the device?

Days , 4-7 days , 1-2 weeks , 2-3 weeks , 3 weeks

4. Have you ever experienced a sensation of your ankle "giving way"?

If yes, When was the last time your ankle "gave way"?

1 month , 1-6 months ago , 6-12 months ago , 1-2 years ago , 2 years ago

5. Does your ankle ever feel unstable while walking on a flat surface?

6. Does your ankle ever feel unstable while walking on uneven ground?

7. Does your ankle ever feel unstable during recreational or sport activity?

8. Does your ankle ever feel unstable while going up stairs?

9. Does your ankle ever feel unstable while going down stairs?

(Docherty et al. 2006, Caffrey et al. 2009).

APPENDIX B

Subject's Data Sheet

NO	<input type="text" value="1"/>	Code	<input type="text" value=""/>	<input type="radio"/> Healthy	<input type="radio"/> CAI	<input type="radio"/> AS
Demographic Data						
AGE	<input type="text"/>	Weight	<input type="text"/>	Height	<input type="text"/>	Level of activity <input type="text"/>
Dominant leg	<input type="text"/>					<input type="text"/>
Gender	<input type="radio"/> Male <input type="radio"/> Female					
ROM/Laxity				Jump		
dorsiflexion lunge test :				Contact time Flight Time		
R	<input type="text"/>	Degree	<input type="text"/>	1	<input type="text"/>	1
L	<input type="text"/>	Degree	<input type="text"/>	2	<input type="text"/>	2
Laxity	<input type="radio"/> Y <input type="radio"/> N					
				R/L		
				3	<input type="text"/>	3
				3	<input type="text"/>	3
Self-report						
FADI <input type="text"/>						
CAIS <input type="text"/>						
<input type="button" value="OK"/> <input type="button" value="Cancel"/> <input type="button" value="Clear Form"/> <input type="button" value="Find"/> <input type="button" value="Print"/>						
Isokinetic Strength				Cutting Task		
Inv Right Inv Left Con <input type="text"/> Ecc <input type="text"/> Con <input type="text"/> Ecc <input type="text"/> Time <input type="text"/> Time <input type="text"/> Time <input type="text"/> Time <input type="text"/> Ev Right Ev Left Con <input type="text"/> Ecc <input type="text"/> Con <input type="text"/> Ecc <input type="text"/> Time <input type="text"/> Time <input type="text"/> Time <input type="text"/> Time <input type="text"/>				Un-planned Pre-planned DM 1 <input type="text"/> TT 1 <input type="text"/> DM 1 <input type="text"/> TT 1 <input type="text"/> DM 2 <input type="text"/> TT 2 <input type="text"/> DM 2 <input type="text"/> TT 2 <input type="text"/> DM 3 <input type="text"/> TT 3 <input type="text"/> DM 3 <input type="text"/> TT 3 <input type="text"/>		

APPENDIX C

Ahmed Almansour
 School of Healthcare Sciences
 Cardiff University
 2F25 Cardigan House
 Heath Park Campus, Cardiff,
 CF14 4XW
 Email: ahmed.pt@hotmail.com

Tel: 020920743633
 Mob: 07872599970



INFORMATION FOR PARTICIPANT IN RESEARCH

Identifying Indicators of Functional Recovery after Ankle Sprain in Physically Active People

We are asking you to take part in a research study being carried out in Cardiff University. Your participation in this study is voluntary. While we would be pleased to have you participate we respect your right to decline. Before deciding if you would like to be part of the trial, please take time to read the following information carefully. If there is anything unclear or you would like more information don't hesitate to ask.

1) What is the purpose of this study?

Ankle sprains are one of the most common injuries, especially among physically active people. In the UK an estimated 302,000 ankle sprains are reported to Emergency Departments each year. One of the major problems for many people after an initial ankle sprain is the high recurrence of ankle sprain and residual symptoms often resulting in the development of chronic ankle instability. The purpose of this study is to identify how people recover after initial ankle sprain. Developing better measurement of recovery from ankle sprain will help determine when it is appropriate to return to previous normal activities or to sport participation.

2) What does this study involve?

This study is for research purposes only and you would receive no therapeutic benefits for taking part. However, the researcher will evaluate your functional performance after injury which may help you to assess your ability to return to your previous normal activities or to sport participation.

If you agree to be involved in this research study, you will undergo certain tests and procedures to measure your recovery at 3 stages:

1 month after injury	3 months after injury	6 months after injury
Assessment in the lab	Assessment in the lab	Assessment in the lab

This assessment will include:

a. Self-reported Assessment

This assessment contains questions individuals answer about their functional level, and pain etc. The answers indicate a person's recovery characteristics over time.

b. Muscles strength assessment

This test will be done using a computer- controlled dynamometer. This system has the capability to test muscle strength in a variety of modes.

c. Jump test

This test is to measure your ability to jump higher. You will be asked to drop off a height then quickly jumping as high as you can.

d. Agility test (cutting manoeuvre)

This test is to measure your ability to move quickly and change directions while maintaining control and balance. A new computerized tool will be used to measure the decision making time and accuracy by responding to a light cue.

e. Muscles activities using Electromyography (EMG)

Small Electrodes will be placed over your ankle muscles. Also Skin preparation consists of shaving the skin over the area of electrode placement will be applied if needed followed by cleaning of the skin with alcohol swabs.

3) Why have I been chosen?

You have been chosen because you are an adult and an active individual with ankle sprain injury that we are interested in looking at and ensuring your performance using different tests. In total 21 subjects will be asked to take part in same group and the result will be compared with subjects with history of ankle sprain and health people.

4) What will happen if I do take part?

If you are happy to take part, you will be asked to sign a consent form. Then you will be asked to attend the Research Centre for Clinical Kinesiology (RCCK) of Cardiff University (School of Healthcare Studies) on 3 occasions (map & direction attached). During the visit you would need to bring training clothes with you. Your height and weight will be collected first, and then you will undergo different tests to measure functional performance.

5) How long these trials will take?

Each visit might take approximately 90 minutes for each participant.

6) What will I have to do before these visits?

You do not have to do anything specific in preparation for this study.

7) Expense?

You will be reimbursed for reasonable travel expenses.

8) What if I choose to take part and then change my mind?

You have the right to withdraw or discontinue from the study at any time.

9) What are the risks of taking part?

There are very few risks associated with this research. These include possibility of loss of balance during cutting manovers or jump test. If this does occur you will be given the appropriate advice from a qualified physiotherapist or referred to the emergency department if needed. However, proper demonstration and instruction will be provided prior to starting.

10) What are the benefits of taking part?

If you take part in this study, there may or may not be direct clinical benefit to you. We anticipate that this research will provide important information to clinicians in sport rehabilitation in their overall assessment of ankle injuries.

11) Will my participation be kept confidential?

The Data Protection Act (1998) ensures that all information collected about you during the course of the study will be kept strictly confidential. All information will be kept secure in either a locked facility or a password protected computer to which only those involved in the research will have access. However, these data will be kept for 5 years and then destroyed.

12) What will happen to the results of the research study?

The results of the study will be used to write a report for a PhD dissertation. It may also be used to write articles for journals for health professionals.

13) What if I have any concerns?

If you have any concerns or any questions about this study, please feel free to contact Ahmed Almansour who will do his best to answer any of your questions on mob: 07872599970 or email: ahmed.pt@hotmail.com .

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2) What does this study involve?

This study is for research purposes only and you would receive no therapeutic benefits for taking part. However, the researcher will evaluate your functional performance which may help you to assess your ability to return to your previous sport activities.

If you agree to be involved in this research study, you will undergo certain tests and procedures to measure your functional performance which include:

a. Self-reported Assessment

This assessment contains questions individuals answer about their functional level, and pain etc. The answers indicate a person's recovery characteristics over time.

b. Muscles strength assessment

This test will be done using a computer- controlled dynamometer. This system has the capability to test muscle strength in a variety of modes.

c. Jump test

This test is to measure your ability to jump higher. You will be asked to drop off a height then quickly jumping as high as you can.

d. Agility test (cutting manoeuvre)

This test is to measure your ability to move quickly and change directions while maintaining control and balance. A new computerized tool will be used to measure the decision making time and accuracy by responding to a light cue.

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Small Electrodes will be placed over your ankle muscles. Also Skin preparation consists of shaving the skin over the area of electrode placement will be applied if needed followed by cleaning of the skin with alcohol swabs.

2) Why have I been chosen?

You have been chosen because you are an adult and an active individual with a history of ankle sprain injury that we are interested in looking at and ensuring your performance using different tests. In total 21 subjects will be asked to take part in same group. The result will be compared with subjects with acute ankle sprain and health people.

4) What will happen if I do take part?

If you are happy to take part, you will be asked to sign a consent form. Then you will be asked to attend the Research Centre for Clinical Kinesiology (RCCK) of Cardiff University (School of Healthcare Studies) on 3 occasions (map & direction attached). During the visit you would need to bring training clothes with you. Your height and weight will be collected first, and then you will undergo different tests to measure functional performance.

5) How long these trials will take?

Each visit might take approximately 90 minutes for each participant.

6) What will I have to do before these visits?

You do not have to do anything specific in preparation for this study.

7) Expense?

You will be reimbursed for reasonable travel expenses.

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 School of Healthcare Sciences
 Cardiff University
 2F25 Cardigan House
 Heath Park Campus, Cardiff,
 CF14 4XW
 Email: ahmed.pt@hotmail.com



Tel: 020920743633
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INFORMATION FOR PARTICIPANT IN RESEARCH

Identifying Indicators of Functional Recovery after Ankle sprain in Physically Active People

We are asking you to take part in a research study being carried out in Cardiff University. Your participation in this study is voluntary. While we would be pleased to have you participate we respect your right to decline. Before deciding if you would like to be part of the trial, please take time to read the following information carefully. If there is anything unclear or you would like more information don't hesitate to ask.

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Ankle sprains are one of the most common injuries, especially among physically active people. In the UK an estimated 302,000 ankle sprains are reported to Emergency Departments each year. One of the major problems for many people after an initial ankle sprain is the high recurrence of ankle sprain and residual symptoms often resulting in the development of chronic ankle instability. The purpose of this study is to identify how people recover after initial ankle sprain. Developing better measurement of recovery from ankle sprain will help determine when it is appropriate to return to previous normal activities or to sport participation.

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This study is for research purposes only. If you agree to be involved in this research study, you will undergo certain tests and procedures to measure your functional performance which include:

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This assessment contains questions individuals answer about their functional level, and pain etc. The answers indicate a person's recovery characteristics over time.

b. Muscles strength assessment

This test will be done using a computer- controlled dynamometer. This system has the capability to test muscle strength in a variety of modes.

c. Jump test

This test is to measure your ability to jump higher. You will be asked to drop off a height then quickly jumping as high as you can.

d. Agility test (cutting manoeuvre)

This test is to measure your ability to move quickly and change directions while maintaining control and balance. A new computerized tool will be used to measure the decision making time and accuracy by responding to a light cue.

e. Muscles activities using Electromyography (EMG)

Small Electrodes will be placed over your ankle muscles. Also Skin preparation consists of shaving the skin over the area of electrode placement will be applied if needed followed by cleaning of the skin with alcohol swabs.

2) Why have I been chosen?

You have been chosen because you are an adult and physically active individual that we are interested in looking at. In total 21 subjects will be asked to take part in same group. The result will be compared with subjects with acute ankle sprain and subjects with recurrent ankle sprains.

3) What will happen if I do take part?

If you are happy to take part, you will be asked to sign a consent form. Then you will be asked to attend the Research Centre for Clinical Kinesiology (RCCK) of Cardiff University (School of Healthcare Studies) on one occasion (map & direction attached). During the visit you would need to bring training clothes with you. Your height and weight will be collected first, and then you will undergo different tests to measure functional and muscles performance.

4) How long these trials will take?

These trials might take approximately 90 minutes for each participant.

5) What will I have to do before these visits?

You do not have to do anything specific in preparation for this study.

6) Expense?

You will be reimbursed for reasonable travel expenses.

5) What if I choose to take part and then change my mind?

You have the right to withdraw or discontinue from the study at any time.

6) What are the risks of taking part?

There are very few risks associated with this research. These include possibility of loss of balance in hopping test or during cutting manoeuvres. If this does occur you will be given the appropriate advice from a qualified physiotherapist or referred to the emergency department if needed. However, proper demonstration and instruction will be provided prior to starting.

7) What are the benefits of taking part?

If you take part in this study, there may or may not be direct benefit to you. We anticipate that this research will provide important information to clinicians in sport medicine in their overall assessment of ankle injuries.

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APPENDIX D

Name:

Group:

Session:

Code:

The Foot and Ankle Disability Index (FADI) Score

Please answer every question with one response that most closely describes your condition within the past week by marking the appropriate number in the box. If the activity in question is limited by something other than your foot or ankle, mark N/A.

- 0 Unable to do 2 Moderate difficulty 4 No difficulty
1 Extreme difficulty 3 Slight difficulty

Standing		Walking up hills	
Walking on even ground		Walking down hills	
Walking on even ground without shoes		Going up stairs	
Walking on uneven ground		Going down stairs	
Stepping up and down curves		Squatting	
Sleeping		Coming up to your toes	
Walking initially		Walking 5 minutes or less	
Walking approximately 10 minutes		Walking 15 minutes or greater	
Home responsibilities		Activities of Daily Living	
Personal care		Light to moderate work (standing, walking)	
Heavy work (push/pulling, climbing, carrying)		Recreational activities	

Sports Modules

Running		Jumping	
Landing		Squatting and stopping quickly	
Cutting, lateral movements		Low-impact activities	
Ability to perform activity with your normal technique		Ability to participate in your desired sports as long as you would like	

Pain related to the foot and ankle:

- 0 Unbearable 2 Moderate Pain 4 No Pain
1 Severe Pain 3 Mild Pain

General level of pain		Pain at rest	
Pain during your normal activity		Pain first thing in the morning	

Researchers Use Only: Score: ____ /136 points
(FADI 104 points & SPORTS 32 points; No Disability 136)

Name:

Group:

Session:

Code:

The chronic ankle instability scale

With this questionnaire, we would like to document the possible implications of your ankle instability problem. The questions below refer to complaints and difficulties/problems you may have while performing activities as a result of your ankle instability.

Read every question carefully. Please rate every question by checking **only one** of the possible boxes that best describes your **present condition** (compared with your preinjury level).

If a question **does not apply** to you or because it relates to something **else** than your ankle instability, please mark **not applicable** (NA).

Try not to reflect too long on a question and do not leave questions unanswered. This questionnaire is personal, so please do not consult with others. If you have doubts about the meaning of a word or question, please use your own interpretation.

1. How much fear do you have of restraining your ankle?

No A little bit Moderately A lot Extremely much

2. To what extent do you have difficulties/problems with cutting or changing directions (during walking, running or jumping) because of your ankle instability problem?

None Some Moderate A lot Unable to do

3. How often do you use an external ankle support when performing sports or recreational activities?

Never Rarely Sometimes Often Always NA

4. To what extent do you avoid performing certain activities (such as walking, running, jumping, cutting) because of your ankle instability problem?

Not at all Rarely Sometimes Often constantly

5. To what extent do you have difficulties/problems with walking on uneven ground because of your ankle instability problem?

None Some Moderate A lot Unable to do NA

6. To what extent has the overall quality of your sports or recreational activities decreased as a result of your ankle instability, when compared with your preinjury level?

Not at all slightly Moderately Strongly Extremely NA

The chronic ankle instability scale (CAIS)

Name:

Group:

Session:

Code:

7. How unstable does your ankle feel?

Not at all Slightly Moderately Strongly Extremely

8. To what extent do you have difficulties/problems with jumping because of your ankle instability problem?

None Some Moderate A lot Unable to do N/A

9. To what extent do you have difficulties/problems with running on even ground because of your ankle instability problem?

None Some Moderate A lot Unable to do N/A

10. To what extent do you have difficulties/problems with running on uneven ground because of your ankle instability problem?

None Some Moderate A lot Unable to do N/A

11. How frequently do you still sprain your ankle?

Not anymore Rarely Sometimes Often Constantly

12. If you sprain your ankle, how often does it cause symptoms such as pain, stiffness or swelling?

Not anymore Rarely Sometimes Often Always N/A

13. To what extent are you concerned about your ankle instability problem?

Not at all Slightly Moderately Very Extremely

14. To what extent has your participation in certain sports or recreational activities decreased as a result of your ankle instability, when compared with your preinjury level?

Not at all Slightly Moderately Much Do not participate anymore N/A