Understanding Intrinsic Risk Factors for Lateral Ankle Sprain in Military Recruits

KHALID K. ALSHAMMARI

PhD thesis **2023**

Understanding Intrinsic Risk Factors for Lateral Ankle Sprain in Military Cadets

Degree of Doctor of Philosophy Sep 2022

Khalid K. Alshammari

School of Health and Society

University of Salford, Salford, UK

Supervisor

Prof Richard Jones

Co-supervisor

Dr Chelsea Starbuck

Dr Anmin Liu

Contents

List of Figures

List of Tables

List of Glossary

2D	Two-dimensional (motion analysis)
3D	Three-dimensional (motion analysis)
Ant	Anterior
ATFL	Anterior talofibular ligament
AUC	Area under the curve
BMW	Bimalleolar width
BMI	Body mass index
CI	Confidence interval
CM	Centimetres
DF	Dorsiflexion
FPPA	Frontal plane projectile angle
HHD	hand-held dynamometer
I^2	Heterogeneity coefficient
IAC	International Ankle Consortium
ICC	Intraclass coefficient
IRR	Incidence Rate Ratio
Kg	Kilograms
LAS	Lateral ankle sprain
LH	Lateral hopping
Max	Maximum
MDD	Minimal detectable difference

Min	Minimum
Nm	Newton meter
NOS	Newcastle Ottawa scale
OR	Odd ratio
p	Statistical significance
PF	Plantarflexion
PL	Posterolateral
PM	Posteromedial
Post	After
Pre	Prior to
RF	Rearfoot
ROAST	Rehabilitation Oriented AsseSsmenT
ROC Curve	Receiver operation characteristics curve
ROM	Range of motion
SEBT	Star excursion balance test
SEM	Standard error of measurement
SLL	Single leg landing
UK	United Kingdom
USA	United States of America
YBT	Y-Balance Test

Dedication

I dedicate this PhD thesis to the one I lost in my first year of this work “my father” and to my heaven “my mother” who I lost recently, may Allah have mercy on them and their souls rest in the paradise.

Acknowledgement

Foremost, I would like to express my sincere gratitude to Allah for giving me the strength and patience to finish this unique journey.

Special thanks go to my excellent supervisors Prof. Richard Jones, Dr. Chelsea Starbuck and Dr. Anmin Liu for giving me an opportunity to a part in this programme. Thank you for your great supervision and tremendous support. You were a true source of inspiration for me, and your knowledge and experience have been valuable and added a lot to me. This work without your motivation, encouragement and excellent guidance would not have been possible.

I owe my deepest gratitude to my siblings, my wife and children for their prayers, patience and endless emotional support while in Manchester and Saudi Arabia.

My sincere gratitude to all colleagues and friends, particularly Dr.Omar Althomali, Dr.Hasan Alrayani, Ayman Alhammad for their advice and help. Special thanks to James Osborne from quintic Ltd who providing indispensable training and information on the quintic camera and software.

I would like to give a special thanks to who I belong to University of Hail for funding my PhD. Moreover, I would like to thank members of applied medical science collage in University of Hail and School of health and Society at the University of Salford members for providing endless kind help and cooperation during my project particularly Steve Horton and Laura Smith.

This thesis would not have been possible without any name from the above.

Abstract

Lateral ankle sprain (LAS) is a common injury among physically active individuals. This PhD study aims to identify the risk factors that contribute to the occurrence of LAS, with a specific focus on military recruits. The findings of this study will assist in developing prevention strategies to reduce the occurrence of LAS among military recruits. The research is divided into three parts: a systematic review and meta-analysis to identify primary intrinsic risk factors, a repeatability and reliability study to establish the validity of measurement tools, and a primary prospective study to investigate the biomechanical risk factors during physical tasks.

The systematic review and meta-analysis aimed to identify the primary intrinsic risk factors for LAS. The repeatability and reliability study aimed to establish the repeatability and reliability of various measurement tools, such as goniometer, sliding breadth calliper, YBT, HHD, 2D motion analysis, and the validity of 2D motion analysis with 3D kinematics. For the repeatability study a sample of twelve healthy and physically active participants were selected from University of Hail.

The primary prospective study aimed to investigate the biomechanical risk factors associated with LAS during single leg landing and lateral hopping tasks. The study recruited 204 participants from the Saudi military recruits who were undergoing a 12-week basic military training programme. The risk factors were assessed at the start of the programme, and injury cases reported during the 12-week duration were included in the study. Anthropometric measurement, dynamic balance by Y-balance test, range of

motion of ankle joint using goniometer, ankle and hip muscle strength using handheld dynamometer and lower limb kinematics via two-dimensional camera.

Statistical analysis was performed using binary logistic regression and multiple logistic regression. The results of the study suggest that individuals with greater body mass, decreased dorsiflexion strength, decreased anterior Y-balance, and decreased the peak of ankle towards dorsiflexion angle during SLL post-initial contact were predictive factors for LAS among the injured compared to the uninjured. These variables could be used to set a screening standard for LAS.

In conclusion, the findings of this study provide valuable insights into the risk factors associated with LAS among physically active individuals, particularly military recruits. The findings could help to reduce LAS incidence and impact among military recruits and could guide screening standards and strengthen injury prevention strategies through targeted training programmes. The measurement tools and methodologies established provide a foundation for future studies on LAS and other musculoskeletal injuries related to physical activity.

CHAPTER 1

1. Introduction

Injuries affecting the lower limbs, particularly the lateral ligaments of the ankle joint, are a common problem among active individuals, including athletes, military personnel and the general population (Willems et al., 2005b). Studies analysing the prevalence of ankle ligament injuries are important due to their high occurrence in daily dynamic activities (Willems et al., 2005b). In the United Kingdom, these types of injuries account for between 3% and 5% of injuries treated in emergency departments (Watts & Armstrong, 2001), with the most frequent injuries affecting the lateral ligaments of the ankle joint (Watts & Armstrong, 2001).

Ankle sprains are a prevalent injury, accounting for up to 5% of all emergency department visits in the UK, with an estimated 5,600 injuries occurring daily (Skinner et al., 1997). Moreover, UK hospital emergency departments treat approximately 42,000 ankle injuries annually (Bridgman et al., 2003). while an estimated 2 million people suffer from these injuries each year in the US (Herzog et al., 2019). Furthermore, Kemler et al. (2015) found that the incidence of ankle sprains in the Netherlands was 5.5 times higher when compared to data from emergency departments, suggesting that not all ankle sprain cases are reported. Studies have also found that certain groups of people, such as military personnel undergoing training and athletes participating in sports like football, tennis, basketball and volleyball, are at a higher risk of ligamentous injuries due to the repetitive motions and excessive loads placed on the joints (Gribble et al., 2016; Herzog et al., 2019).

A study found that in a four-year period, more than 3 million ankle sprains were reported in emergency departments in the United States, with nearly half of these injuries occurring during athletic activity (Waterman et al., 2010). Moreover, data from the National Collegiate Athletic Association (NCAA) revealed that LAS injuries are the most common type of ankle sprain. Individuals involved in high-impact physical activities, such as running, jumping and cutting, have a higher risk of injury due to the increased load on their ligaments, with functional time loss of approximately eight days (Al Bimani et al., 2018). A systematic review of epidemiological data by Doherty et al. (2014) also found that ankle sprains were more common in indoor/court sports and that LAS had the highest prevalence compared with medial or syndesmotic sprains (Doherty et al., 2014).

The lateral ligamentous complex, comprising the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL) and the posterior talofibular ligament (PTFL), is the most affected structure in ankle injuries, with an estimated three-fourths of all ankle injuries involving this complex (Fong et al., 2009). Several studies have demonstrated that the ATFL is particularly susceptible to injury in lateral ankle sprain (LAS) injuries, being the most frequently injured structure (Fong et al., 2009; Butler & Walsh, 2004; Baumhauer et al,.1995). The vulnerability of the ATFL in LAS is likely related to its relatively low ultimate load and anatomical position, with the origin of the ATFL located at the fibular anterior–inferior border and its insertion at the neck of the talus. The ATFL plays a crucial role in preventing anterior displacement and internal rotation of the talus during plantarflexion.

In addition to the ATFL, other structures, such as muscles, nerves and joint capsules, may also be damaged in an ankle sprain, with the nature and severity of the injury determining the extent of damage (Bahr et al., 1998; Ferran & Maffulli, 2006). LAS injuries are typically classified into three grades, with Grade I being a stretched ligament, Grade II being a partially torn ligament with minimal joint mobility and Grade III being a fully torn ligament with joint instability (Fig. 1.1) (Řezaninová et al., 2018).

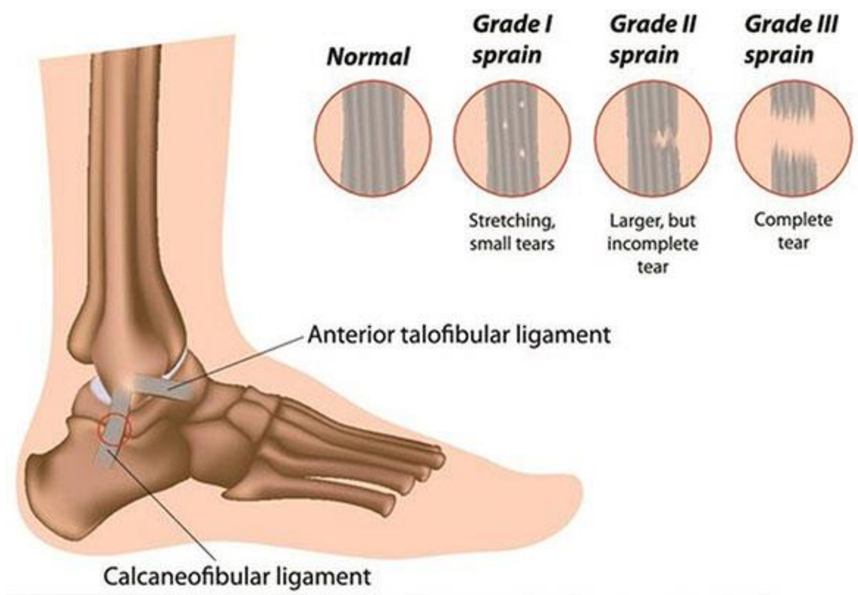


Figure 1.1: Grades of ankle sprain (Řezaninová et al., 2018).

Notably, there is a lack of data on the prevalence of LAS among the Saudi military population. However, studies have shown that military personnel who engage in intense physical activity and repeated movements of joints experience a high incidence of LAS. Herzog et al. (2019) found that 2 million acute ankle sprains occur annually in the United States, with the highest prevalence among athletes, who take around 8–13 days to recover based on the severity of the injury. In addition, Waterman et al. (2010) found that the IRR of LAS among military personnel was 58.4 per 1,000 person-years. Furthermore, Bulathsinhala et al. (2015) found that acute ankle sprains were the most common musculoskeletal injury among military recruits, accounting for up to 49.3% of all injuries, with many resulting in 11 to 13 days of loss of function and pain while Goodrich et al., (2022) reported between one and eight days. During this time individuals will present with swelling, pain, and functional limitations such as an inability to walk and might lead to giving way, which will limit their ability to operate effectively (Fong et al., 2009; Vuurberg et al., 2018). Furthermore, Michels et al. (2021) systematic review of 15 studies highlighted symptoms, such as pain, perceived instability, and recurrent sprains, often continue following an ankle sprain. At 12 months after the initial injury 15.8% of individuals had reported recurrent ankle sprains, whilst 16.1% experienced ongoing pain, and 21.5% perceived their ankle to be unstable. Although the return to activity being relatively brief in comparison to other lower limb injuries such as ACL injuries (Lam et al., 2022). The high prevalence of acute LAS and recurrent injuries in addition the persistent short- and long-term symptoms are likely to impact an individual's operational readiness. This may result in a reduced number of personnel fit for operational duties. Therefore, further research is needed to identify factors that may predispose individuals to acute LAS or recurrent ankle sprains and instability. This will allow the development of targeted prevention programs and rehabilitation strategies to minimise time lost due to injury and optimize return to activity. Enhanced understanding of risk factors and improved management may reduce the burden of ankle sprains on operational readiness.

When it comes to LAS, it is important to assess both the incidence and the burden of these injuries. LAS is a common type of injury, occurring frequently in various populations, including the military. However, the burden of LAS goes beyond just the incidence rate ratio (IRR). In general, the burden of LAS is influenced by factors such as the severity of the sprains, the duration of time loss resulting from the injury and the associated functional limitations. While the incidence may be high, if the time loss and functional impairment caused by LAS are minimal, the overall burden of these injuries may be relatively low. Conversely, if LAS leads to prolonged time loss and significant functional limitations, the burden of these injuries can be substantial.

Rehabilitation and physical therapy are often recommended following LAS to help restore strength, flexibility and range of motion (ROM) to the ankle. It is important to follow a proper rehabilitation programme and allow adequate time for the ankle to heal to minimise the risk of long-term problems or recurrent sprains.

Despite the unique physical demands of the military typically working more than seven hours per day and engaging in activities such as running, jumping, squatting, climbing, marching and lifting heavy weights which lead to an injury and the long-term consequences particularly LAS, no studies have considered the Saudi military population when assessing the intrinsic risk factors for LAS. This dearth of research and screening programmes for LAS in the military population highlights the need for further investigation into intrinsic risk factors and the prevalence of LAS in the Saudi military population. This thesis aims to address this gap in research by developing a risk factor assessment programme for Saudi military recruits prior to their recruitment and training. This will help healthcare providers prevent LAS and standardise the screening programme, which is a previous research recommendation of the International Ankle Consortium (IAC) (Gribble et al., 2016). In addition, this thesis aims to minimise the occurrence of LAS by providing information which will allow a preventive treatment programme for Saudi military recruits.

1.1. Aim

The primary aim of this thesis is to prospectively identify the intrinsic risk factors for LAS in military recruits.

Therefore, the objectives of this thesis are as follows:

A. To systematically review and perform a meta-analysis of the intrinsic risk factors for LAS.

B. To assess the repeatability and reliability of a universal goniometer, a hand-held dynamometer, the Y-balance test (YBT), a sliding breadth calliper and two-dimensional (2D) motion analysis.

C. To assess the validity of 2D motion analysis with 3D kinematics.

D. To prospectively compare 2D kinematics between recruits who sustain an LAS and those who do not during subsequent follow-ups.

E. To prospectively compare the isometric strength and ROM of the ankle dorsi/plantarflexion and eversion/inversion muscles, hip abductors and extensors, dynamic balance, bimalleolar width and 2D kinematics between recruits with/without ankle injuries during subsequent follow-ups.

1.2. Research Questions

The research questions are as follows:

1. Can a systematic review and meta-analysis of previous prospective studies identify the clinical and biomechanical differences between individuals who have sustained LAS and those who have not?

2. Are the selected tools reliable for use in clinical and biomechanical examinations?
3. Is 2D motion analysis a valid tool compared with 3D kinematics?
4. Are there any differences between the clinical variables and kinematics of lower limb joints in individuals with and without LAS?
5. Which risk factors can be measured and have an association with LAS incidence compared with other factors?

1.3. Hypotheses

In this thesis, the following null hypotheses will be tested:

a. H01: A systematic review and meta-analysis of previous prospective studies will not be able to identify any clinical and biomechanical differences between individuals with and without LAS.

b. H02: The tools used to assess clinical and biomechanical variables will be found to be unreliable.

c. H03: The 2D motion analysis is not a valid tool compared with the gold standard of 3D kinematics.

d. H04: There will be no significant differences between the clinical data and kinematics of individuals with and without LAS.

e. H05: There will be no risk factors that have an association with LAS incidence when compared with other risk factors.

CHAPTER 2

Literature Review of Intrinsic Risk Factors for Lateral Ankle Sprain

In this chapter, previous research pertaining to the anatomy and biomechanics of the ankle joint and its associated ligaments will be reviewed. The prevalence and incidence of LAS, as well as the potential risk factors and mechanisms of injury, will also be discussed. Moreover, the various methods and tools used to evaluate clinical, functional and biomechanical risk factors for LAS will be examined.

2.1. Ankle Joint

2.1.1. Ankle Sprain Prevalence and Incidence

Prevalence and incidence are two measures used to understand the frequency of a condition within a specific time frame. Prevalence refers to the number of current cases of a condition, while incidence refers to the number of new cases. Understanding the prevalence and incidence of ankle sprains can provide insight into the epidemiology of the condition and the associated risk factors. A high prevalence of ankle sprains indicates that it is a significant problem that affects a large population; therefore, research should be conducted to develop ways to control it (Karadenizli et al., 2014).

Ankle injuries are a significant issue in the British army, accounting for 15% of all injuries sustained during training (Wilkinson et al., 2011). Studies by Schwartz et al., (2018) and Waterman et al., (2010) have suggested that the high prevalence of ankle ligament injuries is due to overuse and excessive stress on these ligaments, leading to cumulative microtrauma and damage to the affected ligaments. As a result, military personnel are five to seven times more likely to suffer from ankle sprains than the general population.

Waterman et al. (2010) conducted a longitudinal epidemiology study that aimed to investigate the risk factors for ankle sprains among cadets at the United States Military Academy. These occurrences were distributed across a cumulative period of 10,511 cadet person-years, resulting in an overall IRR of 58.4 cases per 1,000 person-years. Notably, among this subset of 614 cadets with fresh ankle sprains, a subgroup of 75 cadets encountered multiple ankle sprains, leading to a total count of 160 ankle sprains. Among these 614 new sprains, 588 instances (95.8%) had documented laterality. The distribution of ankle sprains displayed a relatively even proportion between the right (296 sprains, 48.2%) and left (292 sprains, 47.6%) ankles, with an additional 26 cases designated as indeterminate ankle sprains. Further analysis revealed that the majority of ankle sprains involved the lateral ligament complex (508 sprains, 82.7%), followed by syndesmotic (31 sprains, 5.0%) and medial (21 sprains, 3.4%) sprains.

With the physically demanding nature of military training and operations, the risk of LAS is likely higher in military personnel. However, it is worth noting that the IRR of LAS may vary depending on the specific duties and activities of military personnel. For example, the IRR may be higher in military personnel engaged in more physically demanding activities, such as those in combat or special operations roles. Orr et al. (2015) aimed to investigate the link between injuries among Australian Regular Army soldiers and the loads they are required to carry. The study analysed data from the Australian Defence Force database and found that a total of 404 injuries out of 1,954 were caused by load carriage. Most of these injuries affected the lower limb and back, with bones and joints being the most injured body structures. The study also found that load carriage injuries were most likely to occur during field activities and that muscular stress was the main mechanism of injury.

Goodrich et al. (2022) systematically reviewed the prevalence of ankle sprains in military populations. The study encompassed an analysis of 19 articles, collectively involving a total of 1,671,763 participants across six different countries and four distinct branches of the military. The comprehensive dataset focused on ankle sprains and their prevalence within the military context. Seven of the 19 studies highlighted ankle sprains as the most frequent injury observed, constituting a range of incidence rate ratio (IRR) from 2.20% to 35% of all reported injuries. Additionally, incidence rate per 1,000 person-years spanned from 15.3 to 58.4 across the 19 reviewed studies. Furthermore, ankle sprains were also singled out as the most prevalent within the domain of lower extremity injuries with two out of 19 studies. Due to the high rate of ankle sprains in the military population, which exceeds that of populations with less physically demanding lifestyles, there is a need for more research on prevention methods and rehabilitation programmes. Implementing low-cost prevention strategies could yield substantial benefits for the military population and improve their preparedness.

Fenn et al. (2021) examined the prevalence of foot and ankle injuries among soldiers during military training through a systematic review of 91 studies that included a population of 8,092,281 soldiers from 15 countries. The review found that 9.74% of soldiers experience foot and ankle injuries. The results also revealed that ankle injuries were more common than foot injuries and that acute injuries were more prevalent than non-acute injuries. In addition, the study found that soldiers had a 3.14% chance of sustaining a foot and ankle injury during a three-month training period. The review's findings provide insight into the patterns of foot and ankle injuries during military training and can aid in the development of cost-effective methods to prevent and address such injuries. Ankle sprains are a prevalent injury among the military population, causing significant healthcare costs, lost training and deployment of approximately 7–8 days and negative impacts on overall readiness (Fenn et al., 2021).

The sports with the highest recorded IRRs of ankle sprains, such as rugby, cheerleading, basketball and soccer all involve frequent changes of direction, jumps and player contact (Waterman et al. 2010; Fuerst et al., 2017). These dynamic movements challenge ankle stability through multi-planar torsion and loading. Unexpected collisions with other athletes introduce additional extrinsic risk factors. The study appropriately recognises the interaction between high ankle stress activities and the likelihood of sustaining ligament damage.

Studies have shown a gender-based differentiation in ankle sprain incidences (Waterman et al. 2010; Goodrich et al. 2022). A study by Waterman et al. (2010) revealed a total of 133 women (constituting 14.5% of the female cadet population) experienced incidents of ankle sprains, resulting in an IRR of 96.4 sprains per 1,000 female person-years. By contrast, 481 male participants (accounting for 9.2% of the male cadet group) sustained ankle sprains, yielding an IR of 52.7 sprains per 1,000 male person-years. After conducting a comparative analysis, it became evident that the women exhibited a significantly higher IRR for ankle sprains in relation to the men. The calculated IRR was 1.83 (95% CI, 1.52–2.20), indicating a substantial and statistically meaningful increase in ankle sprain susceptibility among female cadets when using person-years as the metric of exposure. Furthermore, Goodrich et al., (2022) systematic review highlighted lower incidence rates in male personnel ranging from (33.89 to 52.7) per 1000 person-years compared to female personnel (41.17 and 96.4) per 1000 person-years. This disparity may be due to a number of factors including hormonal, environmental, and physical differences; thus, females sustained a higher ratio of these injuries (Fox et al., 2020; Parsons et al., 2021).

In the military context, the burden of LAS holds particular importance. LAS can have significant implications for military personnel, as they can affect operational readiness and performance. Military personnel often engage in physically demanding activities and may be required to maintain high levels of physical fitness. Therefore, the burden of LAS in the military extends beyond IRR and includes considerations of the impact on operational effectiveness, training and mission readiness.

The injury burden in the form of functional time loss and treatment cost of LAS can vary significantly depending on the severity of the sprain and the individual's overall health and lifestyle. Furthermore, research shows that these injuries result in a significant loss of training days; 34% of all injuries affect the ankle and calf muscles, with an average of eight days lost per ankle sprain injury (Schwartz et al., 2018). Previous studies have shown that sports-related ankle sprains result in significant healthcare costs, with the annual cost for management in the Netherlands estimated at €187,200,000 (Hupperets et al., 2010). Moreover, in terms of burden of LAS can cause pain, swelling, bruising and difficulty in walking. It can also lead to impaired function and reduced mobility. In severe cases, surgery may be required to repair the damaged ligaments. LAS can sometimes lead to long-term consequences if not properly treated or not allowed to heal fully. One potential long-term consequence of LAS is the development of chronic ankle instability (CAI) (Witchalls et al., 2012). This condition can occur when the ligaments that support the ankle are damaged and do not heal properly, leading to ongoing instability and an increased risk of recurrent sprains. Another potential long-term consequence of LAS is the development of ankle joint post-traumatic osteoarthritis (McKay et al., 2001). This condition occurs when the joint surfaces of the ankle become damaged due to injury, leading to the breakdown of cartilage and the development of osteoarthritis. Symptoms of ankle joint post-traumatic osteoarthritis can include pain, stiffness and swelling in the ankle joint.

Additional research is warranted to investigate the prevalence of LAS within the Saudi military population. While the existing literature provides valuable insights into the incidence and burden of LAS in various settings, including civilian populations and other military forces, it is important to recognise that the prevalence of injuries can vary among different populations. The Saudi military population may have unique characteristics and risk factors that could influence the occurrence of LAS. Factors such as training protocols, physical demands, footwear and environmental conditions specific to military operations may contribute to differences in injury prevalence compared with other populations.

By conducting research specifically focused on LAS within the Saudi military, it would be possible to obtain accurate and contextually relevant data regarding the extent of this injury problem. This information can then serve as a foundation for developing targeted prevention strategies and implementing appropriate interventions to address the specific needs and challenges faced by Saudi military recruits.

Moreover, investigating the prevalence of LAS within the Saudi military population would contribute to the body of knowledge regarding injury patterns and trends in military settings globally. It would provide valuable insights into the overall burden of this injury type and help advance injury prevention and management protocols not only within the Saudi military but also potentially within other military forces facing similar challenges.

Therefore, undertaking further research to determine the prevalence of LAS among the Saudi military population is crucial for a comprehensive understanding of the injury landscape specific to this context. This research would help customise interventions, enhance the well-being and operational readiness of military personnel and contribute to the advancement of knowledge in the field of military injury prevention and management.

Age and gender factors

Al Bimani et al. (2018) found that males aged 14 to 37 years had a higher rate of LAS compared with females in the same age group based on data collected from emergency departments in the UK. Similarly, Waterman et al. (2010) found that males between the ages of 14 and 24 had a higher incidence of ankle sprains than females, with an incidence ratio of 1.53 (95% confidence interval, 1.41 to 1.66). Lysdal et al. (2022) conducted a systematic review of the mechanism of LAS injuries and found that 63% of total LAS occur in males aged 18 to 33 years, with a mean age of 24 and a standard deviation of 4.4.

Taken together, this body of evidence indicates that males approximately between the ages of 18–24 appear to be a high-risk population for LAS. Thus, the causes and risk factors underlying the increased LAS susceptibility in this group need to be investigated further. Moreover, targeted prevention strategies may be warranted to reduce LAS incidence in adolescent and young adult males.

The study by Fraser et al. (2021) examined the risk of lateral ankle sprain (LAS) in male and female tactical athletes across various military occupations in the US military. The data was collected from the Defence Medical Epidemiology Database, focusing on individuals diagnosed with ankle sprains from 2006 to 2015. The aim was to assess the influence of sex and occupational military category on LAS risk. The findings revealed that enlisted females in all occupational groups had a significantly higher risk of LAS compared to their male counterparts, except for Engineers. Female recruits also consistently had a higher risk of LAS across all occupational groups, except for Ground/Naval Gunfire and that might be explain the effect of level of activity on LAS occurrence between the occupational groups. Additionally, specific tactical athlete specialties showed varying levels of risk. Special Operations Forces, Mechanised/Armor, Aviation, Maintenance, and Maritime/Naval Specialties had a lower risk of LAS, while Artillery, Engineers, and Logistics Specialties had a higher risk which is also may related to poor physical demand in terms of activities linked to the mechanisms of LAS. Administration, Intelligence, and Communications specialties did not show a significant difference in LAS risk. The findings highlight the importance of considering both sex and military occupation when assessing LAS risk in tactical athletes. This information can aid in developing targeted prevention strategies and interventions to reduce the occurrence of LAS in military personnel. The evident in the study design, as it focuses on a specific population (military) and utilises a retrospective cohort analysis. By examining a comprehensive database, the study provides valuable insights into the association between sex, occupation, and LAS risk. These findings have implications for injury prevention, training protocols, and optimising performance in military settings. In summary, this study demonstrates that sex and military occupation are significant factors associated with the risk of lateral ankle sprain in tactical athletes. The findings contribute to a deeper understanding of the multifaceted nature of LAS risk and can inform targeted interventions and strategies for reducing injury rates in military personnel.

2.1.2. Clinical Manifestations of Ankle Sprain

Signs, Symptoms and Diagnosis of Ankle Sprain

An inflammatory response, characterised by swelling, reduced ROM, ligament weakness and biomechanical abnormalities, occurs immediately following LAS (Anandacoomarasamy & Barnsley, 2005; Hauser & Dolan, 2011; Hertel, 2002). If not properly managed, these symptoms may become chronic and lead to recurrent sprains and mechanical and functional deficits. In addition, inadequate management of LAS can result in further complications, such as CAI and post-traumatic ankle osteoarthritis (OA) (Hauser & Dolan, 2011; Robinson & Keith, 2016). Recurrence rates of ankle injuries among those who sustain them for the first time have been estimated to be between 70% and 80% among active people (McKay et al., 2001). CAI has been defined as an alteration in ankle function caused by repeated disturbances in the structural integrity of the ankle with ensuing reported and actual deficiencies in neuromuscular control and mechanical stability (Hertel, 2002).

Cooke et al. (2020) conducted a systematic review of the literature to examine the practicability and measurement properties of lower extremity functional performance tests (FPT) in elite athletes. The review focused on tests commonly used to assess lower extremity function, including measures of strength, power, balance and proprioception. The study also examined factors that may have affected the practicability of these tests, such as equipment and space requirements, administration time and ease of use. The findings of this review indicated the need for improvement in FPT protocols and the reporting of results, including standardising testing procedures and ensuring that measurement properties are optimal to facilitate comparisons between different athletic groups. Such standardisation would enable a more accurate and reliable assessment of the physical attributes of athletes and help guide the development of effective training and injury prevention programmes (Cooke et al., 2020).

The physical status of military personnel and athletes is regularly evaluated at the onset and throughout the duration of their careers. This assessment is used to determine physical attributes, inform the development of training programmes and monitor the exposure to training loads. In addition, the data collected also guide interventions and rehabilitation plans as part of the return to training and performance processes. Return to physical activity is a very important question. Currently, there is a lack of evidence-based criteria to guide return-to-sport (RTS) decisions for individuals with LAS injuries. Tassignon et al. (2019) proposed a number of variables that could be used to create a criteria-based RTS decision paradigm. However, further research is needed to establish consensus on these variables and evaluate their effectiveness in actual RTS decisions through prospective studies. In addition, the authors suggested that utilising complex systems theory and the RTS continuum could aid in the development of an RTS decision-making framework for athletes with LAS injuries (Tassignon et al., 2019). It is crucial to have established screening protocols to make informed RTS decisions for individuals with LAS injuries. Without proper screening, it may be difficult to accurately assess an individual's readiness to return to sports activities.

Furthermore, returning to sports after LAS injury requires careful decision-making to ensure that the athlete is fully rehabilitated and at a low risk for re-injury. However, there is currently no consensus on the optimal criteria for clearance to resume unrestricted participation. Recent studies like that of Smith et al. (2021) have worked to establish evidence-based guidelines through expert surveys. They identified factors like pain, ROM, strength, balance and functional performance as key considerations in the RTS decision. However, variability in specific cut-off thresholds and test selections exists. In addition, individual nuance based on injury severity, recovery trajectory and sports demands plays a role in RTS decisions. More research is needed to synthesise the current best evidence and establish guidelines that optimise safety and outcomes for athletes returning from LAS. As mentioned above, the development of comprehensive, progressive RTS protocols that incorporate objective testing like strength dynamometry alongside sport-specific functional criteria may help provide clarity for clinicians. However, allowing flexibility based on individual progress is also crucial. Continued efforts to find consensus among experts and identify optimal objective measures to guide staged RTS progression can improve the transition back to full participation for athletes after LAS.

The diagnosis of LAS is based on the patient's history and physical examination; however, there are controversies surrounding the best methods for diagnosis. In cases of mild sprains, physical examination and clinical tests may be sufficient for diagnosis and treatment, making imaging studies unnecessary (Watts & Armstrong, 2001). However, in cases of severe sprains or when there is uncertainty about the extent of the injury, imaging studies can provide valuable information for diagnosis and treatment planning (Chen et al., 2019; Fong et al., 2009).

The diagnostic tools for LAS are various, one is the use of imaging studies to confirm the diagnosis of LAS. Imaging tools, such as X-ray, magnetic resonance imaging (MRI) and ultrasound, can be used to confirm the diagnosis and determine the extent of the injury. According to a systematic review by Fong et al. (2009), an X-ray can be useful in ruling out bony injuries, but it is not reliable in identifying ligamentous injuries. MRI and ultrasound have been found to have high sensitivity and specificity in detecting ankle ligament injuries, with MRI being the most accurate imaging modality and considered the gold standard diagnostic tool for LAS, as it allows for the identification of ligamentous injury and other associated injuries.

While imaging studies can be helpful in identifying certain types of ankle injuries, they are not always necessary for the diagnosis of LAS and may not provide additional information beyond what can be obtained through a thorough physical examination. This is particularly true in cases where the diagnosis is clear-cut, and the symptoms are typical of LAS. Moreover, these are comparatively expensive and can add to the financial burden for patients (Chen et al., 2019; Fong et al., 2009).

Another diagnostic tool is the use of different clinical classification systems for diagnosing and categorising the severity of LAS. Various clinical classification systems emphasise different criteria based on signs, symptoms and physical exam findings for grading LAS injuries. For example, the CAI Tool (CAIT) is a patient-reported questionnaire consisting of nine questions that cover common complaints and instability symptoms to assess functional impairment from LAS (Delahunt et al., 2018). By contrast, other clinical grading systems like the Ankle Joint Functional Assessment Tool grade LAS based on ankle ROM, ligament laxity and ability to bear weight. The CAIT scores the patient on a scale of 30 points, with a cut-off value of 27.5. Another tool used to assess patients is the Rehabilitation-Oriented Assessment Tool (ROAST) from the IAC, which has 10 parts to assess patients: ankle joint pain, ankle joint swelling, ankle ROM, ankle joint arthrokinematics, ankle joint muscle strength, static postural balance, dynamic postural balance, gait, physical activity level and specific ankle joint patient-reported outcome measures (Delahunt et al., 2018). These tools help evaluate the signs and symptoms of LAS and provide additional information to support the diagnosis of LAS.

In summary, some of the major controversies surrounding LAS include the role of imaging studies. While X-rays and MRIs can identify fractures or major structural damage, overuse of imaging can lead to unnecessary radiation and cost without improving the management of simple LAS. Given the various grading scales for LAS severity based on different criteria, clinical classification systems lead to inconsistencies in injury descriptions between studies. For treatment methods, there is a debate around the ideal balance of rest, protection, early mobilisation and when to introduce strengthening to optimise LAS recovery. For return-to-sport decisions, the timelines and criteria for safe return to sports vary widely in the literature. However, return to sport in LAS being relatively brief in comparison to other lower limb injuries such as ACL injuries (Lam et al., 2022) Thus, further studies focusing on LAS diagnosis and screening could help address some of these areas of uncertainty. For example, research should focus on validating clinical exams against imaging to identify when radiography is truly warranted, comparing common classification systems to determine the most valid and reliable approach, investigating outcomes from different rehabilitation protocols to optimise evidence-based care and establishing return-to-play consensus guidelines that synthesise the best available evidence. The goal would be to improve LAS diagnosis, screening tools and management by addressing areas of controversy through focused research on the acute injury stage.

Grading of ankle sprain

Ankle sprains are classified into three grades based on the severity of the ligamentous injury. This classification is essential for determining the appropriate course of treatment and recovery time for the individual.

Grade I sprains, also known as mild sprains, involve minimal damage to the ligament and typically do not require medical supervision. The individual may experience some pain and swelling, but the joint remains stable and the ROM is not affected. This type of sprain is typically caused by an inversion injury and has a recovery period of three to seven days (Petersen et al., 2013; Řezaninová et al., 2018; Watts & Armstrong, 2001).

Grade II sprains, or moderate sprains, involve a partial tear of the ligament and result in more significant pain, swelling and tenderness. The severity of the tear can vary, with some individuals experiencing a few torn fibres while others may have a tear that affects nearly the full thickness of the ligament. These sprains often require medical attention and have a recovery period of 10 to 21 days. Individuals with a history of grade II sprains are at risk of developing joint instability and recurrent sprains due to the weakened ligamentous apparatus (Řezaninová et al., 2018; Watts & Armstrong, 2001).

Grade III sprains, or severe sprains, involve a complete tear of the ligament and result in significant pain, swelling, soreness and instability of the joint. These sprains are often easy to diagnose and require immediate medical attention. The individual may also experience a feeling of giving way in the joint and may have difficulty bearing weight. Recovery from this type of sprain typically takes six to eight weeks (Chen et al., 2018; Fong et al., 2009; Watts & Armstrong, 2001).

It is important to note that the classification of ankle sprains can be difficult to determine and may require additional testing, such as stress tests and arthrography, to accurately diagnose the extent of the injury. It is important to note that the severity of ankle sprains can also be influenced by other factors, such as the number of previous sprains, age and the overall health of the individual (Konradsen, 2002). In addition, proper management and rehabilitation of ankle sprains is crucial to prevent future complications, such as CAI and OA (Hauser & Dolan, 2011; Konradsen, 2002; Robinson & Keith, 2016).

Severity of signs and symptoms

The symptoms of an ankle sprain vary depending on the degree of ligament damage, with partial tears causing moderate pain and complete tears leading to severe pain and limited movement. Swelling, oedema and hemarthrosis are common indicators of an ankle sprain, and the presence of a 'drawer symptom', in which the joint is not stable, can indicate damage to the ligaments responsible for joint stability (Fong et al., 2009).

2.1.3. Mechanism of lateral ankle sprain

The occurrence of LAS injury is typically attributed to a complex interplay of movements, such as sudden inversion and internal rotation of the ankle joint, which can be further compounded by rapid plantarflexion. These movements cause a significant stretch on the lateral ligaments of the foot, making them more susceptible to injury.

Epidemiology studies (Bahr & Bahr, 1997; McKay et al., 2001) have found that the majority of ankle sprains occur during activities such as hopping, landing, twisting or cutting. These functional movement tasks are often used in movements commonly performed in sports and military contexts (Bansbach et al., 2017; Fong et al., 2009). Due to the high prevalence of LAS among all ankle injuries, researchers have focused on understanding the mechanisms behind this injury. Certain foot movements, such as inversion, internal rotation, supination and plantarflexion, have been identified as being associated with an increased risk of LAS. In addition, jumping with an inverted and plantarflexed ankle joint beyond the physiological limit may also lead to LAS (Downing et al., 1978; Dubin et al., 2011; Fong et al., 2009; Gehring et al., 2013; Lysdal et al., 2022; Willems et al., 2005a). Chu et al. (2010) suggested that the velocity of inversion also plays a significant role in determining the risk of LAS and proposed a threshold of 300°/s for ankle inversion velocity. Supination, which involves simultaneous adduction, plantarflexion and inversion, has also been found to increase the risk of LAS when performed beyond the physiological limit of 48° inversion and 10° internal rotation (Fong et al., 2009).

The ground strike phase of gait or landing is a critical phase in determining the risk of LAS, as it is when the biomechanics of the muscles and ligaments are most likely to be disturbed. Factors that have been associated with an increased risk of ankle sprains can be broadly categorised as extrinsic and intrinsic (Fong et al., 2009; Gehring et al., 2013). Extrinsic factors include environmental and external factors, such as shoe-surface interaction, training intensity and weather (Murphy et al., 2003). Other external factors include personal error, type of sports, activity level, equipment used and time (Brockett & Chapman, 2016; Halabchi et al., 2016). Intrinsic factors include an individual's physical characteristics, such as age, gender, history of ankle sprains, foot width, limb dominance, eversion to inversion strength ratio, lower running speed and decreased dorsiflexion muscle strength (Fong et al., 2009; Willems et al., 2005b). Kobayashi et al. (2016) found in a meta-analysis that the risk factors significantly associated with an increased risk of LAS include body mass index (BMI), fast concentric plantarflexion strength, slow eccentric inversion strength, reaction time of the peroneus brevis and passive inversion joint position sense. Therefore, understanding the clinical, functional and biomechanical factors that contribute to ankle injury can aid in the development of preventative strategies and more effective rehabilitation protocols (Figure 2.1) (Baumhauer et al., 1995; Fong et al., 2009; Fong et al., 2012; Gehring et al., 2013)

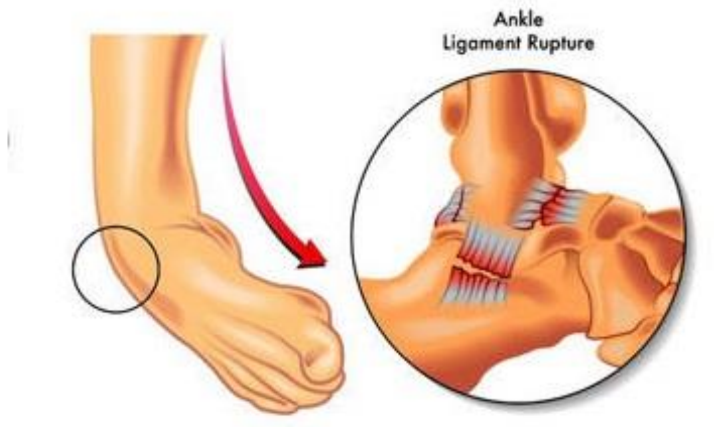


Figure 2.1: Combination of foot inversion, internal rotation and plantarflexion that puts stress on the lateral ankle ligament (Gehring et al., 2013)

The risk of injury to a ligament is influenced by the maximum stretch it can tolerate. Biomechanical studies have shown that ankle injury cannot be attributed solely to the ankle joint; the angle excursions of the pelvis, hip and knee joints may also contribute to the injury (Gehring et al., 2013). This suggests that the injury mechanism is complex and multifactorial, involving not only the ankle joint but also the adjacent joints and tissues. Therefore, further research is needed to better understand the mechanisms of LAS injury and identify the potential risk factors to prevent its occurrence.

Foot position during injury

LAS injuries are primarily caused by inversion of the foot with internal rotation, accompanied by either plantarflexion or dorsiflexion. Several studies have investigated the primary mechanism behind LAS injury.

Purevsuren et al. (2018) conducted a study to investigate the influence of ankle dorsiflexion and plantarflexion on LAS. Their results revealed that the CFL is more susceptible to injury during combined ankle dorsiflexion and inversion, whereas the ATFL is more likely to be injured during combined ankle dorsiflexion and internal rotation. Furthermore, during plantarflexion, various combinations of inversion and internal moment may lead to ATFL injuries. Nonetheless, inversion remains the primary mechanism associated with LAS.

Fong et al. (2009) and Kernozek et al. (2008) reported that ankle inversion is the primary mechanism of LAS, and the injury occurs when the ankle exceeds 40° of inversion. In a recent systematic review conducted by Lydsal et al. (2022), which included 15 articles and 24 quantitative case reports, greater inversion of the ankle joint was found to be profoundly associated with LAS. The peak inversion angle ranges from 2.0° to 142°, with a mean of 67.5°, while the peak inversion velocity range is from 468°/s to 1,752°/s. The authors also identified that internal rotation and plantarflexion movements of the foot remain as causative movements for LAS after inversion.

Moreover, Tropp (2002) suggested that ankle inversion at initial contact is the major cause of LAS, with the peak inversion occurring at 0.09 to 0.13 seconds after initial contact. If inversion, plantarflexion and adduction of the foot occur simultaneously, the acquired position of the foot is termed as supination of the foot. Ashton-Miller et al. (1996) reported that supination of the foot places maximum tension on the lateral ligaments of the ankle and increases the chance of LAS. However, it is important to note that inversion remains the primary position of the foot, resulting in LAS.

These studies provide strong evidence that ankle inversion is the primary mechanism of LAS injury, with greater inversion angles and velocities associated with a higher risk of injury. However, the simultaneous occurrence of other movements, such as plantarflexion and adduction, can also contribute to the injury, particularly when the foot is in a supinated position.

These findings emphasise the importance of understanding the role of ankle movement in the occurrence of LAS and can aid in the development of effective prevention and treatment strategies. While there has been extensive research on the mechanisms of LAS and the associated risk factors, there remain several gaps. For example, there is a need for further research on the role of proprioception, neuromuscular control and muscle strength in the development of LAS, as well as the effectiveness of various prevention and rehabilitation strategies. In addition, more research is needed to fully understand the biomechanics of ankle sprains during dynamic activities, such as jumping and cutting movements. Further research in these areas could provide valuable insights into the development, prevention and treatment of LAS, ultimately improving outcomes for patients and athletes.

2.2. Risk Factors for Lateral Ankle Sprain

Several influential conceptual models have been proposed in the literature to understand the multifactorial nature of injury causation during sports activities. Meeuwisse's (1994) model examines how intrinsic risk factors predisposing an athlete to injury interact dynamically with extrinsic enabling factors and inciting events causing acute injuries. Bittencourt et al. (2016) expanded upon this model by making it recursive to account for changing risk factors and susceptibilities over time through repeated exposures and recovery/outcome phases. While providing useful epidemiologic frameworks, these general models of injury aetiology remain largely theoretical and have yet to be thoroughly tested and validated, particularly within military contexts across diverse occupational roles and exposures (Bittencourt et al., 2016; Meeuwisse, 1994). Furthermore, Kalkhoven et al., (2020) proposed a detailed conceptual framework that maps the specific pathways leading from modifiable and non-modifiable physiological factors to resultant tissue loading, stresses and strains causing overuse athletic injuries. However, validation of the utility and predictive capability of each model component through rigorous research is needed.

Delahunt and Remus (2019) worked to integrate the comprehensive injury-causation model as a framework to identify and discuss the various risk factors associated with LAS and CAI, as reported in the literature. The interactions of intrinsic and extrinsic risk factors for LAS were studied with reference to the comprehensive injury-causation model proposed by Bahr and Krosshaug et al. (2005). The complex interactions of internal or intrinsic risk factors, such as age, sex, body composition, health (a history of ankle-joint injury), physical fitness (muscle strength, anatomy), skill level (postural balance) and psychological factors, predispose an individual to the risk of injury. The predisposed individual becomes susceptible to injury once exposed to the extrinsic risk factors, which further heighten the risk of injury. Most of the evidence supports the role of age and health (a history of ankle-joint injury) as intrinsic risk factors for LAS. In terms of extrinsic risk factors, athletes participating in court and field sports have the highest risk. Understanding these risk factors can guide the efficient use of resources in injury prevention. For example, implementing a risk-reduction intervention for a young adolescent basketball player with a history of LAS would be prudent. An exercise-based injury risk-reduction programme should also evaluate the athlete’s body composition, physical health (muscle strength) and skill level (postural balance). In addition, the use of an ankle-joint brace during practices and matches can provide external mechanical stability to the ankle joint and further mitigate the injury risk (Delahunt & Remus, 2019). They also suggested that the availability of research on risk factors for recurrent ankle sprains and CAI is limited; thus, it is not feasible to create a summary graphic that aligns with the comprehensive injury-causation model proposed by Bahr and Krosshaug et al. (2005).

Chandran et al., (2021) described the longitudinal NCAA Injury Surveillance Programme methodology that tracks injury rates and patterns using a large sample of self-reported data from convenience sampling of collegiate athletic programmes. However, limitations of self-reported data, variations in reporting practices and issues generalising the findings from student-athletes to professional military populations warrant consideration when assessing the utility of military injury research (Chandran et al., 2021).

Prior research has highlighted the existence of multiple risk factors that can contribute to the occurrence of a LAS. They suggest that if the risk factors for an injury are known, a screening tool could be designed to prevent the injury (Al Amer & Mohamed, 2020; Fong et al., 2009; Powers et al., 2017). To understand the risk factors for injury, Bahr and Krosshaug (2005) posited that the design of effective injury prevention strategies is hindered by a lack of comprehensive understanding of the causes of injuries. A multifactorial approach, encompassing both internal and external risk factors, as well as the specific mechanisms of injury, should be implemented to account for the complex nature of injury causation. Emphasis should be placed on the need for a comprehensive model that accounts for the context of the injury, including the playing situation and player and opponent behaviours, as well as an analysis of the whole body and joint biomechanics at the time of injury. This approach can provide a more holistic understanding of the factors that contribute to injury and inform the development of targeted prevention strategies (Bahr & Krosshaug, 2005). Thus, they proposed the injury-causation model for knee and ankle injuries, a framework that illustrates the interplay of internal and external risk factors in the occurrence of such injuries.

Previous researchers, including Al Amer and Mohamed (2020), Fong et al. (2009) and Powers et al. (2017), also raised concerns about the feasibility and effectiveness of using a periodic health examination to screen for factors that increase the risk of injuries in physically active individuals, with the goal of implementing targeted intervention programmes to decrease injury incidence. The main question being addressed is whether screening tests can be used to identify individuals who are at a higher risk of sports injuries and subsequently implement specific preventive measures. The article highlights three steps to validate a musculoskeletal injury screening test. The first is to demonstrate the correlation between the test markers and injury risk in prospective studies. The second is to evaluate test properties like sensitivity, specificity and predictive values in relevant populations. The third is to use appropriate statistical methods for analysis.

However, there are challenges in applying this framework to military populations. Few screening studies with military trainees have progressed through all validation steps. For example, while some tests like ankle dorsiflexion ROM correlate with injury in military samples, a full evaluation of test properties is lacking. In addition, the high physical demands of military training make it difficult to predict injuries with high accuracy due to an overlap in risk profiles.

Overall, while sports medicine approaches have advanced the foundational epidemiologic understanding of injury risks and continue to provide valuable backgrounds, focused military-specific research is still needed to validate and test the applicability of these models and frameworks towards understanding and mitigating diverse injury risks across different military occupations, training programmes and multifactorial exposures.

Nonetheless, principles like tracking marker and injury data over time, analysing test characteristics and using predictive statistical models could be applied to improve screening validity in military cohorts. Areas like optimising injury definitions, controlling extraneous risks and studying markers specific to key military tasks may help overcome inherent challenges. The thoughtful application of scientific methodology provides the best opportunity to enhance screening tests, even if reaching the same standards as civilian models remains difficult in demanding military environments. Research focused on incremental gains and contributions to a multifaceted screening process is likely the most realistic.

Risk factors for LAS have been identified through retrospective and prospective studies (McKay et al., 2001; Plisky et al., 2006). While retrospective studies can be useful, they cannot determine whether a risk factor is the cause or outcome of a condition (Murphy et al., 2003). By contrast, prospective studies can help establish the cause of the factors involved in the injury (Verhagen et al., 2000). These risk factors are commonly separated into two categories: extrinsic and intrinsic (Murphy et al., 2003). Extrinsic risk factors are external factors present in the environment that can cause LAS, whereas intrinsic risk factors are related to the body system itself (McKay et al., 2001). It is important to understand these factors separately to identify the cause of LAS and establish effective interventions. Risk factors can also be classified as modifiable and non-modifiable, with modifiable intrinsic risk factors being of particular clinical importance, as addressing them can help reduce the injury rate (Hupperets et al., 2010).

2.2.1. Extrinsic Risk Factors

Various external factors can influence the human body and increase the risk of LAS, such as the type of sports, ground surface, intensity of training, environment and footwear (De Noronha et al., 2006). The extrinsic risk factors for LAS have been extensively studied. Wearing an ankle brace has been shown to reduce the risk of LAS (McGuine et al., 2012). Uneven surfaces can put the foot in an unstable position, leading to microtraumas and stress on ankle ligaments, thus increasing the risk of LAS (Self et al., 2000). However, there is no evidence to support the effect of environmental temperature on the risk of ankle sprain.

While footwear itself is an external variable that military organisations can control, the interaction between the footwear and an individual's internal risk profile is complex. For example, recruits with certain foot shapes or biomechanics may be predisposed to injury in particular boot designs, suggesting that intrinsic risks interact with this extrinsic factor. In addition, subjective perceptions of comfort and fit are intrinsic and could modify injury risk in different boots. Finally, choices in boot models provided to recruits enable them to select options aligned to their foot structure and mechanics.

Taken together, these individual internal factors blur the lines between extrinsic and intrinsic risks when it comes to military footwear. Rather than a purely extrinsic, modifiable condition, the influence of footwear on injury risk involves an interplay between the boots themselves and a recruit's unique characteristics and selections. This suggests that a balanced approach is likely needed, where key boot design features are standardised by the military to optimise safety, but the recruits are also provided with enough options to find the best individually suited model. Allowing recruits some control to modify footwear to their intrinsic needs while still mandating certain extrinsic standards could be the ideal way to minimise boot-related injury risks.

Moreover, the military population provides an ideal setting for studying extrinsic risk factors for LAS as they have a controlled physical work routine, repetitions of exercises and uniform footwear and climatic conditions for all recruits in a certain region. Hence, selecting a military population for research would help control all the external factors for LAS in this population.

2.2.2. Intrinsic Risk Factors

Intrinsic risk factors are those that originate from internal influences on the human body and can include a variety of factors, such as sex, height, mass, foot characteristics, joint laxity, muscle strength, postural control, muscle weakness, poor proprioception and biomechanical abnormalities (Beynnon et al., 2001; Noronha et al., 2006). In addition, studies have identified other intrinsic factors, such as slow eccentric inversion strength, BMI, passive inversion joint position sense, fast concentric plantarflexion strength, reaction time of the peroneus brevis and hip muscle strength (Doherty et al., 2014; Fong et al., 2009; Kobayashi et al., 2016). These intrinsic risk factors are of great clinical importance as they can increase an individual's susceptibility to LAS. Understanding and addressing these intrinsic factors may be key in preventing and treating LAS in individuals. By identifying and targeting these specific factors, interventions can be developed to reduce the risk of injury and promote effective rehabilitation.

Milgrom et al. (1991) conducted a study consisting of 390 infantry recruits who were followed prospectively over a period of 14 weeks. Data were collected on the recruits' demographic characteristics, medical history and physical fitness levels, as well as information on any ankle sprains that occurred during the study period. The findings suggested the incidence of LAS to be 18%, but no statistically significant difference was observed in the incidence of LAS between recruits who trained in modified basketball shoes or standard lightweight infantry boots. The method used by Milgrom et al. in 1991 to compare injured and uninjured groups of recruits, without controlling for extrinsic risk factors such as footwear or carrying load, represents a limitation. Specifically, the lack of controlling for potential extrinsic injury risk factors prevents definitive conclusions about the influence of intrinsic factors on injury risk. To better isolate the effects of intrinsic factors on lower extremity injury, future studies should aim to control or account for extrinsic variables such as footwear type, carrying load magnitude, and load carriage duration. Implementing measures to control or quantify extrinsic factors would strengthen the ability to draw conclusions about the relationship between intrinsic risk factors and injury risk in this population. However, a statistically significant association was identified between the incidence of LAS and body mass, as well as a previous history of ankle sprain. Recruits with larger mass moments of inertia and a prior history of ankle sprain were found to have a higher incidence of LAS during basic training. The researchers concluded that these factors may be useful in identifying military recruits who are at an increased risk of LAS and in developing targeted prevention strategies

(Milgrom et al., 1991). It is worth noting that the study was conducted in 1991 and based on a specific population of military recruits, which limit the generalisability of the results to other populations or other activities. Moreover, the methods and measurements used in the study might be outdated and no longer reflect current standards. Thus, the identification of body mass moments of inertia and previous ankle sprain history as risk factors for LAS has important implications for screening, prevention and rehabilitation. These factors could help identify military recruits at higher LAS injury risk for targeted prevention programmes focusing on balance, proprioception and landing mechanics. Ankle sprain rehabilitation could be tailored based on understanding how body mass distribution affects dynamic joint stability during military tasks. Footwear design considerations like midsole cushioning and ankle support features may help redistribute forces and minimise strain for heavier recruits. Preparedness training periods before enlistment could focus on improving intrinsic factors, such as balance, reaction time, strength and movement patterns, to make recruits more resilient to higher LAS risk from body inertia.

While the 1990s study methods may not reflect current practices, the findings indicate the value in assessing body mass and prior injury history when screening recruits. These factors can be used to guide customised prevention and rehabilitation. More research is needed on modern military populations, especially among women. The results may provide a foundation for integrated strategies targeting identified risk factors.

Kobayashi et al. (2016) investigated the intrinsic risk factors of LAS in a systematic review and meta-analysis. Eight studies met their inclusion criteria, whereby the data were pooled to estimate the risk of LAS associated with various intrinsic risk factors, such as previous ankle sprains, ankle instability, muscle weakness and proprioception (the ability to sense the position of one's body and limbs in space). The study highlighted the importance of intrinsic factors, such as higher BMI, slow eccentric inversion strength, fast concentric plantarflexion strength, passive inversion proprioception and delayed reaction time of peroneus brevis. It is important to note that the studies included in this review were undertaken on different populations, settings and methodologies, which could limit the generalisability of the findings (Kobayashi et al., 2016).

Rice et al. (2017) prospectively investigated whether anthropometric characteristics and gait patterns are risk factors for ankle inversion injury in male military recruits. In 1,065 male recruits, bilateral plantar pressure and 3D lower limb kinematics were recorded. During a subsequent barefoot run, the sample size was reduced to 419. The recruits were followed for a period of 32 weeks, during which ankle injuries were recorded. The results of the study found that a narrower bimalleolar width and increased earlier peak plantar pressure under the fifth metatarsal were associated with an increased risk of ankle inversion injury. A lower body mass, BMI and a smaller calf girth were also associated with LAS. Rice et al. (2017) identified certain anthropometric characteristics as risk factors for ankle inversion injury, including narrower bimalleolar width, lower body mass, lower BMI and smaller calf girth. In addition, they found that increased early peak pressure under the fifth metatarsal was associated with higher injury risk. A narrower bimalleolar width indicates smaller ankle bone structure and joint surface area, which provides less inherent stability and may allow for more joint motion beyond normal limits, thereby increasing susceptibility to ankle sprains. Lower body mass and BMI could reflect lower muscle mass and strength levels around the ankle. The muscular support may be less capable of dynamically stabilising the joint during military activities. Similarly, smaller calf muscles indicate reduced strength and control of ankle motion, especially resistance to excess inversion or internal rotation, which commonly causes LAS. Excess pressure on the lateral forefoot could promote greater pronation and altered foot mechanics, disrupting the optimal alignment and motion up the chain to destabilise the ankle. It may also signify foot mobility restrictions medially. In summary, these anthropometric and biomechanical factors appear to influence intrinsic joint stability and movement patterns in a way that may overload the lateral ankle complex during dynamic military manoeuvres. Understanding the logical connection of each factor to ankle joint integrity and neuromuscular control will assist with targeted prevention approaches.

These findings suggest several potential prevention strategies as the wider bimalleolar width, greater calf girth and higher body mass/BMI could protect against ankle sprains by enhancing joint stability. While these anatomical factors cannot be directly modified, focused strengthening of the calf and other musculature around the ankle may help compensate. Orthotics or gait retraining that target pressure redistribution under the fifth metatarsal may help offload this high-risk area. Proprioceptive training may make recruits less susceptible to injury with certain high-risk anthropometric profiles. Gradually ramping up the intensity of military training demands could improve tissue tolerance in lower BMI/mass recruits (Rice et al., 2017).

Psaila and Ranson (2017) prospectively investigated the potential risk factors for lower leg, foot and ankle injuries in 127 recruits from the Maltese armed forces. The demographic data, along with the smoking status, were recorded in the initial medical screening. Four risk factors were studied, namely, BMI, foot posture index, fitness level and foot and ankle ability measure. Data were collected six months prior to the start of the training, and the recruits were followed for injury incidence for 135 days of basic military training. There were 45 total injuries that were recorded in this duration, out of which 33 were due to sudden cause (sudden onset) and 12 were gradual onset injuries. The results demonstrated that out of the four selected independent variables, only recruit fitness level was associated with the development of injury, and the most frequently injured part was the foot (Psaila & Ranson, 2017).

2.2.2.1. Clinical risk factors

Previous history of ankle sprain

Pourkazemi et al. (2018) prospectively investigated and identified the predictors of recurrent ankle sprains following a previous history of LAS in a research laboratory at the University of Sydney. A sample of convenience was recruited, including 70 controls and 30 individuals who had sustained an initial LAS. The potential predictors of recurrent ankle sprains were measured, including demographic information, perceived ankle instability, ankle joint ligamentous laxity, passive range of ankle motion, balance, proprioception, motor planning and control and inversion/eversion peak power. The participants were followed up monthly, and the number of recurrent ankle sprains was recorded over a 12-month period. The results showed that a combination of 10 predictors, including a recent index sprain, younger age, greater height and weight, perceived instability, increased laxity, impaired balance and greater inversion/eversion peak power, explained 27%–56% of the variance in the occurrence of recurrent ankle sprains. The regression model correctly classified 90% of the cases. The strongest independent predictors were a history of an index sprain (OR = 8.23, 95% CI = 1.66, 40.72) and younger age (OR = 8.41, 95% CI = 1.48, 47.96). These findings could form the basis for screening and interventions targeted to reduce the risk of LAS so that recurrent injury could be prevented (Pourkazemi et al., 2018).

Assessing risk factors is crucial for diagnosing and preventing LAS, as it is a significant issue that may lead to professional impairment. Previous studies have shown that athletes with a history of LAS are more likely to suffer recurrent ankle sprains and experience residual symptoms that impact their professional performance.

Yeung et al. (1994) conducted research focusing on the consequences of sprains and found that 73% of athletes had a recurrent ankle sprain. In addition, about 59% of those athletes had to cease their professional performances due to disability or residual symptoms, such as function time lost and financial costs (Kaufman et al., 2000).

Therefore, conducting further research to identify and understand the risk factors associated with LAS, especially in physically active individuals, such as the military population, is necessary. The occurrence of ankle sprains in physically active individuals is a significant issue that may lead to professional impairment; thus, further analysis is required.

Range of motion (ROM)

Hadzic et al. (2009) conducted a study to explore the risk factors for LAS among soccer players. The study included 38 male soccer players with a mean age of 22.6 years. The researchers measured several potential risk factors, including age, gender, BMI, foot dominance, ankle ROM and strength. The researchers found that only a decrease in dorsiflexion ROM was associated with LAS and that no other factors were significantly associated with LAS in this population.

Noronha et al. (2013) conducted a cross-sectional study to identify the intrinsic risk factors for LAS among physically active individuals. The study included 125 participants with a mean age of 21.5 years. The researchers measured several potential risk factors, including BMI, ankle ROM, muscle strength and foot posture. The researchers found that dorsiflexion ROM was not significantly associated with LAS in this population.

Attenborough et al. (2017) conducted a case-control study to investigate the association between ankle ROM and LAS in a military population. The study included 94 participants (47 cases and 47 controls) with a mean age of 27.5 years. The researchers measured ankle ROM using a goniometer. The researchers found that dorsiflexion ROM was not associated with LAS in this population and that other factors, such as previous injury and lower limb alignment, may be more important predictors of LAS.

Baumhauer et al. (1995) conducted a case-control study to identify the risk factors for ankle sprains in basketball players. The study included 145 players (52 cases and 93 controls) with a mean age of 20.3 years. The researchers measured several potential risk factors, including ankle ROM and foot posture. The researchers found that increased inversion ROM was significantly associated with ankle sprains in this population.

Overall, these studies show conflicting results regarding the role of ankle ROM in predicting LAS. While Hadzic et al. (2009) found a significant association between decreased dorsiflexion ROM and LAS in soccer players, Noronha et al. (2013) and Attenborough et al. (2017) did not find a significant association between ankle ROM and LAS in physically active individuals and military populations, respectively. However, Baumhauer et al. (1995) found a significant association between increased inversion ROM and ankle sprains in basketball players. These conflicting results suggest that more research is needed to fully understand the association between ankle ROM and LAS.

Dynamic balance

Dynamic balance is an essential aspect of movement and postural control, which involves maintaining stability while executing motion. In recent years, a growing body of research has linked LAS to deficits in dynamic balance during single-leg stance and the star excursion balance test (SEBT) or Y-balance test (YBT) (Gribble et al., 2012; Hartley et al., 2018; Hegedus et al., 2015; Plisky et al., 2009). The SEBT, which assesses an individual's dynamic balance by measuring their ability to reach different directions while maintaining a single-leg stance, has been found to be associated with increased risk of injury when performed in three specific directions: anterior, posteromedial and posterolateral. YBT has been developed from SEBT, and both have the same assessment. However, YBT has three specific directions (Plisky et al., 2009).

A systematic review of Hegedus et al. (2015) evaluated the measurement properties and correlation with injury of clinician-friendly lower extremity physical performance tests in athletes. The second part of the review focused on tests for the hip and thigh, knee and foot and ankle. The purpose of the review was to provide clinicians with a comprehensive understanding of the available lower extremity physical performance tests and their ability to identify injury risk factors in athletes. The study found that certain tests, such as the YBT, had good measurement properties and were associated with an increased risk of lower extremity injury in athletes. The review concluded by providing recommendations for future research in the area of lower extremity physical performance testing in athletes.

On the other hand, Bansbach et al. (2017a) compared postural stability between Special Operations Forces operators with a self-reported ankle injury within one year and healthy matched controls during a single-leg jump-landing task. The results showed no significant differences in dynamic postural stability index or landing kinematics between the injured and uninjured groups. However, within the injured group, the anterior-posterior stability index was significantly higher on the uninjured limb compared with the injured limb. These findings suggest that single-ankle injuries sustained by operators may not lead to deficits in dynamic postural stability, and injured operators are likely to be able to return to baseline measures through rehabilitation and daily activity.

While this study did not find a significant association between self-reported ankle injuries and dynamic postural stability as measured by the SEBT, previous research has shown that decreased performance on SEBT is associated with an increased risk of ankle ligament injury. Therefore, the SEBT may be a useful tool for identifying individuals at risk for ankle ligament injury and for guiding injury prevention and rehabilitation programmes (Bansbach et al., 2017; Doherty et al., 2014). The SEBT requires the individual to reach eight directions while maintaining dynamic balance and reaching the furthest possible point with a single-leg stance, as illustrated in Figure 2.2.

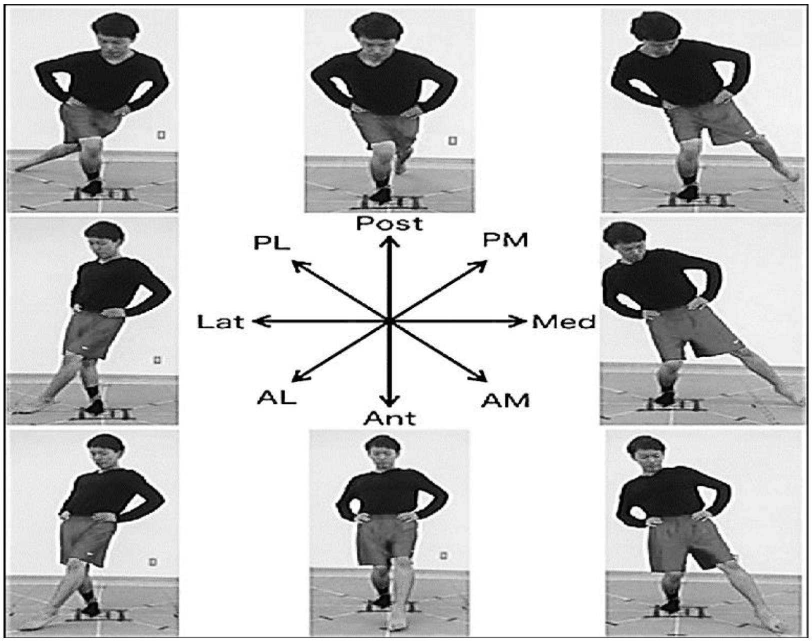


Figure 2.2: Direction of lower limb movements in a star excursion balance test

(Kobayashi et al., 2019)

Plisky et al. (2009) conducted a study to determine the validity and reliability of the YBT in measuring dynamic balance in athletes. The study included healthy collegiate athletes and demonstrated that the YBT is a reliable and valid tool for measuring dynamic balance in athletes and (ICC) ranged from 0.89 to 0.93 (ICC) and coefficient of variation ranged from 3.0% to 4.6%. They also found that low scores in the posterolateral, anterior and posteromedial directions of the YBT were associated with poor ankle balance, which could increase the risk of LAS. The authors suggest that using the YBT to identify individuals with poor ankle balance may be beneficial in developing preventative strategies for ankle injuries, particularly LAS.

Low scores on the posterolateral, anterior and posteromedial directions of the YBT suggest that an individual may have decreased dynamic control in these specific planes of motion. This lack of control may make the ankle more susceptible to rolling inwards, thereby increasing the risk of LAS. This provides a logical reason for the association between poor balance and LAS, wherein inadequate balance increases the risk of landing on an unstable surface or in an unstable position, which can cause an ankle sprain due to foot twisting (Wikstrom et al., 2010).

Noronha et al. (2013) and Attenborough et al. (2016) utilised the YBT in their prospective studies to investigate dynamic balance. Their findings suggest that the posterolateral direction of SEBT is a crucial predictive factor of LAS. The participants who performed well in the posterolateral direction had a lower risk of LAS (hazard ratio of 0.96, 95% CI 0.92–0.99) compared with those who did not perform well. This observation can be attributed to the higher strength of the lateral ankle ligaments, contributing to maintaining balance in the posterolateral direction. Therefore, individuals with stronger lateral ligaments have enhanced posterolateral balance and a reduced risk of LAS. The study highlights the importance of strengthening the lateral ankle ligaments to prevent ankle sprains, particularly in the posterolateral direction.

Overall, biomechanics suggest that the ability to maintain dynamic stability and control of ankle motion in multiple planes is crucial for reducing the risk of ankle sprains. The YBT can provide valuable information about an individual’s ankle balance and injury risk. YBT assesses an individual’s ability to maintain balance and control while performing dynamic movements in multiple directions, which may replicate the conditions leading to ankle ligament injuries. By identifying individuals with decreased balance and stability during the YBT, clinicians may be able to intervene and implement preventative measures to reduce the risk of ankle ligament injuries.

Bimalleolar width (BMW)

Bimalleolar width has been suggested to be an important factor associated with the risk of LAS, as a narrow bimalleolar width may increase susceptibility to injury. This is due to the fact that a narrow bimalleolar width can result in a smaller moment arm for the evertor muscles, which can reduce the ability of these muscles to resist inversion. Trojian and McKeag (2006) reported that a narrow bimalleolar width could also lead to reduced single-leg stability due to a smaller support base. However, the role of foot width in stability was not addressed in this study.

Further research was conducted by Rice et al. (2017) in a military population, where bilateral plantar pressure and lower limb kinematics of 419 military recruits were evaluated, and a follow-up measurement was conducted at 32 weeks after completing training. Logistic regression analysis indicated that a narrower bimalleolar width was associated with a 14.1% increase in ankle injury risk. This finding highlights the significance of even a one-millimetre difference in bimalleolar width. The use of sliding breadth callipers to accurately measure width from 0.0 to 80.0 mm adds to the reliability of the testing.

Although the studies by Trojian and McKeag (2006) and Rice et al. (2017) suggested a correlation between bimalleolar width and LAS, there is still a need for further research to establish a clearer understanding of the association between the two. For example, the mechanisms through which a narrow bimalleolar width increases the risk of LAS require further investigation. In addition, whether bimalleolar width is an independent risk factor for ankle sprains or if it is merely a reflection of other anatomical or biomechanical factors that contribute to ankle instability remains unclear. Additional studies on different populations, such as athletes or non-military individuals, could help determine if the association between bimalleolar width and ankle sprains is consistent across different groups. Ultimately, more research is needed to better understand the role of bimalleolar width in ankle stability and determine whether interventions aimed at increasing bimalleolar width could effectively reduce the risk of ankle sprains.

Muscle weakness

Ankle muscles

Ten muscles cross the ankle joint. They are responsible not only for producing movement but also stabilising the ankle joint. The strength of ankle muscles, including the tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius muscles, was prospectively investigated by Beynnon et al. (2001) using a plantar dorsiflexion test and inversion-eversion tests but found no significant correlation between ankle sprain and ankle muscle strength. Willems et al. (2005a) also found no difference in plantarflexion, eversion or inversion muscle strength between LAS-injured and uninjured participants. However, Willems et al. (2005b) conducted tests on inversion-eversion isokinetic concentric-eccentric and plantarflexion–dorsiflexion muscle strength and concluded that the chances of getting LAS increase when concentric dorsiflexion muscle strength decreases. Hadzic et al. (2009) reported that people with heightened levels of plantarflexor strength had a reduced range of ankle dorsiflexion movement and were at higher risk of LAS. In addition, Hadzic et al. (2009) demonstrated that higher strength of the plantarflexors (odds ratio 1.22, 95% CI 1.04–1.43, $p < 0.05$) is a significant LAS risk factor.

Abdel-Aziem and Draz (2014) stated that peroneal muscles are responsible for eversion of the foot, and their weakness can result in decreased control of foot movement and a more inverted foot position, leading to LAS. This occurs because a lack of eversion force reduces the ability of the muscles to resist inversion and return the foot to a neutral position, thereby preventing inversion sprains (Abdel-aziem & Draz, 2014). Yildiz et al. (2003) found that participants suffering from CAI exhibited isokinetic concentric and eccentric weakness in the muscles responsible for ankle eversion, indicating a association between peroneal muscle weakness and ankle instability. Kaminski and Hartsell (2002) also found that peroneal muscle weakness was associated with ankle instability. In a systematic literature review, Kobayashi et al. (2016) confirmed muscle weakness and a deficit in concentric inversion force in patients with CAI. Therefore, muscle imbalance can lead to relaxation of the peroneal and ankle muscles, which increases the risk of ankle sprain. Further research is necessary to explore the underlying mechanisms of muscle weakness and imbalance to develop effective prevention and rehabilitation strategies for ankle sprain.

Although the studies discussed previously provide some insights into the association between ankle muscle strength and ankle sprains, further research in this area is still needed. Some studies have found no significant correlation between ankle muscle strength and ankle sprains, while others have suggested that specific muscles, such as the plantarflexors and dorsiflexors, may play a role in ankle sprain risk.

Further research is needed to confirm the findings and explanations discussed in the passage, gain a more thorough understanding of the association between peroneal muscle weakness, muscle imbalance and ankle instability, and better understand the complex interplay between ankle muscle strength, joint stability and ankle sprain risk. This could involve examining the role of specific muscle groups in different types of ankle sprains, as well as exploring the potential influence of factors such as age, sex and sport-specific demands on ankle muscle strength and injury risk. Moreover, research could focus on developing effective interventions, such as strengthening exercises or neuromuscular training, to reduce ankle sprain risk in different populations.

Existing studies have focused on patients with CAI; however, additional research is needed to determine if these findings apply to individuals with acute ankle sprains or those who have never experienced an ankle injury.

Moreover, the mechanisms behind muscle weakness and imbalance need to be explored in greater detail, including the role of neural factors, to better inform prevention and treatment strategies. In addition, more research is needed to investigate the potential benefits of various interventions, such as exercise programmes or neuromuscular training, in improving peroneal muscle strength and reducing the risk of ankle sprains.

Hip muscles and their role in LAS

The hip muscles are responsible for stabilising the pelvis, which, in turn, affects the position of the lower limbs and feet. Weakness or imbalance in these muscles can lead to compensatory movements and altered alignment of the lower extremities, which can increase the risk of injury, including LAS (Powers et al. 2017; Meyer et al., 2013). De Ridder et al. (2017) conducted included a total of 133 male youth soccer players. Hip extensor muscle strength was assessed at the beginning of the season using a hand-held dynamometer. The results showed that reduced hip extension muscle strength was an independent risk factor for LAS in male youth soccer players, and no other study variable could be identified as a risk factor. The study suggests that hip muscle strength should be considered when designing injury prevention programmes for LAS in youth soccer players. The association between hip muscle strength and LAS occurrence can be explained by the fact that weak hip extensors muscles lead to increased hip adduction and internal rotation, which, in turn, increase the stress on the ankle joint, leading to an increased risk of LAS (De Ridder et al., 2017).

Kawaguchi et al. (2021) conducted a prospective cohort study to identify the risk factors for inversion ankle sprains in 145 male collegiate soccer players with a mean age 18 years. They assessed several potential intrinsic risk factors at baseline, including hip abductor strength. Players were then monitored for ankle sprains during one season.

The findings revealed that 21.4% of the players suffered an inversion ankle sprain during the season. The injured players showed significantly lower isometric hip abductor strength compared with the uninjured ones. Hip abductor weakness was identified as an independent risk factor for ankle sprain in the regression analysis. The authors theorised that hip abductor weakness could allow excess hip adduction and internal rotation during cutting motions, propagating down the chain to increase ankle inversion moments and sprain risk.

The results of this study provide evidence that hip muscle performance may contribute to ankle stability during the multi-directional demands of football. Specifically, the findings suggest that assessing hip strength during preseason screening could be valuable for identifying players at risk of ankle injury. Additionally, targeted strengthening programs for hip abductors could help mitigate modifiable weakness and reduce the risk of ankle injury in football players. However, the isolated straight-leg test position may not fully replicate functional strength deficits. Testing through sport-specific ranges and movements could better reveal relevant weaknesses. Other intrinsic factors like proprioception and postural control may also interact with hip strength to influence injury risk. Overall, this study provides initial evidence that hip abductor weakness is an ankle sprain risk factor in male soccer players. The findings can guide future research on isolated versus functional strength assessment and the development of integrated prevention programmes.

Furthermore, a prospective cohort study by Powers et al. (2017) examined hip abductor strength as a risk factor for non-contact LAS in male soccer players. They suggested that soccer players with weaker baseline hip abductor strength were more likely to experience LAS during the season. The authors also proposed that hip abductor weakness could allow greater hip adduction/internal rotation, disrupting optimal lower extremity alignment and dynamic stability during cutting and landing manoeuvres, which may increase injurious inversion stress on the ankle.

Powers et al (2017) study also provides evidence that hip abductor weakness is an intrinsic risk factor for LAS in soccer. The findings suggest the value of assessing hip strength preseason to identify high-risk players who may benefit from prevention programmes. Exercises targeting hip abductor and external rotator strength, proprioception and proper biomechanics may help reduce the heightened ankle sprain risk associated with hip muscle performance deficits. However, there were some limitations of this study including that this study was limited to male soccer players, results may not generalise to other sports or females. It did not measure other strength variables or risk factors like balance or ankle ROM. Furthermore, it was unable to determine if hip abductors alone predict injury. Moreover, they concluded that reduced hip abductor strength predicts future LAS injury risk in competitive male soccer players. Adding measurement of hip abductor strength to injury screening could help identify athletes at high risk for LAS. However, hip strength is likely only one aspect of a complex, multifactorial injury risk profile. However, the isolated hip strength test may not fully replicate functional demands. Future studies should examine how hip strength assessed through sport-specific motions relates to ankle sprain risk. In addition, other intrinsic factors like balance and foot posture should be considered along with hip strength. Overall, this study indicates that screening for hip abductor weakness and implementing preventive exercises may reduce ankle sprain incidence in soccer. Thus, hip abductor strength must need to be study also in the military population as well to find the association of this risk factor with LAS.

Thus, the previous studies aligned the possible reasons why the hip muscles play an important role in controlling lower extremity alignment and stability during dynamic movements, such as running and jumping. Weakness in the hip muscles could lead to compensatory movements at the ankle joint, which could increase the risk of ankle sprains. Another possible reason is that reduced hip extension muscle strength could lead to altered biomechanics and loading patterns at the ankle joint, which could increase the stress on the ankle ligaments and the risk of injury. Further research is needed to fully understand the mechanisms behind this association (McCann et al., 2017).

Moreover, increased hip internal rotation causes an increase in the knee abduction angle, which is associated with medial knee collapse or knee valgus (Peel et al., 2020). Specifically, they found that individuals with weaker hip abductor and external rotator muscles had increased dynamic knee valgus, which is a movement pattern associated with an increased risk of lower limb injuries, including ACL (McLean et al., 2005).

In addition to the hip abductor and external rotator muscles, other hip muscles may also affect foot positioning due to disturbance in the lower limb biomechanics. Neelapala et al. (2016) commented on the role of gluteal muscle strength in ankle positioning. The authors also noted that weak hip gluteal muscles can cause the femur to move in a more internally rotated manner, as described above, leading to knee valgus and a pronated foot position.

Dynamic knee valgus, as mentioned above, is a movement pattern that involves a combination of several movements of the lower limb, including adduction and internal rotation of the femur, abduction of the knee, anterior tibial translation, external tibial rotation and ankle eversion (Wilczyński et al., 2020). This movement pattern has been associated with an increased risk of lower limb injuries, particularly ACL injury (McLean et al., 2005).

Hollman et al. (2006) explored the association among frontal-plane hip and knee angles, hip-muscle strength and EMG recruitment in healthy women during a step-down task. The findings suggest that reduced strength and activation of hip muscles, especially the gluteus maximus and medius, may correlate with increased weight-bearing knee valgus, which is associated with a greater risk of knee injuries. Gluteus maximus recruitment was found to have a greater association with reduced knee valgus than external rotation strength during step-down tasks. Thus, the study highlighted that hip abductor muscle weakness was associated with increased knee valgus, which leads to reduced stability and causes the foot to adopt a more pronated position (Hollman et al., 2009). This finding is significant because a supinated foot position is a causative mechanism of LAS, whereas a pronated foot decreases the chance of LAS. Furthermore, weaker hip abductors are linked to increased knee valgus (Figure 2.3), which reduces stability and causes the foot to adopt a more pronated position, thereby decreasing the chance of LAS injury but increasing the risk of medial ankle sprain. These findings highlight the importance of strengthening the hip muscles to prevent knee injuries and improve lower extremity biomechanics during functional activities.

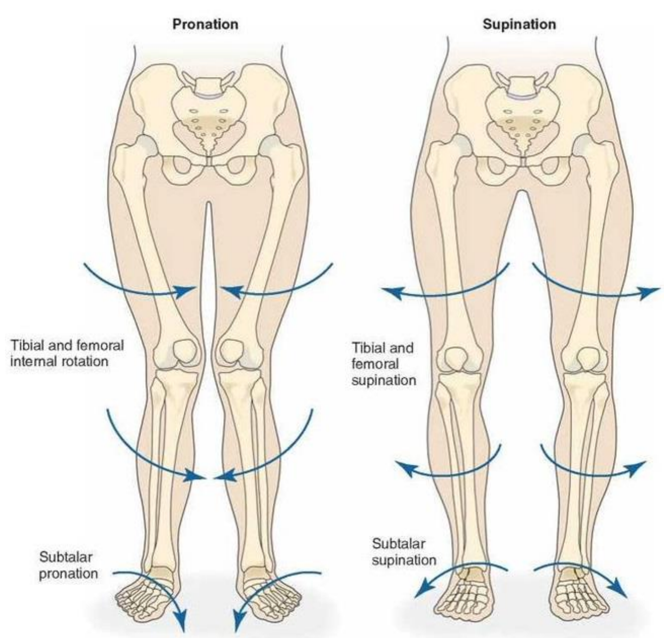


Figure 2.3: Position of the foot under the influence of the hip and knee joints (Patel & Nelson, 2000)

Prospective investigations with kinematic data are lacking in the literature despite the strong association of biomechanical factors with the risk of LAS. Therefore, further investigation is required to understand the biomechanical aspects of the ankle joint and identify specific parameters that may increase the incidence of LAS. In addition, the biomechanics of the ankle joint are influenced by the joint anatomy and multi-axial motions, and violation of these basic principles may increase the risk of ankle sprain. Previous retrospective and cross-sectional studies have limitations in determining the causes of differences between subjects with initial and recurrent ankle sprains; thus, a prospective study is necessary to identify the causes of LAS injury. While several studies have reported on the association between various intrinsic factors, no consensus has been reached on specific predictive intrinsic risk factors for LAS. Therefore, further research is necessary to identify predictive intrinsic risk factors. All potential risk factors should be thoroughly investigated to develop targeted prevention plans for reducing the occurrence of LAS.

2.2.2.2. Biomechanical risk factors

Ankle inversion angle and inversion time

Willems et al. (2004) conducted a prospective study to investigate the association between static alignment of the lower leg, plantar pressure and 3D kinematics of the lower limb with the incidence of LAS. The study did not find any significant differences in inversion angle or maximum ankle inversion time between the injured and non-injured groups. By contrast, Milgrom et al. (1991), Fong et al. (2011), Rice et al. (2017) and Willems et al. (2004) studied lower limb kinematics in the military population during running and did not find significant differences in kinematic variables between the LAS-injured and uninjured groups.

However, the injured group in Willems et al.'s study had lower maximum knee flexion angles with a delay in maximum knee time during running. This delay in maximal knee flexion may have contributed to the corresponding delayed maximal inversion of the ankle, resulting in increased load and loading time on the lateral ligaments. Therefore, delayed maximal knee flexion during running may be a significant risk factor for LAS. This finding highlights the importance of considering specific kinematic parameters of the knee joint in addition to those of the ankle joint to fully understand the biomechanical mechanisms underlying the occurrence of LAS.

Pre-landing muscle activity

Pre-activation of muscles is an essential mechanism in preventing LAS as it restricts ankle motion during landing. Failure of the muscles to control ankle motion during landing can result in injury, including LAS. Research has focused on the pre-landing muscle activity of the lower leg, particularly the peroneus longus (PL), peroneus brevis (PB) and tibialis anterior (TA) muscles. Electromyography (EMG) records the activity of these muscles during the pre-landing phase. Larger EMG amplitudes and earlier onset of pre-landing EMG activity are vital in positioning the foot during subsequent joint movements until sole touchdown. Pre-activation stiffens the muscles, contributing to foot stability until sole contact with the ground. Evidence suggests that initial muscle stiffness allows the muscle-tendon complex to store and release elastic energy, which limits joint rotation after foot contact.

Mitchell et al. (2008) studied the reaction times of the PL, PB and TA muscles in a simulation of a previously injured, unstable ankle and compared the reaction times between LAS-injured and uninjured groups. Their findings demonstrated that activation in an unstable ankle was significantly slower ($p < 0.025$) than in a stable ankle. They concluded that a slower reaction time in the PL, PB and TA muscles caused functional ankle instability, and fast and strong reactions in these muscles can prevent LAS. Therefore, rehabilitation programmes for LAS should include ankle evertor strengthening exercises to enhance muscle strength and prevent LAS.

Centre of pressure (COP) and pressure distribution

The mechanics of human gait and movement, specifically the COP, vertical ground reaction force and pressure distribution, have been identified as critical factors in determining the risk of ankle sprain (Willems et al., 2004). Several prospective studies have found that a laterally positioned COP and pressure distribution resulting from a habitual inverted foot position increase the likelihood of ankle inversion and plantarflexion during landing and the entire stance phase, leading to an increased risk of LAS (Fong et al., 2011; Milgrom et al., 1991; Rice et al., 2017; T. Willems et al., 2004).

In a study by Andersen et al. (2004), foot landing was assessed based on pressure distribution under the sole. They found that LAS injuries were frequently associated with landing in a manner that shifted the centre of pressure towards the fourth and fifth metatarsals. This pressure distribution caused the foot to adopt an inverted position during landing, resulting in a high inversion moment around the ankle joint. Therefore, controlling the COP and pressure distribution during landing may reduce the risk of ankle sprain, particularly LAS.

Overall, these findings emphasise the importance of proper foot position and pressure distribution during landing to reduce the risk of ankle sprain, particularly LAS.

Landing biomechanics and sagittal plane movement in the lower limbs

The association between sagittal plane movement in the lower limbs, including knee flexion/extension and ankle dorsi/plantarflexion, during landing and the risk of LAS remains unclear due to conflicting evidence. For instance, Bansbach et al. (2017) retrospectively aimed to investigate whether there were differences in postural stability and landing kinematics in Special Operations Forces operators with a self-reported ankle injury within the past year compared with healthy controls. The study involved 55 participants, 11 of whom had a self-reported ankle injury. The study found no significant differences in landing kinematics at the ankle, knee and hip between Special Operations Forces operators with a self-reported ankle injury within the past year and the uninjured controls. In addition, within the injured group, there were no significant differences in landing kinematics between the injured and uninjured limbs. These findings suggest that single ankle injuries sustained by operators may not lead to significant changes in landing kinematics during a single-leg jump-landing task.

By contrast, Mineta et al. (2021) observed an association between knee and hip angles and LAS during a landing task. They found that the peak angle of pelvic internal rotation ($p = 0.009$, HR 1.08 (95% CI 1.02–1.15)) and the peak angle of knee varus ($p < 0.001$, HR 1.16 (95% CI 1.10–1.22)) after single-leg landing were predictive factors of LAS. These conflicting findings highlight the need for further research to elucidate the role of sagittal plane movement in LAS risk.

Effect of knee position on ankle movements

The position of the knee plays an important role in determining the efficiency of ankle movements, such as plantarflexion and dorsiflexion. Brockett and Chapman (2016) found that ankle dorsiflexion is maximally efficient during knee extension, which can prevent LAS by resisting excessive plantarflexion. By contrast, Baumbach et al. (2014) reported that minimal knee flexion results in efficient ankle dorsiflexion due to the effect of the gastrocnemius muscle on ankle dorsiflexion. Their study aimed to determine the minimal degree of knee flexion that could help decrease the restriction of ankle dorsiflexion due to gastrocnemius. The tests were conducted in non-weight-bearing and weight-bearing positions, and the results suggested that ankle dorsiflexion was significant only in full knee extension or at 20° of knee flexion. Beyond this range, dorsiflexion does not improve.

2.3. Screening Tasks

Ankle sprains are a common injury in both military and athletic populations, with a significant impact on physical performance and training time loss. Proper assessment of risk factors can help target prevention strategies and act as primary prevention by controlling modifiable risk factors before injury occurs. To accurately assess the risk of ankle sprain, both external and internal factors must be evaluated, and dynamic biomechanical variables should be taken into consideration (Arnold et al., 2009; Bahr & Bahr, 1997; Docherty et al., 2005; Gribble et al., 2012; McKay et al., 2001; Waterman et al., 2010; Willems et al., 2005b), as indicated by the literature review in the current thesis.

Most ankle sprains occur during dynamic activities (Willems et al., 2005b). Tasks like jumping, hopping or landing are examples of dynamic tasks.

Such tasks can also involve attempting to perform purposeful segment movements (attempting to reach out for something) without compromising the prevailing support base (Gribble et al., 2012). Dynamic biomechanical variables must also be taken into consideration when assessing the risk of ankle sprain. A poor landing technique, for example, during parachuting, can worsen the position of the ankle and damage the lateral ligaments (Ekeland, 1997). Epidemiology studies by McKay et al. (2001) and Bahr and Bahr (1997) reported that most ankle sprains occur while hopping, landing, twisting or cutting. In such functional movement tasks, the participants attempt to imitate actions undertaken in the sporting and military fields. Therefore, assessing the risk factors through tasks that mimic common movements associated with ankle sprains in the military population will improve the understanding of the risks for military recruits.

A range of controlled tasks and simulated sports manoeuvres have been studied to screen for LAS risk. Single-leg drop landings allow a standardised assessment of the sagittal plane ankle biomechanics during landing (Goldblatt & Richmond, 2003). However, they lack unpredictability and multi-directional loading during real-world LAS mechanisms (Howe et al., 2019). Sidestep cutting tests incorporate lateral movements linked to ankle sprains but introduce more variables and require complex motion capture (McLean et al., 2005). Lateral hopping provides frontal plane stress but reduces emphasis on sagittal plane control (Delahunt et al., 2006). Unanticipated tasks have improved sports relevance but removed pre-planned movement analysis (Fong et al., 2009).

The choice of screening task depends on the specific purpose and constraints of the assessment. Each test has trade-offs in terms of comprehensiveness, standardisation and sport relevance that must be considered.

Single-leg landing and lateral hopping are two widely accepted screening tests to identify individuals at higher risk of injury due to their ability to mimic functional movement tasks associated with ankle sprains (Arnold et al., 2009; Docherty et al., 2005; Waterman et al., 2010). The ease of performing a task in a clinical setting is one of the basic selection parameters used to determine the chosen tests. The benefit of these tests is that they can be performed in a simple, quick and cost-effective manner (Arnold et al., 2009; Waterman et al., 2010). Thus, efficient and practical assessment of risk factors through such tasks will help clinicians prepare for possible injuries, design prevention strategies and reduce ankle sprains in military and athletic populations.

A combination of sagittal plane (e.g. single leg landing) and non-sagittal (e.g. lateral hop) tasks could provide a comprehensive ankle sprain risk profile. However, single-leg landing allows an efficient isolated evaluation of sagittal plane ankle control during a controlled landing similar to injury mechanisms. When applied critically and in combination with other tasks, it can have value as part of a multifaceted screening process.

Identifying athletes at higher risk for injury can allow clinicians to provide these individuals with prophylactic training programmes that aim to reduce the risk of injury. In conclusion, assessing the risk factors for ankle sprain is critical to the development of effective prevention and treatment programmes for the military population, where ankle sprain is a common occurrence (Fenn et al., 2021; Herzog et al., 2019; Jordaan &

Schwellnus, 1994; Schilz & Sammito, 2021; Waterman et al., 2010). Moreover, it would help clinicians prepare for possible injuries, design major prevention strategies for reducing ankle sprain and save individuals from the consequences of LAS, including training time loss.

2.3.1. Single-leg Landing

Studies have shown that a lack of sufficient joint control during landing is a primary factor in ankle sprains (Howe et al., 2019; Zhang, 2000). Ankle joint kinematics can determine the ability to control and modify the large joint reaction forces exerted on the ankle during landing (Zhang, 2000). Thus, ankle sprains often occur in sports during jumping, landing and cutting motions that load the ankle in vulnerable positions (Waterman et al., 2010).

Evaluating individuals at risk of ankle sprain through dynamic tasks, such as single-leg landing, and assessing their joint control and landing kinematics can help identify the risks and design prevention strategies. Thus, a variety of controlled tasks and sport-specific manoeuvres have been studied to screen for biomechanical risk factors for ankle sprain. Each approach has its merits and limitations, as single-leg landings allow standardised assessments but may not replicate the unpredictability and multi-directional loads during real ankle sprains (Howe et al., 2019). Sidestep cutting tests better represent manoeuvres linked to ankle sprains but introduce more variables and require more complex motion capture (McLean et al., 2005). Lateral hopping challenges frontal plane control but reduces emphasis on sagittal plane biomechanics (Koshino et al., 2016). Unanticipated tasks have improved ecological validity but remove the ability to analyse pre-planned movement strategies (Brown et al., 2004). Crossover hopping combines lateral and sagittal demands but has not been extensively validated (Koshino et al., 2019).

Ideally, a comprehensive screening battery would incorporate linear and lateral, anticipated and unanticipated, and simple and complex tasks to assess ankle sprain risk from multiple perspectives. However, time and resource constraints often limit clinical and research screens. Furthermore, single-leg landings represent a reasonable compromise as a standardised test, allowing reliable analysis of sagittal plane ankle biomechanics during a controlled jump landing. This has led to single-leg landing being widely studied as a controlled task to assess ankle sprain risk biomechanics (Doherty et al., 2015; Doherty et al., 2016; Howe et al., 2019). However, single-leg landings may not fully replicate the unpredictable, dynamic demands of sports; thus, their limitations regarding sport specificity must be considered. This suggests that a balance of efficiency and completeness is needed when selecting screening tasks.

Nevertheless, several studies have utilised single-leg landing to assess the biomechanical risk factors for ankle sprain. Doherty et al. (2015) had participants perform single-leg landings from a step. They found that those with ankle instability had greater ankle inversion and internal rotation on landing. However, landings from 0.3 m may not replicate typical jump heights. Brown et al. (2004) had subjects land from a 0.45-m platform. They reported less knee and hip flexion in those with instability; however, the height may exceed common sporting jumps. Delahunt et al. (2006) used a 40-cm platform and found that ankle instability altered ankle and knee kinematics. However, they did not calculate joint kinetics. Hoch et al., (2015) assessed single-leg landings and identified associations between ankle dorsiflexion ROM and landing kinematics. However, ankle strength was not considered.

While single-leg landing is a commonly used task, there is variability in the methodology and outcomes assessed. Key limitations include platform heights exceeding normal jumps, limited kinetics analysis and isolated examination of the ankle joint. Optimising jump height, capturing complete joint loads and profiling both proximal and distal biomechanics would enhance single-leg landing screens. Moreover, they can provide insights into sagittal plane ankle control during landing when applied critically.

Individuals with a history of ankle sprain show kinematic differences not only at the ankle level but also in proximal joints, such as the hip and knee (Caulfield & Garrett, 2002; Gribble & Robinson, 2010; Terada & Gribble, 2015). Other study has also revealed that changes in landing patterns occur in individuals with acute ankle sprain within two weeks after injury (Doherty et al., 2016). Therefore, controlling the position of the human foot during landing is crucial, and changing the angle or other parameters during training can significantly reduce the possibility of ankle sprain.

In summary, while controlled single-leg landings allow a standardised assessment, a battery of tests replicating the unpredictability, multi-directional loading and sport-specific motions linked to ankle sprains may provide a more comprehensive and functional screen for ankle injury risk. However, single-leg landings can be a simple preliminary screening tool when time or resources are limited.

2.3.2. Lateral Hopping

Lateral hopping is a functional test that has been shown to be useful for evaluating the functional limitation of ankle joints and assessing neuromuscular control. The lateral hop test was originally developed by Docherty et al. (2006) as a dynamic test to identify deficits in those with functional ankle instability compared with healthy controls. They found that the test could discriminate between groups, demonstrating initial validity.

Later studies like that of Delahunt et al. (2007) provided further evidence of the kinematic and neuromuscular differences during lateral hopping in those with instability. The test's relevance is supported by the ankle positioning and multi-directional loads involved, challenging lateral stability and replicating injury mechanisms (Koshino et al., 2016).

However, its reliability has been questioned due to poor standardisation. Following one method will improve consistency between trials and subjects compared with inconsistency which is lead to discrepancy in functional test such as hopping (Reiman & Manske, 2009). This helps minimise performance variability compared with an open-ended hop. The fixed barrier provides a consistent target distance/height across trials and subjects such as the protocol used by (Ridder et al., 2015). Thus, standardisation method of using 15 cm hurdle will allow the participant during the trials to avoid inconsistency (Reiman & Manske, 2009).

Overall, with proper standardisation, the lateral hop test serves as a dynamic and functionally relevant screening task to assess deficits in those with ankle instability versus healthy controls. The lateral movements and multi-plane ankle demands during continuous hopping replicate the sports activities linked with ankle sprains. Therefore, clinicians can consider using the lateral hop test as part of a comprehensive evaluation of ankle function.

Moreover, this test can reveal alterations to kinematic, kinetic and muscle movement patterns among participants with functional instability (FI) and ankle sprain. The ability to move laterally during the hop exerts stress on the ankle joint's lateral ligament complex and the peroneal muscles responsible for the dynamic stabilisation of the ankle joint. These structures play a crucial role in maintaining ankle stability and preventing ankle sprains. The primary reason of this study opted to have participants hop over a barrier is to increase the eccentric load and simulate a more dynamic landing, similar to the mechanisms often involved in lateral ankle sprain (LAS) injury (Fong et al 2009). LAS frequently occurs during dynamic manoeuvres that load the ankle in awkward positions, especially landing from a jump. Therefore, adding the barrier increases the jump height, landing impact forces, and need for rapid stabilisation on one leg - all of which up the demand and better mimic dynamic activity.

Several studies have suggested that lateral hopping can also be used to identify deficits in functional performance in individuals with FI. Docherty et al. (2005) found a positive link between deficits in performance during a side hop step and FI. The participants with FI performed worse than the uninjured controls, indicating that the side hop test is a useful way to assess deficits in functional performance in the FI group based on the participants' ability to move laterally. Similarly, Delahunt et al. (2007) reported differences in muscle activity (rectus femoris, peroneus longus, tibialis anterior and soleus) and kinematics (frontal, transverse and sagittal plane movements and velocities for the hip, knee and ankle joints) of the lower limb in participants with FI compared with a control group during lateral hop pre-landing and post-landing.

Furthermore, lateral hopping has been shown to be a valuable tool for identifying functional deficits in individuals with a history of ankle sprain. Yoshida et al. (2018) recruited 27 subjects with a history of ankle sprain and tested both their injured and uninjured limbs using a 3D motion analysis system. They found that the injured limbs demonstrated longer duration in a side-hop test, as well as greater ankle inversion/eversion and dorsal flexion/plantarflexion. Ankle motion and muscle activity were also reduced in the injured limbs, indicating that lateral hopping is an effective test to assess functional deficits in individuals with an ankle sprain.

2.4. Tools to Measure Parameters Related to LAS

2.4.1. Goniometer

Ankle joint limitation has been identified as a potential predictor of LAS, and measuring ankle ROM is useful in this regard (Halabchi et al., 2016). The goniometer is the most commonly used tool for measuring joint ROM, as it is a quick and inexpensive assessment tool used in research and clinical settings (Burr et al., 2003). The reliability of goniometers varies from moderate to high across various studies (Beynnon et al., 2001b; Konor et al., 2012).

Several prospective studies, including Beynnon et al. (2001), Baumhauer et al. (1995), Willems et al. (2005) and Hadzic et al. (2009), have assessed ankle ROM during active or passive measurements using a goniometer. Hadzic et al. (2009) used a universal goniometer set to 0° to measure the possibility of ankle sprain in volleyball players but did not report their measurement error. Milgrom et al. (1991) used a universal goniometer to measure hip ROM in male infantry recruits and found no association between internal and external hip rotation in individuals who had experienced LAS compared with those who had not. These findings suggest that ankle ROM measured using a goniometer can provide valuable information for predicting LAS. However, the reliability of the tool and the specific measurement technique should be considered when interpreting the results. The majority of the aforementioned perspective studies did not conduct reliability analyses before data collection, with the exception of Willems et al. (2005) who utilised a reliability study. Willems et al. reported intraclass correlation coefficients ranging from 0.82 to 0.98, however no data on measurement error or the coefficient of variation was provided.

2.4.2. Hand-held Dynamometer (HHD)

When measuring muscle strength, a gold standard isokinetic dynamometer is often used, but it may not be feasible for large-scale studies. As an alternative, the HHD is a popular tool for measuring muscle strength due to its simplicity, portability and cost-effectiveness. It also provides a quick and objective measurement of muscle strength in various populations, including older adults, athletes and individuals with neuromuscular disorders.

However, HHD has its limitations. It requires some level of training and experience to achieve consistent results. The examiner must also pay close attention to the placement and stabilisation of the device during testing to ensure accurate and reliable results. In addition, HHD measurements may be influenced by factors such as the size and shape of the limb being tested, the positioning of the patient and the level of cooperation of the patient.

Despite these limitations, HHD remains a valuable tool for measuring muscle strength in various settings, and its advantages outweigh its disadvantages in many cases. With proper training and attention to detail, HHD can provide a reliable and cost-effective alternative to more expensive and specialised instruments like isokinetic dynamometers.

HHD can measure the force generated by muscles in Newtons, pounds or kilogrammes and has been shown to have fair to excellent reliability in various studies. For example, Alfuth et al. (2016) reported measuring ankle eversion/inversion strength inter-rater reliability values indicative of fair to excellent reliability (ICCs of 0.60 and 0.83) for measuring ankle inversion strength using a handheld dynamometer (HHD) in different positions and standard error of measurement were low and ranged from (0.3 to 0.7) newton meter (Nm). In conclusion, HHD to be highly reliable for measuring muscle strength while maintaining intraobserver reliability.

2.4.3. Dynamic Balance (YBT)

The SEBT is a commonly used tool for assessing dynamic balance in multiple directions (Gribble et al., 2012; Plisky et al., 2006). It has been found to have good inter-rater and intra-rater reliability, making it a popular tool in clinical and research settings (Gribble et al., 2012). In addition, it has been shown to have good concurrent validity with other balance tests, such as the Balance Error Scoring System (Gribble et al., 2009). The SEBT is also easy to administer, requiring minimal equipment and space. Furthermore, YBT has been developed from SEBT, and both have the same assessment. However, YBT has only three specific directions (Plisky et al., 2009). Some limitations of the SEBT should also be considered. The test requires a certain level of lower extremity function; hence, individuals with severe lower extremity injuries or disabilities may not be able to perform the test. In addition, the SEBT has been criticised for being task-specific and not necessarily measuring the overall balance ability (Hertel et al., 2006). Finally, the SEBT has been found to have a learning effect, meaning the participants tend to improve their scores with repeated testing, potentially leading to inflated results (Gribble et al., 2012).

Despite its limitations, such as its limited directions of reach, it remains a popular tool among clinicians and researchers due to its reliability and ease of administration.

A study conducted by Hyong and Hyouk (2014) focused on individuals with ankle injuries and utilised the YBT, which is a variation of the SEBT that uses three specific directions of reach: anterior, posterolateral and posteromedial. The researchers found that the YBT demonstrated high reliability in measuring dynamic balance, as indicated by the high ICC values ranging from 0.88 to 0.94. In addition, the standard error of measurement (SEM) ranged from 2.41 cm to 3.3 cm, indicating the degree of random error in the measurements.

These findings suggest that the YBT, a specific version of the SEBT, is a reliable tool for assessing dynamic balance in individuals with ankle injuries. The high ICC values indicate strong agreement between repeated measurements, while the SEM values provide an estimate of the measurement error. The reliability of the YBT makes it a valuable tool for clinicians and researchers in evaluating postural balance and monitoring the progress of individuals with ankle injuries.

In addition, Hertel et al. (2002) assessed the reliability of SEBT in a healthy population and reported ICC values of 0.81–0.96. They concluded that SEBT is a highly reliable tool for assessing postural balance in multiple directions.

However, it should be noted that SEBT or YBT have some limitations, including the need for training to administer and interpret the test results accurately (Gribble & Hertel, 2003). Moreover, YBT scores may be affected by factors such as age, sex, leg length and limb dominance (Gribble & Hertel, 2003). Despite these limitations, YBT remains a valuable tool for assessing dynamic balance in clinical and research settings and can be used to assess the dynamic balance in an individual.

2.5. Research Gap

The available literature on LAS provides valuable insights into its risk factors and possible measures for assessing those risks. However, some studies have limitations that warrant further consideration. Rabin et al. (2014) noted that studies have identified several risk factors for LAS, but there is a need to determine the most predictive factors. For instance, assessing lower limb kinematics to check the association of these angles with LAS is essential, but previous studies provide scant information from this perspective. Although knee, hip and ankle kinematics seem to be associated with LAS, studies assessing kinematics have shown varied results. Similarly, clinical factors have been explored previously, but conflicting results have been reported.

For example, several studies have compared 2D and 3D analyses in the lower limbs, particularly the ankle, during functional tasks. They concluded that 2D is a reliable and valid assessment method (Gwynne & Curran, 2014; Herrington et al., 2017b; Maykut et al., 2015; Munro et al., 2012). Therefore, the aim of this thesis is to identify the risk factors for LAS using clinically valid and non-expensive equipment and portable and easy-to-use devices as an alternative to the gold standard (3D and an isokinetic dynamometer). The chosen research strategy aims to increase the ease and efficiency of screening a large number of recruits at risk of LAS using 2D video analysis high-speed cameras, an HHD, a goniometer and a YBT. Frontal plane projection angle (FPPA), which is the angle of the joints during motion in the frontal plane, can provide information about the range, height and time of motion. However, there have been no studies investigating the correlation between the direct risk or incidence of ankle sprain and FPPA. Therefore, this topic requires further examination in the context of LAS (Herzog et al., 2019). The limitations of previous studies have been identified, such as the high cost and dependency on advanced technology, which hinder the generalisation and clinical application of the findings.

Therefore, it is crucial to assess the reliability and validity of the tools used to assess the associated parameters for LAS. This assessment is necessary before large data collection to build confidence in the results of these tools and enhance the worth of the outcomes (Davis et al., 2017; Herrington et al., 2017; Kelln et al., 2008; Munro et al., 2012). It will also help identify the best tools that can be used in research and clinical settings to assess LAS risk factors accurately. Standardised methods with established validity and reliability will improve the quality of data collected in this study. Therefore, this study aims to propose an appropriate method that is both reliable and valid for identifying the risk factors of ankle sprain.

Moreover, there is a gap in the literature on the assessment of LAS risk factors among military recruits in the Saudi population. The current literature indicates that there are numerous studies investigating ankle sprain risk factors, but very few have focused on military cohorts outside of three prospective studies (Milgrom et al., 1991; Mei-Dan et al., 2005) from over 1,200 pieces of evidence, with none in Saudi Arabia. Consequently, there is a lack of substantial research on intrinsic LAS risk factors for military recruits (Mei-Dan et al., 2005). As ankle injuries are a leading cause of discharge or hospitalisation for military personnel during training in Saudi Arabia, this study seeks to address this gap. A military environment during basic training is advantageous due to the homogenous age and similar physical fitness levels of the recruits. In addition, all recruits are exposed to similar extrinsic factors, such as footwear, no carrying load, level of training intensity and ground surfaces, minimising variations in the external environment. Prior studies had some limitations such as Rice et al (2017) investigated the intrinsic risk factor of LAS and used footwear and barefoot as well as it included carry load and that were extrinsic risk factors which had direct or indirect effect on intrinsic risk factors of LAS. By controlling for these extrinsic factors, this study can allow the assessment of the intrinsic risk factors for ankle sprains in military recruits in Saudi Arabia, considering the prior studies limitations. Furthermore, focusing specifically on the Saudi military will help address the lack of data on this population, who are at high risk for ankle injuries during training. The primary limitations of prior studies are that they previous studies on LAS epidemiology and risk factors have been retrospective in nature. While this study used a prospective cohort design to establish temporality and better determine predictive relationships. Furthermore, prior studies didn’t investigate LAS comprehensively clinically, functionally and biomechanically. While this study investigated most risk factors associated to LAS according to the literature review and the systematic review and meta-analysis (chapter 3). In addition, prior prospective studies never utilised two-dimensional (2D) camera for kinematic risk factors. While this study was the first study utilised 2D camera which is simple, fast accurate and non-expensive. Additionally, prior studies had some limitations such as investigating the intrinsic risk factor of LAS and used footwear, barefoot or carry load on the same sample and that were extrinsic risk factors which had direct or indirect effect on intrinsic risk factors of LAS. While this study controlled these extrinsic factors, this study can confidently assess the intrinsic risk factors. Then, potential intrinsic risk factors like hip muscles strength along explicit biomechanical variables have not been well studied as predictors of first-time LAS. While this study evaluated an array of potential intrinsic risk factors including hip strength imbalances. Furthermore, previous studies have often relied on self-report for injury diagnosis and mechanism. While this study utilised physical examination by a physician to clinically confirm all LAS diagnoses and injury mechanisms. Moreover, the previous studies never address the Saudi military population. However, in the current study the Saudi military population were studied.

In summary, the existing literature on LAS has identified various risk factors and measures for assessing those risks, but there are gaps that need to be addressed. First, there is limited research on intrinsic LAS risk factors for military recruits in Saudi Arabia, despite ankle injuries being a common reason for discharge or hospitalisation during military training, which is the focus of the present study. The advantage of studying military recruits is that they are a homogenous group with similar physical fitness levels and exposure to extrinsic factors. Second, the constraints of time and technology have limited the scope of previous studies and reduced their clinical application. To address these issues, this study aims to identify LAS risk factors using clinically valid and non-expensive equipment and portable and easy-to-use devices. The study will also examine the association of the lower limb FPPA and sagittal plane angles with LAS, a correlation that has not been explored previously. The selected tests will be evaluated for their association with the occurrence of LAS and their validity and accuracy in taking such measurements and to identify key risk factors for future prevention and intervention.

This study aims to fill the gap in research and contribute to medical practice by identifying the risk factors and introducing prevention strategies. The findings of this study can contribute to the development of more targeted intervention strategies to reduce injury risk and can be used for future prevention and primary intervention for military recruits at risk of LAS.

Need for the Study:

This study is needed to identify the risk factors for LAS in the Saudi military population due high incidence and prevalence between the military recruits. Understanding the epidemiology and risk factors in this specific population will provide key insights into providing evidence-based injury risk mitigation strategies and training practices within the Saudi military. The following reasons necessitate this research:

1. Saudi military focus: Studying LAS in the Saudi military will provide population-specific data. This can lead to tailored recommendations that align with the unique needs and demands of Saudi military recruits.
2. High prevalence: LAS injuries are common in the military population. Identifying the risk factors in the Saudi military can address this significant health concern and burden.

3. Intrinsic risk factors of LAS: After identifying the risk factors of LAS the researcher could recommend a plan for preventing injury such as reduce a body mass.
4. Inform training practices: The data on the risk factors can directly suggest training practices or modified in the Saudi military to implement preventive strategies. This evidence-based approach will enhance the effectiveness of training programmes.
5. Operational readiness: Preventing LAS through modified training will likely improve the operational readiness and well-being of Saudi military recruits.

In summary, this study is critical to elucidate the epidemiology and risk factors for LAS specific to the Saudi military. The risk factors data can guide evidence-based changes to training practices and injury prevention strategies, programs focused on improving ankle joint stability, balance, lower limb biomechanics, and foot and ankle strengthening which have the potential to reduce the burden of injury, enhance readiness and improve the health of Saudi military recruits.

CHAPTER 3

Intrinsic Risk Factors of Lateral Ankle Sprain (LAS): A Systematic Review

The main objective of this chapter is to conduct a systematic review of previously published prospective studies to provide scientific literature that can eliminate bias in other stages of the review process. This will help in evaluating the intrinsic factors that contribute to LAS. The review will focus on identifying and analysing the quality of prospective studies to identify the most reliable evidence on intrinsic risk factors for LAS. The results of this review will be used to inform the design of the current study and identify key areas for future research.

3.1. Introduction

LAS is a highly prevalent injury among activity-related lower limb musculoskeletal injuries (Shah et al., 2016; Waterman et al., 2010). It is also the most frequently treated traumatic injury in emergency departments and healthcare centres (Doherty et al., 2014). Incidence among highly active populations has been significantly associated with the risk of LAS occurrence. For instance, acute ankle sprains are the most frequently reported injury among collegiate athletes in the United States, accounting for 15% of all injuries reported in this demographic (Hootman et al., 2007; Roos et al., 2017). Furthermore, 788,469 (9.74%) foot and ankle injuries were reported among 8,092,281 military personnel in 15 different nations (Fenn et al., 2021). LAS can have a poor long-term prognosis, with up to 70% of patients suffering lingering symptoms. Improper management of LAS can lead to ankle instability, chronic pain, early degenerative bony changes and chronic instability, eventually leading to osteoarthritis in 7%–42% of cases (Anandacoomarasamy & Barnsley, 2005; Hauser & Dolan, 2011; Thompson et al., 2018; Valderrabano et al., 2006). The direct and indirect annual costs of treating LAS are estimated to be more than US$6 billion in the US (Shah et al., 2016).

Several prospective studies and systematic reviews have been conducted to identify the intrinsic risk factors for LAS; however, the results are contradictory, making it difficult to pinpoint a specific factor that could lead to LAS (Vuurberg et al., 2018).

Although relatively recent systematic reviews on LAS have been reported (Kobayashi et al., 2016), it is important to note that these reviews have certain limitations. The reviews included a relatively small number of articles, which may limit the comprehensiveness of their findings. In addition, they tend to assess only a limited number of risk factors, as elaborated in Section 3.3.1. Therefore, further research is needed to address these limitations and provide a more comprehensive understanding of the risk factors associated with LAS. The current systematic review aims to overcome these limitations by conducting a more extensive search of the literature and including a wide range of studies that have examined the various risk factors for LAS. By synthesising the available evidence from a larger pool of studies, this review aims to provide a more robust and comprehensive analysis of the risk factors associated with LAS, thereby filling the gaps in the existing literature and informing future research and clinical practice. This chapter aims to identify the likely intrinsic risk factors for LAS via a systematic review and meta-analysis to improve understanding of the associated risk factors and develop screening tools and preventative strategies. Synthesising and evaluating current research can provide further insights into previously identified intrinsic risks associated with LAS. Notably, the evidence base for this review was significantly expanded as a result of these methodological improvements. In contrast to the review by Kobayashi et al. (2016), which comprised only eight studies and 1,101 participants, the 14 studies included in the current review represented a total of 2,445 participants. The conclusions reached in this systematic review, as compared with the earlier review, have greater statistical power and generalisability due to the larger pool of higher-quality evidence (Kobayashi et al., 2016).

In summary, LAS is a highly prevalent injury, with sports activities significantly associated with its risk. LAS has a poor long-term prognosis and a high rate of recurrence, leading to chronic instability and early degenerative bony changes. The direct and indirect annual costs of treating LAS are estimated to be more than US$6 billion in the US. Despite several studies identifying the intrinsic risk factors for LAS, none have agreed on a single outcome, making it difficult to pinpoint a specific factor. Thus, this thesis aims to identify the likely intrinsic risk factors for LAS via a systematic review and meta-analysis to develop screening tools and preventative strategies.

3.1.1. Aims and Objectives

This study aims to systematically review the literature and perform a meta-analysis to identify the risk factors associated with LAS.

3.1.2. Research Question

6. Is a systematic review and meta-analysis of previous prospective studies able to identify the clinical and biomechanical differences between individuals who sustain LAS and those who do not?

3.2. Materials and Methods

To systematically synthesise the prospective studies, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement was used (Moher et al., 2009) to investigate the intrinsic risk factors for LAS.

Studies following the inclusion criteria stated below were included in the systematic review and meta-analysis:

- The population included male or female healthy individuals ≥15 years old.
- Exposure resulted in the form of injury or non-injury.
- Results were observed during a subsequent follow-up.
- LAS injured and uninjured participants were reported to compare these two groups.
- The study outcome focused on the intrinsic risk factors for LAS.

The study design includes prospective studies published from January 1990 to January 2022 written in English. This study was prospectively registered with the International Prospective Register for Systematic Reviews, PROSPERO, under registration number CRD42020169972.

3.2.1. Literature Search Strategy and Study Identification

An extensive manual search was carried out using the following electronic databases: Cumulative Index to Nursing and Allied Health Literature (CINAHL), Ovid Online, Science Direct, MEDLINE, Allied and Complementary Medicine Index (AMED) and PubMed. For an extended manual search, the following search terms were used: risk factor for lateral ankle sprain OR risk factor for lateral ankle sprain OR risky OR predictor factor for lateral ankle sprain OR prediction of lateral ankle sprain (prospective).

3.2.2. Selection of Studies

The Mendeley system was used to select and organise the references, and the studies meeting the following criteria were selected:

- Full-text prospective studies written in English.
- Prospective cohort studies that specified LAS risk factors with a baseline assessment and subsequent follow-up to monitor LAS occurrence and development.
- Study participants that include both men and women aged ≥15.
- Studies with an outcome duration of 6 months.

3.2.3. Data Extraction

Data were extracted from the selected articles by two reviewers (KA and OA). In case of any disagreement between KA and OA, a third reviewer, CS, acted as a consultant to resolve disputes, e.g. any perceptual disputes. The extracted data contained the following details (Table 3.1):

- Title and author of the study.
- Year of publication.
- Sample size (number of participants).
- Tasks performed by the participants and the observer.
- Outcomes.
- Results.

A descriptive synthesis was applied to identify the risk factors for LAS.

3.2.4. Methodological Quality

For a risk bias assessment (especially for reporting bias), the Newcastle–Ottawa Scale (NOS) (Appendix A) was used by two reviewers (KA and OA) (Wells et al., 2010).

The NOS ranks studies using scores from 0–9. According to NOS, the ranking and quality of research is as follows:

- 7–9 indicates high quality.
- 5–6 indicates moderate quality.
- 0–4 indicates low quality (Wells et al., 2010).

In any case where a meta-analysis could not be performed due to dissimilarities between the outcomes of two studies, a fixed-effect model was used, where one assumes a fixed population effect size. By contrast, random models assume that effect sizes are sampled from a population with an effect size. For the meta-analysis, the Review Manager 5 (RevMan 5.4) software package was used.

3.3. Results

3.3.1. Characteristics of the Studies

Figure 3.1 illustrates the flow chart used for the study selection. In total, 1,219 articles were potentially relevant to the searched keywords. A total of 624 articles were included after the exclusion of duplicated articles, from them 448 articles were further excluded as the titles and abstracts indicated their irrelevance to the inclusion criteria. Moreover, from 176 articles, 114 articles were excluded after reading the abstracts. Finally, 62 articles were included full text, but 48 from them did not specify LAS data, like they had participants younger than 15 years and were subgroups or retrospective data. Thus, these were all excluded. Overall, 14 articles fulfilled the eligibility criteria and were included in the systematic review and meta-analysis (see Table 3.3 in Supplementary Data). The publication years of the included studies ranged from January 1990 to January 2022.

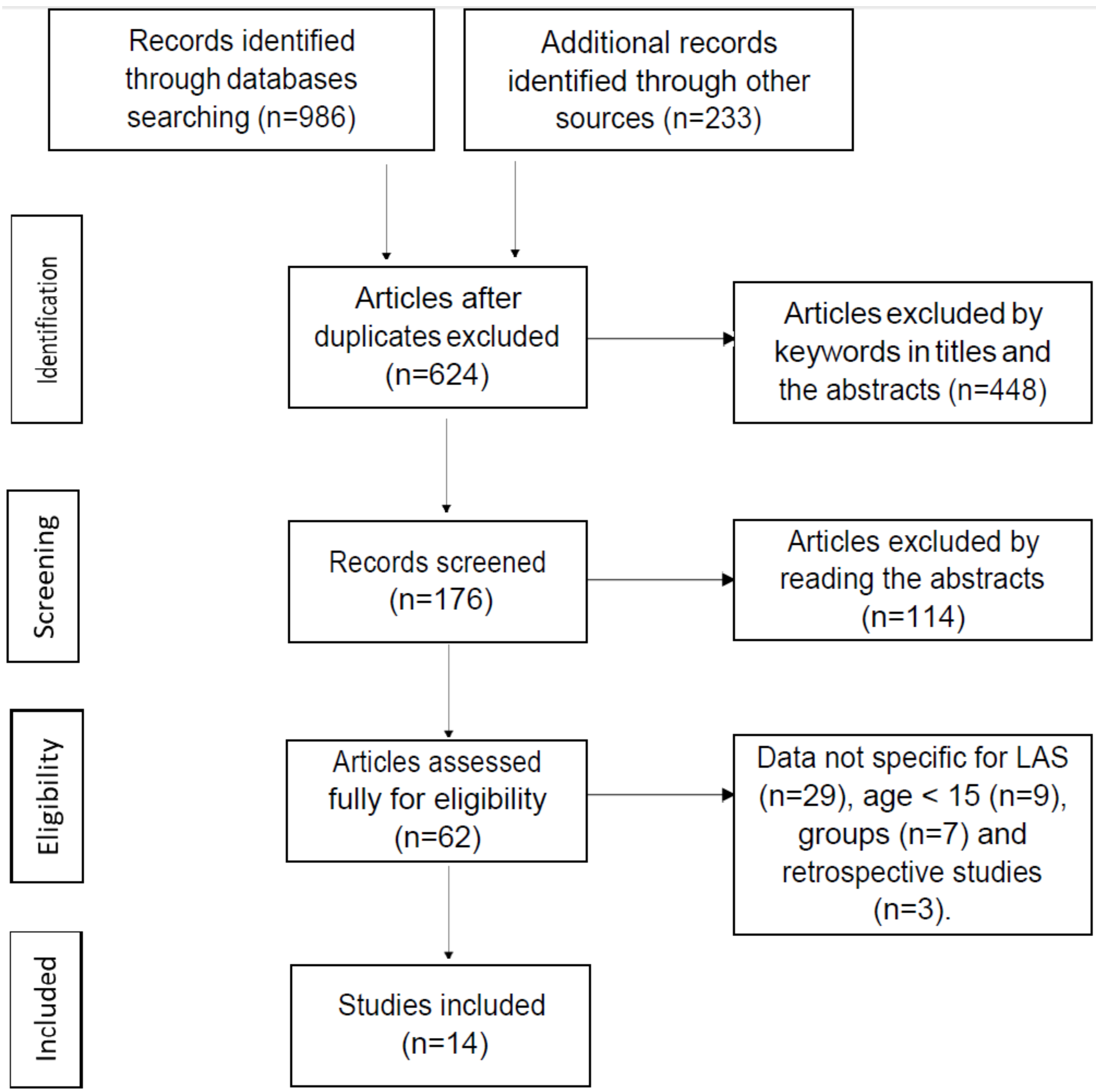


Figure 3.1: Flowchart illustrating the process for study selection

Highlights of the selected studies

Brief information about the study design, sample size, LAS incidence, follow-up duration and NOS of the selected studies is presented in Table 3.1.

Table 3.1: Brief information about the selected studies: author's name, year of publication, NOS ranking score, study design, sample size, LAS outcome, incidence percentage and follow-up period

Study	NOS score	Cohort	Sample size	LAS	Incidence (%)	Follow-up period (weeks)
(Milgrom et al., 1991)	5	Prospective	390	69	17.69%	14
(Baumhauer et al., 1995)	4	Prospective	145	15	10.34%	-
(Beynnon et al., 2001)	7	Prospective	118	20	16.94%	-
(Willems et al., 2004)	4	Prospective	223	21	9.41%	72
(Mei-Dan et al., 2005)	5	Prospective	83	27	32.53%	16
(Willems et al., 2005a)	7	Prospective	159	32	20.12%	156
(Willems et al., 2005b)	7	Prospective	241	44	18.25%	156

Study	NOS score	Cohort	Sample size	LAS	Incidence (%)	Follow-up period (weeks)
(Witvrouw et al., 2006)	7	Prospective	100	28	28%	26
(Hadzic et al., 2009)	6	Prospective	38	12	31.57%	24
(Fousekis et al., 2012)	4	Prospective	100	17	17%	40
(Noronha et al., 2013)	4	Prospective	125	31	24.80%	52
(Attenborough et al., 2016)	5	Prospective	94	11	11.70%	-
(Henry et al., 2016)	6	Prospective	210	14	6.66%	-
(Rice et al., 2017)	7	Prospective	419	27	6.44%	32

3.3.2. Methodological Quality

Brief information about the methodological quality of the included studies according to their NOS rankings is presented in Table 3.2. The quality rankings of the 14 included studies are as follows:

- Five studies were rated as high quality under NOS, ranging from 7–9.
- Five studies were rated as moderate quality under NOS, ranging from 5–6.
- Four studies were rated as low quality under NOS, ranging from 2–4.

Table 3.2: Methodological quality of the included studies according to NOS

	Selection				**Comparability**		**Outcome**			**Total Quality**	
Author(s)	Represent selected cohort	Select non-exposed	Ascertain non-exposure	Outcome not available at the start	Important aspect	Additional aspect	Outcome assessment	Follow up 1 m/3 m.	Adequacy of follow-up >80%	Score	Quality
(Milgrom et al., 1991)	1	1	1	0	1	0	1	0	0	5	Moderate
(Baumhauer et al., 1995)	1	0	0	0	1	0	0	0	0	4	Low

(Beynnon et al., 2001)	1	1	1	1	1	1	1	0	0	7	High
(Willems et al., 2004)	1	1	0	0	0	0	1	1	0	4	Low
(Mei-Dan et al., 2005)	1	1	1	0	1	0	0	1	0	5	Moderate
(Willems et al., 2005a)	1	1	1	0	1	1	1	1	0	7	High
(Willems et al., 2005b)	1	1	1	0	1	1	1	1	0	7	High
(Witvrouw et al., 2006)	1	1	1	0	1	1	1	1	0	7	High

	Selection				Comparability		Outcome			Total Quality	
Author(s)	Represent selected cohort	Select non-exposed	Ascertain non-exposure	Outcome not available at the start	Important aspect	Additional aspect	Outcome assessment	Follow up 1 m/3 m.	Adequacy of follow-up >80%	Score	Quality
(Hadzic et al., 2009)	1	1	1	0	1	0	1	1	0	6	Moderate
(Fousekis et al., 2012)	1	1	0	0	0	0	1	1	0	4	Low
(De Noronha et al., 2013)	1	1	0	0	0	0	0	1	1	4	Low
(Henry et al., 2016)	1	1	1	0	1	1	1	0	0	6	Moderate
(Attenborough et al., 2017)	1	1	1	0	0	1	0	0	1	5	Moderate
(Rice et al., 2017)	1	1	1	0	1	1	1	1	0	7	High

3.3.3. Functional Details of the Selected Studies

Functional details of the selected studies, including the selected population, the tasks performed by the participants, the measurements taken to assess the participants and the outcomes, are shown in Table 3.3.

Table 3.3: Functional details of the selected studies

No.	Study	Population	Task	Measurements	Outcomes
1	(Milgrom et al., 1991)	390 male infantry recruits	- Sit-ups / 60 - Chin Ups - 2-km run - Walking	- Anthropometric measurement - Hip internal and external rotation - Thigh and calf circumference - Tibial length - Medial tibial intercondylar distance - Leg length discrepancy - Foot length, foot width - Isometric quadriceps strength at 85° of flexion - Isometric quadriceps strength - Foot type, arch height and hindfoot inclination	- Increase in quadriceps strength - Increase in medial tibial intercondylar distance - Increased external and internal hip joint rotation - Incidence of LAS linked to large body mass moment of inertia, previous history, gastrocnemius circumference, leg length, foot length and foot width of the recruits during training

No.	Study	Population	Task	Measurements	Outcomes
2	(Baumhauer et al., 1995)	145 college athletes (73 men, 72 women)	hockey, lacrosse or soccer	- Demographic information - Ankle ligament stability - Ligamentous stability of the ankle by anterior drawer and talar tilt tests - Isokinetic ankle strength - Anatomic foot and ankle alignment using a goniometer - Generalised joint laxity (Beighton method)	- Lower eversion to inversion anatomic ratio - Higher subtalar inversion range of motion (ROM) - Reduced dorsiflexion to plantarflexion strength - No significant differences in demographic variables - No significant differences in generalised joint laxity - No significant differences in ankle strength
3	(Beynnon et al., 2001)	118 college athletes (male-to-female ratio)	soccer, lacrosse or field hockey	- Demographic information - Ankle joint laxity (Beighton method) Foot and ankle alignment without weightbearing by a goniometer, as well as with weightbearing, during standing using the criterion reported by Dahle et al. (1991) - Isokinetic ankle strength - Centre of gravity (CoG) - Muscle reaction times by electromyography (EMG)	- No differences in limb dominance, generalised joint laxity, anatomic foot type and CoG - No difference in response time dorsiflexion, inversion, gastrocnemius, anterior tibialis and peroneal longus - Lower isokinetic strength - Increased calcaneal inversion in women - Enlarged tibial varus in women - Higher extension ROM at the metatarsophalangeal joints (MTPJ)

No.	Study	Population	Task	Measurements	Outcomes
4	(Willems et al., 2004)	223 PE students	Stance phase during running	- Foot scan (Plantar pressure) - 3D kinematic lower leg alignment data	- No significant differences in peak pressure underneath - Increase in total contact time - Higher eversion excursion of the rearfoot - Medially directed pressure at first metatarsal contact, forefoot flat and heel off - At the last foot contact, the X-component of the centre of pressure (CoP) is located more laterally - Delay in kinematic maximal inversion velocity and knee flexion velocity - Higher extension ROM at the first MTPJ
5	(Willems et al., 2005a)	159 female PE students	Walking	- Anthropometric measurement - Ankle joint position sense - Concentric ankle muscle strength - Lower limb alignment using a goniometer - Postural control - Ankle muscle reaction time	- No significant differences in anthropometric measurements - Lower passive joint position sense - Increased dorsiflexion muscle strength - Higher extension ROM at the first MTPJ - Reduction in limits of stability (LOS) endpoint excursion - Reduction in LOS maximal endpoint excursion - No difference in muscle reaction time

No.	Study	Population	Task	Measurements	Outcomes
6	(Willems et al., 2005b)	241 male PE students	Jumping Running	- Anthropometric measurements - Functional motor performance using a flamingo balance test and endurance shuttle run - Ankle joint position sense - Isokinetic ankle muscle strength - Leg alignment using a goniometer - Postural control using a Neurocom balance master - Ankle muscle reaction time	- No significant differences in anthropometric measurements - Poorer scores on a flamingo balance test - Reduced cardiorespiratory endurance and slower running speeds - Lower concentric dorsiflexion muscle strength - Reduced directional control - Higher extension ROM at the first MTPJ - Decreased reaction time in the tibialis anterior muscle and the gastrocnemius muscle - No significant differences in joint position sense
7	(Mei-Dan et al., 2005b)	83 female infantry recruits	Basic training	- Anthropometric measurements - Longitudinal arch from footprint using a Harris mat device	- Low arch increases the susceptibility to ankle sprains
8	(Witvrouw et al., 2006b)	200 PE students		- Palpation technique for the peroneus tertius muscle - Isokinetic ankle muscle strength	- Absence of peroneus tertius muscle is not a predictor for ankle sprain - No difference in eccentric and concentric isokinetic eversion and strength of concentric dorsiflexion

No.	Study	Population	Task	Measurements	Outcomes
9	(Hadzic et al., 2009)	38 professional male volleyball players	5 minutes warm-up on a cyclo-egometer 20-sec stretch of plantar and dorsiflexors	- Bilateral ankle plantarflexion and dorsiflexion strength - Ankle ROM	- Lower ROM of dorsiflexion and higher strength of plantarflexion are risk factors for ankle sprain - Lower range of dorsiflexion limits the ability for a safe landing after a jump
10	(Fousekis et al., 2012)	100 male professional soccer players	Playing soccer	- Anthropometric measurements - Isokinetic muscle strength (dorsi/plantar) - Flexibility or ROM using a goniometer - Joint stability (anterior drawer test) - Neuromuscular coordination (proprioception) - Previous history - Lower limb asymmetry	- Increased eccentric isokinetic ankle - Increased body mass index (BMI) - Lower limb length asymmetry - Anterior laxity and flexibility for ankle joint - Incorrect foot positioning during landing - Isokinetic muscle strength asymmetries of ankle dorsal and plantarflexors
11	(De Noronha et al., 2013)	125 college athletes	None	- Anthropometric measurements - Foot lift test for balance - Dorsiflexion ROM measured by weight-bearing lunge - Star excursion balance test (SEBT) - Side recognition task by motor imagery - LAS history	- Lower SEBT PL performance - LAS history is a factor - No differences in other tests

No.	Study	Population	Task	Measurements	Outcomes
12	(Attenborough et al., 2016)	94 female netball players	vertical jump (VJ) height	- Postural control (static, dynamic) - Muscle power via assessed VJ using either a Vertec VJ device (Sports Imports, Hilliard, USA) or a belt mat device (Sport Books Publisher, Toronto, Canada) - Ankle joint laxity - Perceived ankle instability by CAIT - Previous history	- Lower SEBT PL performance - High number of foot lifts during a unilateral stance - Poor scores in a demi-pointe balance test
13	(Henry et al., 2016)	210 male amateur soccer players	Vertical jump	- Dorsiflexion lunge test - Dynamic lower limb stability by 10-degree incline squat - Lower limb relative power output during (SCMJs) - Double-leg balance using a computer-interfaced wobble board (KMS)	- Reduced power output in the lower limbs - Poorer double-leg balance scores - No other significant risk factors found
14	(Rice et al., 2017)	1,065 injury-free male recruits	Running	- Bilateral plantar pressure - Three-dimensional (3D) lower limb kinematics - Bimalleolar width	- Reduced width and smaller calf girth linked with those who had lower BMI - Earlier time for peak foot pressure under the fifth metatarsal - Frontal plane rearfoot kinematic variables are not predictive of LAS

3.3.4. Statistical Analysis of Risk Factors

All the included studies were investigated to identify the associated risk factors of LAS. The standard mean difference (SMD), p-value, heterogeneity (I^2) and effect size (Z score) were analysed from forest plots.

The SMD in a meta-analysis forest plot is a measure of the difference between two groups' means, expressed in standard deviation units. It indicates the size of the effect of the intervention or exposure being studied on the outcome measure. A positive SMD indicates that the intervention/exposure leads to higher scores on the outcome measure compared with the control group, while a negative SMD indicates the opposite. The magnitude of the SMD can be interpreted using effect size guidelines, such as Cohen's d, where a value of 0.2 is considered a small effect size, 0.5 is a moderate effect size and 0.8 or higher is a large effect size.

Heterogeneity refers to the degree of variability in effect sizes across studies. A high level of heterogeneity suggests that the studies are not all measuring the same thing or that there are differences in study design, population characteristics or other factors that affect the treatment effect. Heterogeneity can be quantified using the I^2 statistic, which represents the proportion of total variation in effect sizes due to heterogeneity rather than chance.

Interpreting I^2 can be somewhat subjective, but generally, an I^2 value less than 25% indicates low heterogeneity, 25% to 50% indicates moderate heterogeneity and over 50% indicates high heterogeneity. The absence of heterogeneity, denoted by a value of 0%, in the injured and uninjured groups suggests no variation in effect size estimates between the two groups (Higgins & Thompson, 2002). If heterogeneity is high, it may be necessary to explore potential sources of variation and consider subgroup analyses or sensitivity analyses to determine if the overall effect size is robust to these factors.

The overall effect size is typically accompanied by a confidence interval (CI), which provides a range of values within which the true effect size is expected to lie with a certain level of probability. A narrow CI indicates greater precision and reliability of the estimate. In this review was used 95% CI. The Z score estimates the effect size as it is a standardised score that reflects how many standard deviations the effect size is from the null hypothesis. The Z score associated with the SMD is used to determine the statistical significance of the effect, where a Z score greater than 1.96 (corresponding to a p-value of 0.05 or less) indicates that the effect is statistically significant, which means it is unlikely to have occurred by chance alone.

Details of the identified risk factors from the included literature are given below.

3.3.4.1. Anthropometric and demographic characteristics

Body mass

According to the systematic review, body mass was a factor in nine studies. Among these studies, four (Beynnon et al., 2001; Willems et al., 2005a; Willems et al., 2005b; Rice et al., 2017) were rated as high quality with an NOS score of 7, three (Milgrom et al., 1991; Baumhauer et al., 1995; Attenborough et al., 2016) were rated as moderate quality with an NOS score of 5 and two (Noronha et al., 2013; Fousekis et al., 2012) were rated as low quality with an NOS score of 4. The results of the studies were as follows:

- The studies exhibited greater heterogeneity in the injury outcomes among male participants, with a value of 81%, whereas no heterogeneity (0%) was observed in the injury outcomes among female participants. The overall analysis of the studies showed 66% heterogeneity (Figure 3.2).

- In male participants, the injured group exhibited a statistically significant increase in body mass compared with the uninjured group, with an SMD of 0.20 (95% CI: 0.04–0.36) and a Z score of 0.24 (p = 0.02), as presented in Figure 3.2.
- In females, there was no significant difference in body mass between the injured and uninjured groups, as indicated by an SMD of 0.02 (95% CI: -0.29–0.25) and a Z score of 0.13 (p > 0.05), as shown in Figure 3.2.
- In general, the injured group showed a statistically significant higher body mass compared with the uninjured group, with an SMD of 0.14 (95% CI: 0.01–0.21) and a Z score of 0.68 (p = 0.03), as illustrated in Figure 3.2.

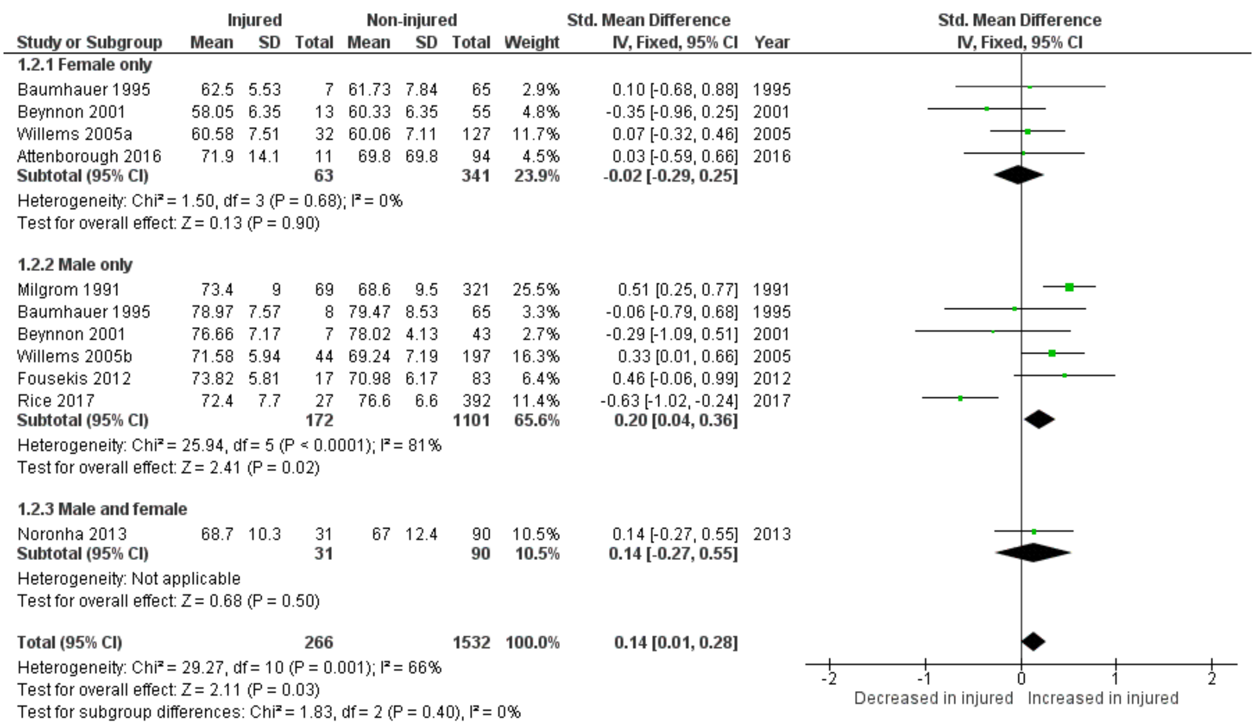


Figure 3.2: Forest plot: Association between ankle sprain and body mass

Body mass index (BMI)

In the systematic review, it was found that BMI was examined as a risk factor in five studies. Rice et al.'s (2017) study was rated as high quality with an NOS score of 7, while the other four studies (Willems et al., 2005a, 2005b; Fousekis et al., 2012; Noronha et al., 2013) were rated as low quality with an NOS score of 4. The results of these studies are as follows:

- The studies displayed a higher degree of heterogeneity (89%) in the injury outcomes observed among male participants, while heterogeneity was not applicable to the injury outcomes in female participants.
- In male participants, the meta-analysis indicated a non-significant difference in BMI between the injured and uninjured groups, as demonstrated by an SMD of 0.09 (95% CI: -0.14–0.31) and a Z score of 0.74 ($p > 0.05$) (refer to Figure 3.3).
- Regarding females, only one study provided data on BMI and reported no significant difference between the injured and uninjured groups, with an SMD of 0.13 (95% CI: 0.26–0.52) and a Z score of 0.66 ($p > 0.05$), as depicted in Figure 3.3.
- The overall analysis showed no statistically significant difference in BMI between the injured and uninjured groups, with an SMD of 0.12 (95% CI: -0.02–0.33) and a corresponding Z score of 1.69 ($p > 0.05$).

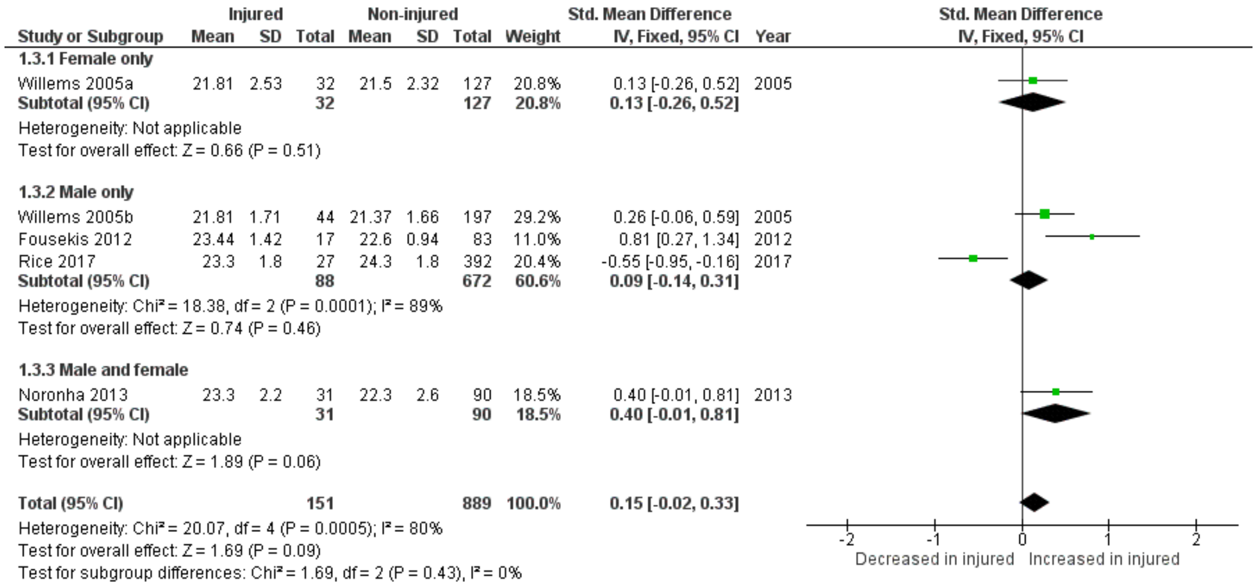


Figure 3.3: Forest plot: Association between ankle sprain and body mass index (BMI)

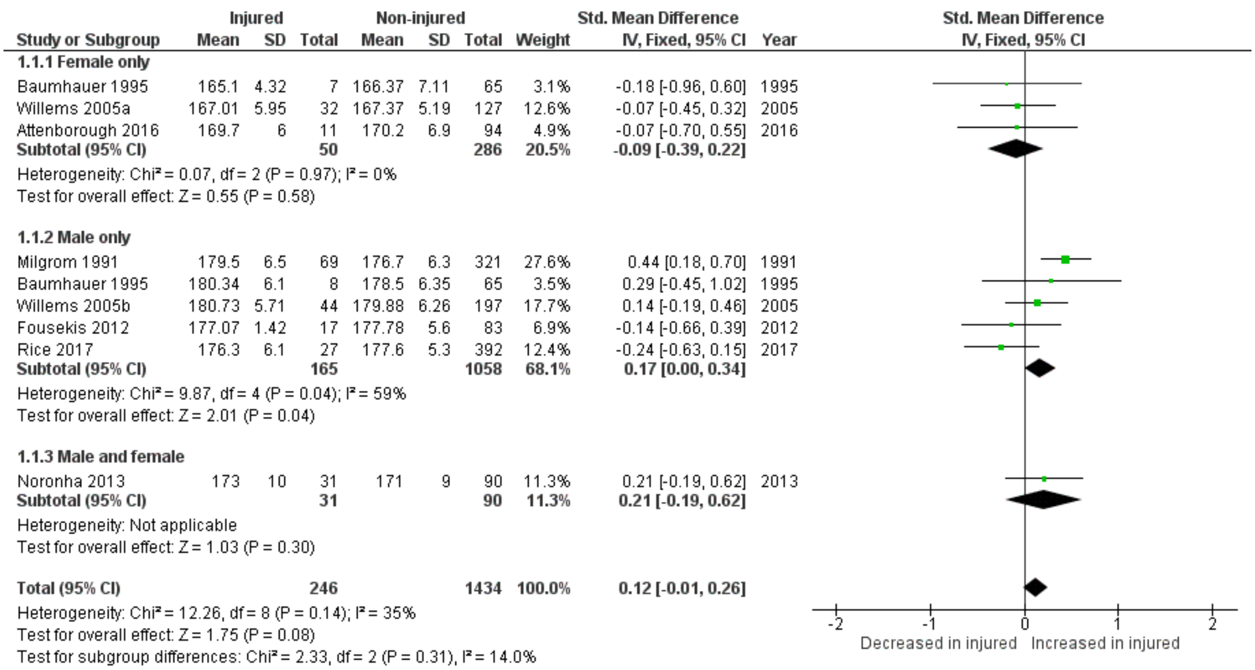
Height

A systematic review examined eight studies to determine if height is a potential risk factor for injury. Among these studies, three (Willems et al., 2005a; Willems et al., 2005b; Rice et al., 2017) were considered high quality with an NOS score of 7. Three studies (Milgrom et al., 1991; Baumhauer et al., 1995; Attenborough et al., 2016) were rated as moderate quality with an NOS score of 5. Two studies (Noronha et al., 2013; Fousekis et al., 2012) were rated as low quality with an NOS score of 4.

The studies found the following results regarding height as a possible risk factor:

- The male participants' outcome exhibited a 59% level of heterogeneity, whereas the female participants showed no heterogeneity (0%). The overall analysis of all the studies indicated a heterogeneity level of 14%, as shown in Figure 3.4.

- In the male injured group, a moderate statistically significant difference in height was observed compared with the uninjured group, with an SMD of 0.17 (95% CI: 0.00 to 0.34) and a Z score of 2.01 (p = 0.04), as illustrated in Figure 3.4.
- The forest plot in Figure 3.4 showed no significant difference in height between the injured and uninjured female groups, with an SMD of 0.09 (95% CI: -0.39–0.22) and a Z score of 0.55 (p > 0.05).
- The pooled analysis revealed no significant difference between the injured and uninjured groups, with an SMD) of 0.12 (95% CI: -0.01–0.26) and a Z score of 1.75 (p > 0.05), as shown in Figure 3.4.



Study or Subgroup	Injured Mean	Injured SD	Injured Total	Non-injured Mean	Non-injured SD	Non-injured Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
1.1.1 Female only									
Baumhauer 1995	165.1	4.32	7	166.37	7.11	65	3.1%	-0.18 [-0.96, 0.60]	1995
Willems 2005a	167.01	5.95	32	167.37	5.19	127	12.6%	-0.07 [-0.45, 0.32]	2005
Attenborough 2016	169.7	6	11	170.2	6.9	94	4.9%	-0.07 [-0.70, 0.55]	2016
Subtotal (95% CI)			**50**			**286**	**20.5%**	**-0.09 [-0.39, 0.22]**	
Heterogeneity: Chi² = 0.07, df = 2 (P = 0.97); I² = 0%									
Test for overall effect: Z = 0.55 (P = 0.58)									
1.1.2 Male only									
Milgrom 1991	179.5	6.5	69	176.7	6.3	321	27.6%	0.44 [0.18, 0.70]	1991
Baumhauer 1995	180.34	6.1	8	178.5	6.35	65	3.5%	0.29 [-0.45, 1.02]	1995
Willems 2005b	180.73	5.71	44	179.88	6.26	197	17.7%	0.14 [-0.19, 0.46]	2005
Fousekis 2012	177.07	1.42	17	177.78	5.6	83	6.9%	-0.14 [-0.66, 0.39]	2012
Rice 2017	176.3	6.1	27	177.6	5.3	392	12.4%	-0.24 [-0.63, 0.15]	2017
Subtotal (95% CI)			**165**			**1058**	**68.1%**	**0.17 [0.00, 0.34]**	
Heterogeneity: Chi² = 9.87, df = 4 (P = 0.04); I² = 59%									
Test for overall effect: Z = 2.01 (P = 0.04)									
1.1.3 Male and female									
Noronha 2013	173	10	31	171	9	90	11.3%	0.21 [-0.19, 0.62]	2013
Subtotal (95% CI)			**31**			**90**	**11.3%**	**0.21 [-0.19, 0.62]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 1.03 (P = 0.30)									
Total (95% CI)			**246**			**1434**	**100.0%**	**0.12 [-0.01, 0.26]**	
Heterogeneity: Chi² = 12.26, df = 8 (P = 0.14); I² = 35%									
Test for overall effect: Z = 1.75 (P = 0.08)									
Test for subgroup differences: Chi² = 2.33, df = 2 (P = 0.31), I² = 14.0%									

Figure 3.4: Forest plot: Association between ankle sprain and height

Leg dominance

According to the systematic review, there was no significant distinction detected in leg dominance between the groups that had sustained injuries and those that had not.

Previous history

The studies investigating the association between a prior history of LAS were not in agreement. Milgrom et al. (1991), Baumhauer et al. (1995) and Noronha et al. (2013) concluded that a previous history of LAS could predict future LAS, whereas Attenborough et al. (2016) and Henry et al. (2016) found no correlation between a prior history of LAS and the risk of LAS.

3.3.4.2. Muscle weakness

The suspected risk factors for LAS, including concentric dorsiflexion, concentric plantarflexion, concentric eversion, concentric inversion, eccentric eversion and eccentric inversion at 30° and 120°, were examined in Willems et al. (2005a) and Willems et al. (2005b), two high-quality studies with an NOS 7 rating. Beynnon et al. (2001) conducted high-quality research with an NOS 7 rating, examining concentric and eccentric muscle strength (dorsiflexion, plantarflexion, eversion and inversion) at a neutral angle. Hadzic et al. (2009) also evaluated concentric dorsiflexion at a neutral angle as a risk factor, with a moderate-quality rating of NOS 6.

Concentric dorsiflexion at 30°

- Only one study (Willems et al., 2005b) reported concentric dorsiflexion at 30°; thus, heterogeneity is not applicable.
- The male participants in the injured group showed significantly lower concentric dorsiflexion strength than the uninjured group, with an SMD of -0.66 (95% CI: -0.87 to -0.09) and a Z score of 3.91 ($p < 0.01$) (Figure 3.5).

- Similarly, in Willems et al. (2005a), the female participants in the injured group also had significantly lower strength of concentric dorsiflexion, with an SMD of -0.48 (95% CI: 0.87–0.09) and a Z score of 2.41 (p = 0.02) (Figure 3.5).
- Overall, the meta-analysis showed that the injured group had lower concentric dorsiflexion strength compared with the uninjured group, with an SMD of -0.59 (95% CI: -0.84–0.33) and a Z score of 4.54 (p < 0.01) (Figure 3.5).

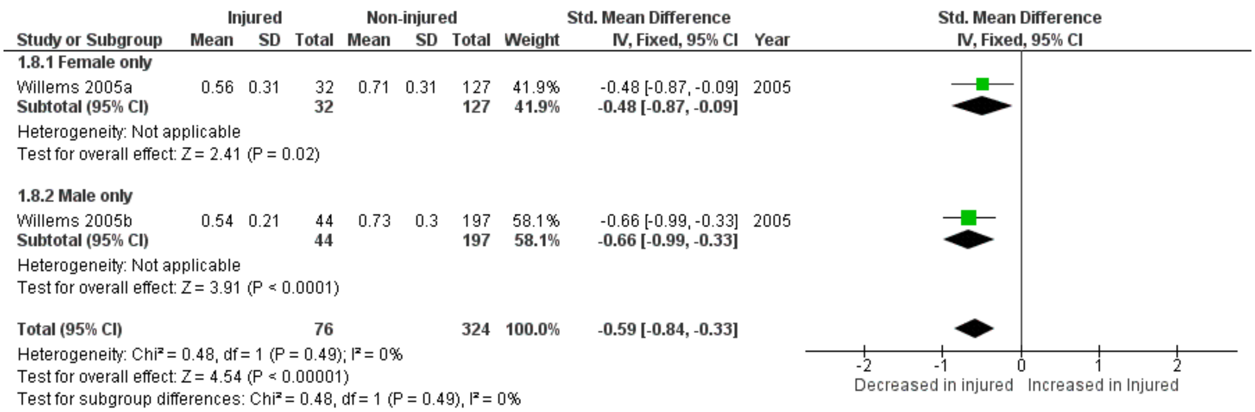


Figure 3.5: Association between ankle sprain and concentric dorsiflexion at 30°

Concentric dorsiflexion at 120°

- Given that only the study by Willems et al. (2005b) assessed concentric dorsiflexion at 120°, heterogeneity was not applicable, as depicted in Figure 3.6.
- There was no significant difference observed in concentric dorsiflexion strength at 120° among males, with an SMD of 0.09 (95% CI: -0.24–0.42) and a Z score of 0.55 (p > 0.05).
- In females, Willems et al. (2005a) found no significant difference, with an SMD of 0.25 (95% CI: -0.13–0.64) and a Z score of 1.28 (p > 0.05).

- The overall forest plot indicated no significant difference in concentric dorsiflexion strength at 120°, with an SMD of 0.16 (95% CI: -0.09–0.41) and a Z score of 1.25 ($p > 0.05$), as shown in Figure 3.6.

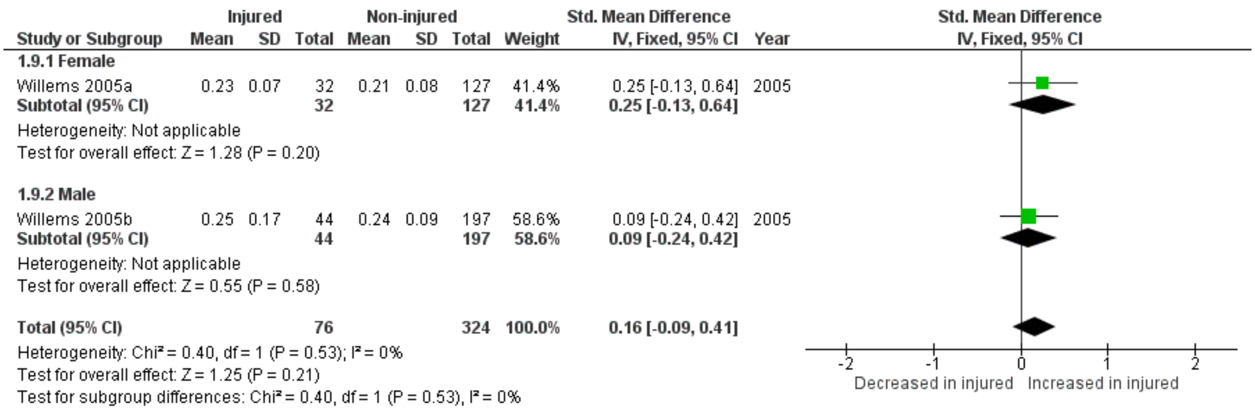


Figure 3.6: Forest plot: Association between ankle sprain and concentric dorsiflexion at 120º

Concentric dorsiflexion at a neutral angle

- The estimation of heterogeneity was not applicable for concentric dorsiflexion strength at the neutral angle, as only one study was included (Figure 3.7).
- There was no significant difference in concentric dorsiflexion strength at a neutral angle between the injured and uninjured males, with an SMD of 0.03 (95% CI: -0.48–0.55) and a Z score of 0.13 ($p > 0.05$).
- Similarly, there was no significant difference among females, with an SMD of –0.02 (95% CI: -0.63–0.58) and a Z score of 0.08 ($p > 0.05$), as shown in Figure 3.7.
- Overall, the analysis did not reveal a significant difference in concentric dorsiflexion strength at a neutral angle between the injured and uninjured groups,

with an SMD of 0.01 (95% CI: -0.38–0.40) and a Z score of 0.05 (p > 0.05) (Figure 3.7).

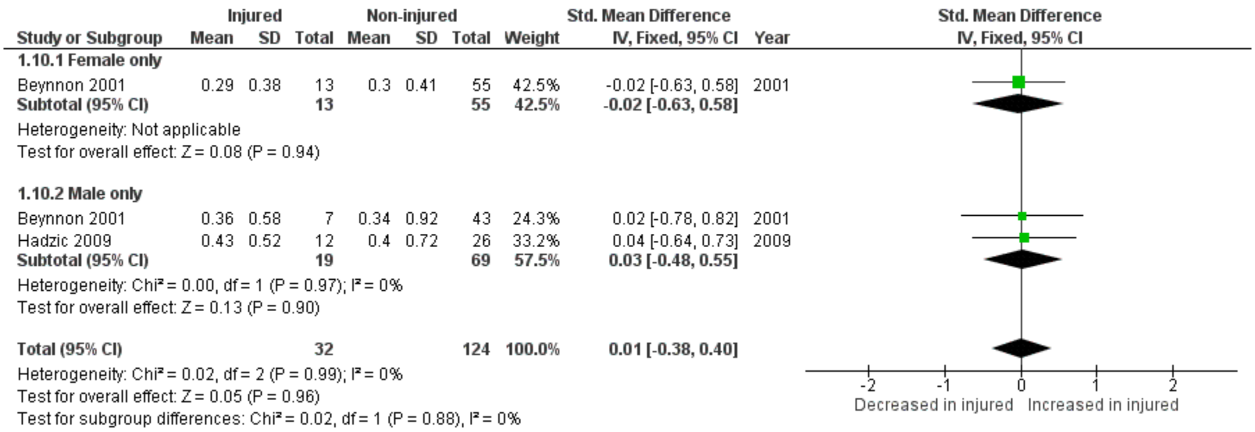


Figure 3.7: Forest plot: Association between ankle sprain and concentric dorsiflexion at a neutral angle

Concentric plantarflexion at 30°

- Heterogeneity was not applicable.
- The male participants in Willems et al. (2005b) demonstrated a lower strength of concentric plantarflexion at 30° compared with the uninjured group, with an SMD of -0.40 (95% CI: -0.73 to -0.07) and a Z score of 2.37 (p = 0.02) (Figure 3.8).
- In females, Willems et al. (2005a) found no significant difference between the injured and uninjured groups, as indicated in Figure 3.8.
- Overall, a trend towards lower plantarflexion strength at 30° was observed in the injured participants, with an SMD of -0.30 (95% CI: -0.55 to -0.05) and a Z score of 2.32 (p = 0.02) (Figure 3.8).

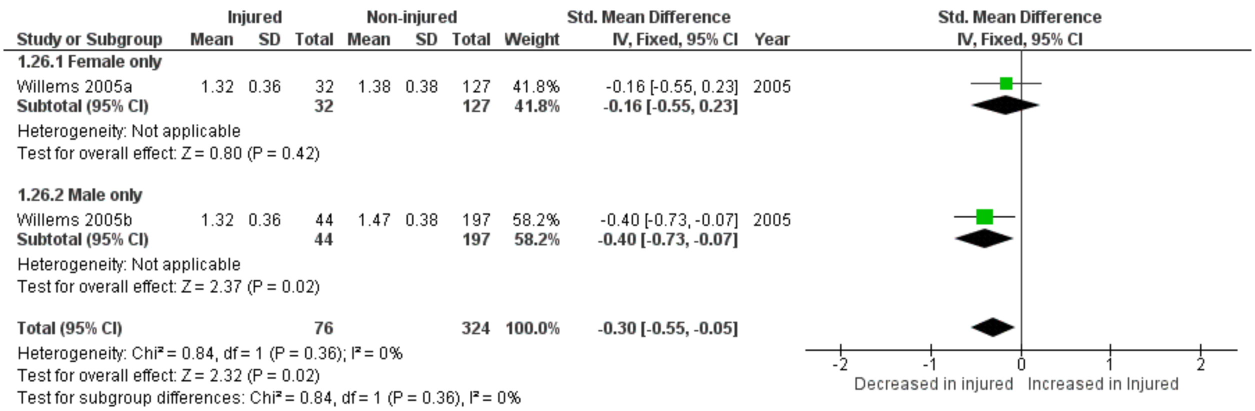


Figure 3.8: Forest plot: Association between ankle sprain and concentric plantarflexion muscle strength at 30°

Concentric plantarflexion at 120°

- Heterogeneity was not applicable.
- For the males, Willems et al. (2005b) indicated that the injured group showed significantly stronger muscle strength at 120° compared with the uninjured group, with an SMD of 0.34 (95% CI: 0.01–0.66) and a Z score of 2 ($p = 0.05$), as depicted in Figure 3.9.
- In females, Willems et al. (2005a) exhibited that the injured group also demonstrated significantly higher muscle strength of plantarflexors at 120° compared with the uninjured group, with an SMD of 0.43 (95% CI: 0.04–0.82) and a Z score of 2.15 ($p = 0.03$).
- Overall, the injured group showed a significant increase in the strength of plantarflexors compared with the uninjured group, with an SMD of 0.37 (95% CI: 0.12–0.62) and a Z score of 2.91 ($p < 0.01$), as shown in Figure 3.9.

Study or Subgroup	Injured Mean	Injured SD	Injured Total	Non-injured Mean	Non-injured SD	Non-injured Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
1.27.1 Female									
Willems 2005a	0.63	0.23	32	0.51	0.29	127	41.4%	0.43 [0.04, 0.82]	2005
Subtotal (95% CI)			**32**			**127**	**41.4%**	**0.43 [0.04, 0.82]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 2.15 (P = 0.03)									
1.27.2 Male									
Willems 2005b	0.65	0.3	44	0.56	0.26	197	58.6%	0.34 [0.01, 0.66]	2005
Subtotal (95% CI)			**44**			**197**	**58.6%**	**0.34 [0.01, 0.66]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 2.00 (P = 0.05)									
Total (95% CI)			**76**			**324**	**100.0%**	**0.37 [0.12, 0.62]**	
Heterogeneity: Chi² = 0.13, df = 1 (P = 0.72); I² = 0%									
Test for overall effect: Z = 2.91 (P = 0.004)									
Test for subgroup differences: Chi² = 0.13, df = 1 (P = 0.72), I² = 0%									

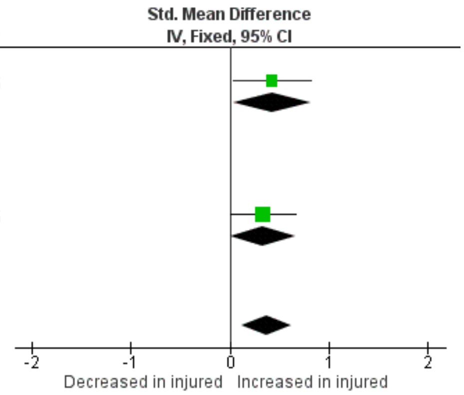


Figure 3.9: Forest plot: Association between ankle sprain and concentric plantarflexion muscle strength at 120°

Concentric plantar flexion at a neutral angle

- Heterogeneity was not applicable.
- There was no significant difference in muscle strength for concentric plantarflexion at a neutral angle between the injured and uninjured groups in both males and females, as indicated by a low Z score and $p > 0.05$ in Figure 3.10.

Study or Subgroup	Injured Mean	Injured SD	Injured Total	Non-injured Mean	Non-injured SD	Non-injured Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Year
1.28.1 Female									
Beynnon 2001	0.9	1.93	13	0.88	1.78	55	63.6%	0.01 [-0.59, 0.62]	2001
Subtotal (95% CI)			**13**			**55**	**63.6%**	**0.01 [-0.59, 0.62]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.04 (P = 0.97)									
1.28.2 Male									
Beynnon 2001	1.1	1.81	7	0.92	3.32	43	36.4%	0.06 [-0.74, 0.85]	2001
Subtotal (95% CI)			**7**			**43**	**36.4%**	**0.06 [-0.74, 0.85]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.14 (P = 0.89)									
Total (95% CI)			**20**			**98**	**100.0%**	**0.03 [-0.45, 0.51]**	
Heterogeneity: Chi² = 0.01, df = 1 (P = 0.93); I² = 0%									
Test for overall effect: Z = 0.11 (P = 0.91)									
Test for subgroup differences: Chi² = 0.01, df = 1 (P = 0.93), I² = 0%									

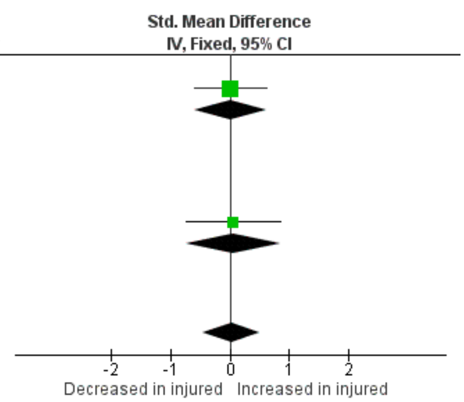


Figure 3.10: Forest plot: Association between ankle sprain and concentric plantar flexion at a neutral angle

Concentric eversion at 30°, 120° and a neutral angle

The results indicated no significant difference in concentric eversion strength between the injured and uninjured groups for both males and females at 30° (Figure 3.11), 120° (Figure 3.12) and at a neutral ankle angle (Figure 3.13), as evidenced by the low Z scores and p-values greater than 0.05.

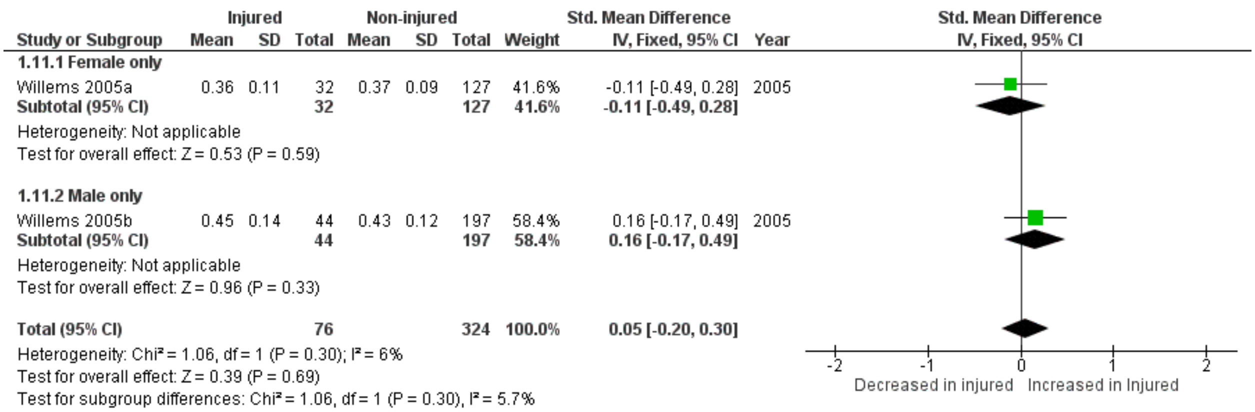


Figure 3.11: Forest plot: Association between ankle sprain and concentric eversion at 30°

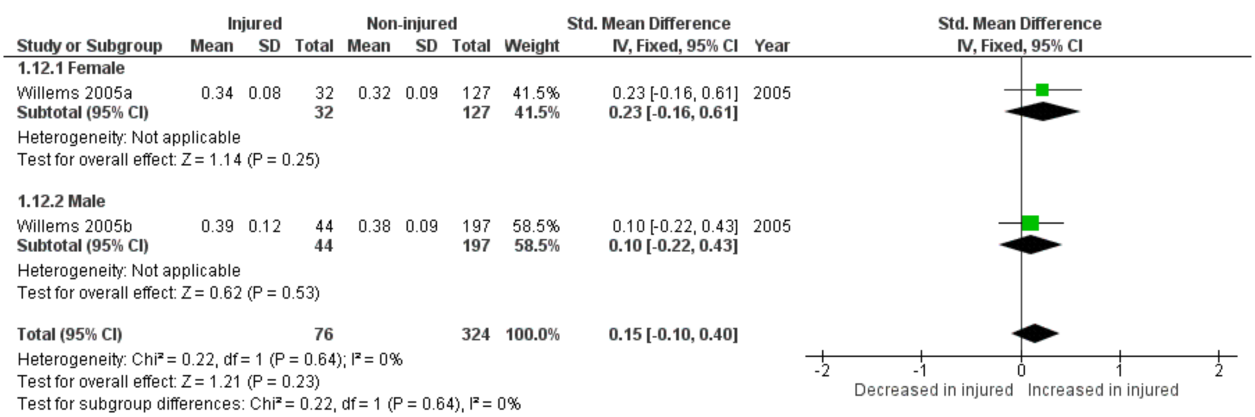


Figure 3.12: Forest plot: Association between ankle sprain and concentric eversion at 120°

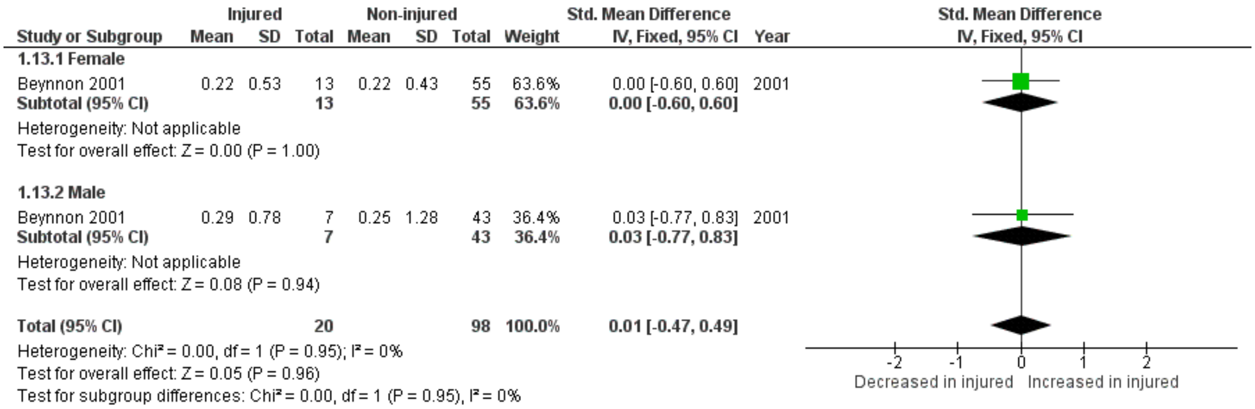


Figure 3.13: Forest plot: Association between ankle sprain and concentric eversion at a neutral angle

Eccentric eversion at 30°, 120° and a neutral angle

Overall, no significant difference was observed between the injured and uninjured groups in eversion at 30° (Figure 3.14), 120° (Figure 3.15) and at a neutral angle (Figure 3.16) in both males and females.

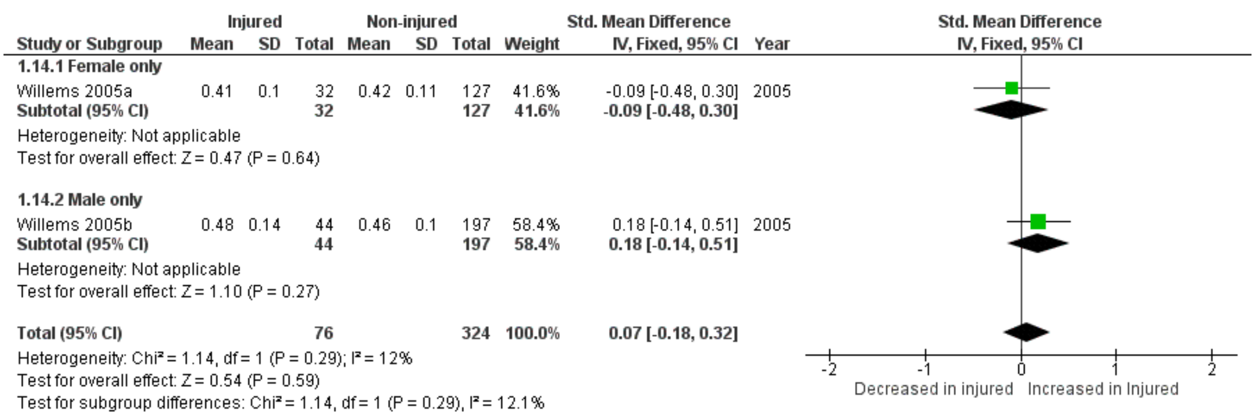


Figure 3.14: Forest plot: Association between ankle sprain and eccentric eversion at 30°

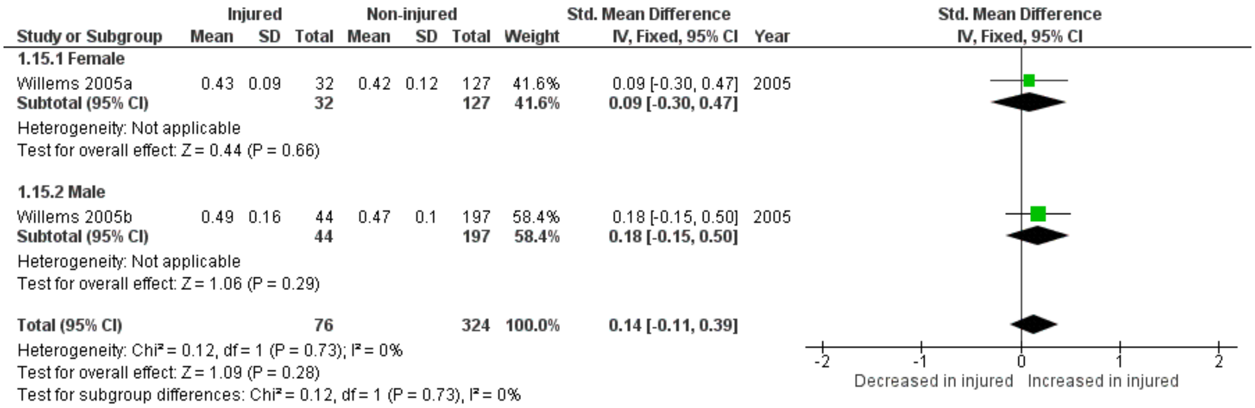


Figure 3.15: Forest plot: Association between ankle sprain and eccentric eversion at 120°

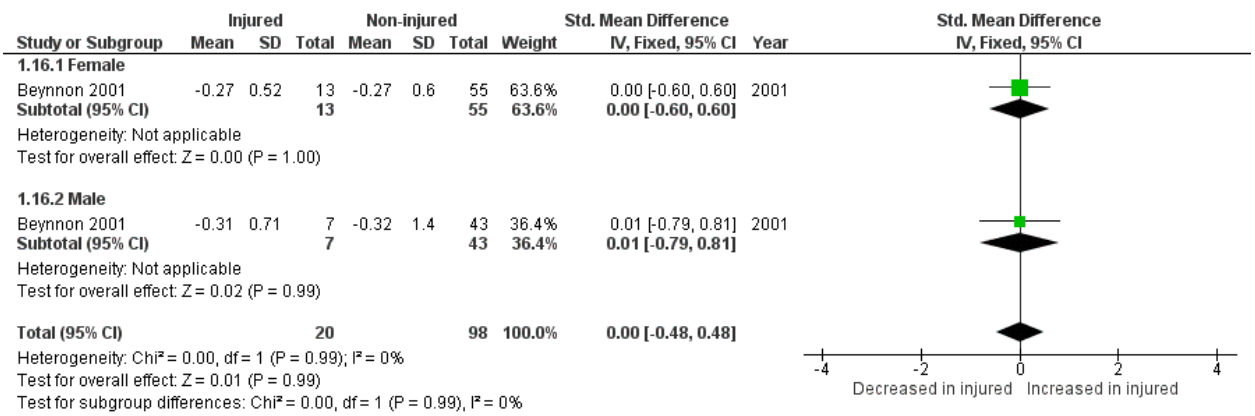


Figure 3.16: Forest plot: Association between ankle sprain and eccentric eversion at a neutral angle

Concentric inversion at 30°, 120° and a neutral angle

Overall, there was no significant difference observed between the injured and uninjured groups in inversion at 30° (Figure 3.17), 120° (Figure 3.18) and at a neutral angle (Figure 3.19) in both males and females.

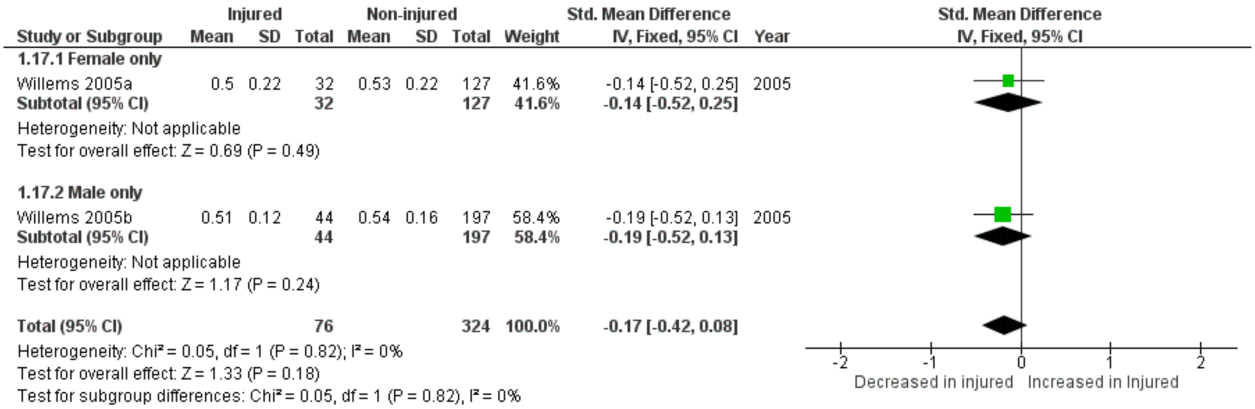


Figure 3.17: Forest plot: Association between ankle sprain and concentric inversion at 30°

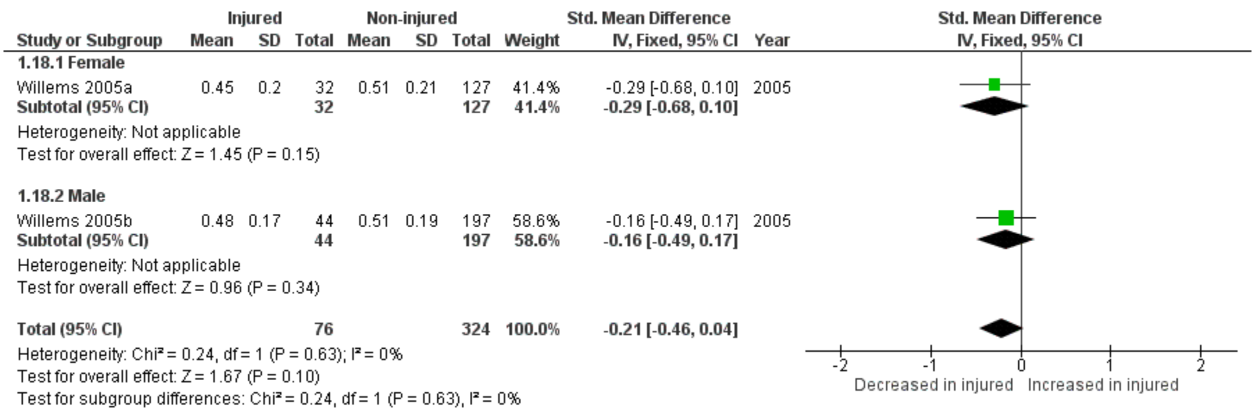


Figure 3.18: Forest plot: Association between ankle sprain and concentric inversion at 120°

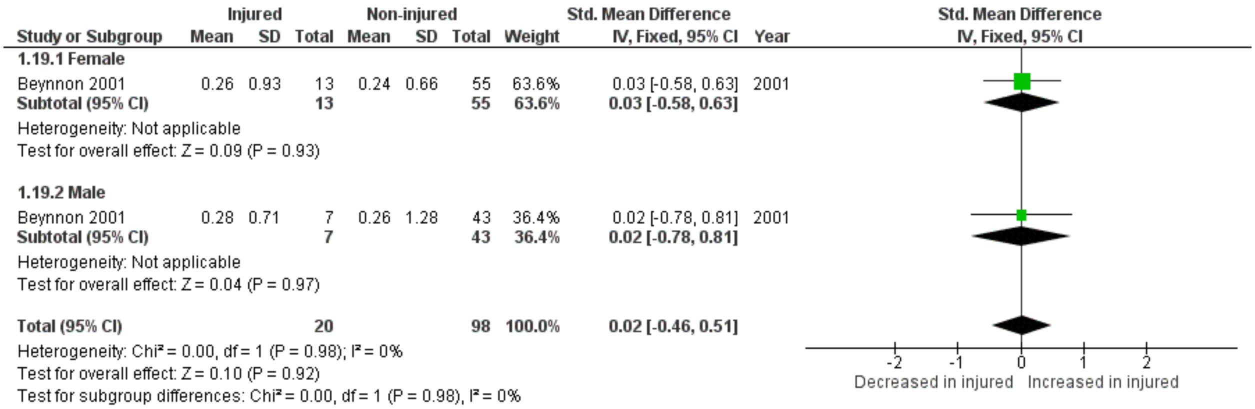


Figure 3.19: Forest plot: Association between ankle sprain and concentric inversion at a neutral angle

Eccentric inversion at 30°, 120° and a neutral angle

There was no significant difference observed in eccentric inversion at 30° (Figure 3.20), 120° (Figure 3.21) and at a neutral angle (Figure 3.22) between the injured and uninjured groups in both males and females.

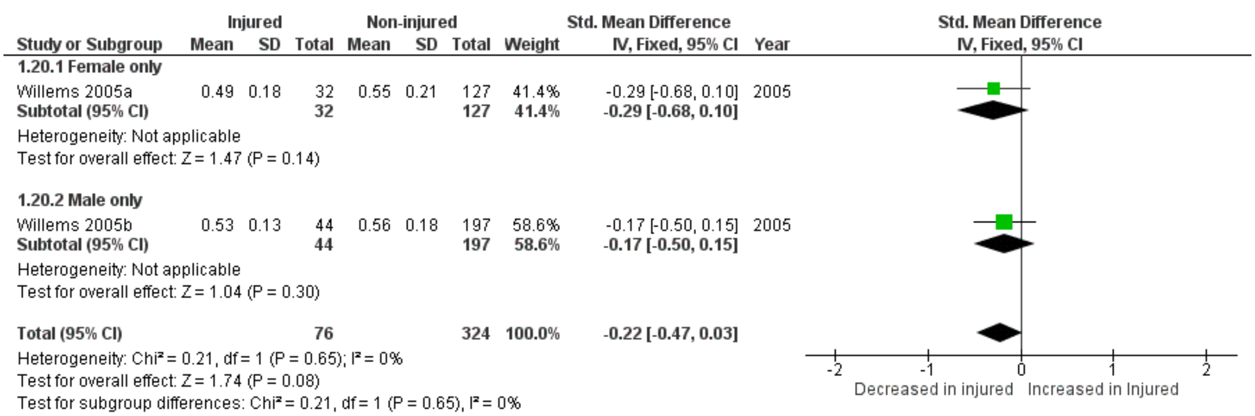


Figure 3.20: Forest plot: Association between ankle sprain and eccentric inversion at 30°

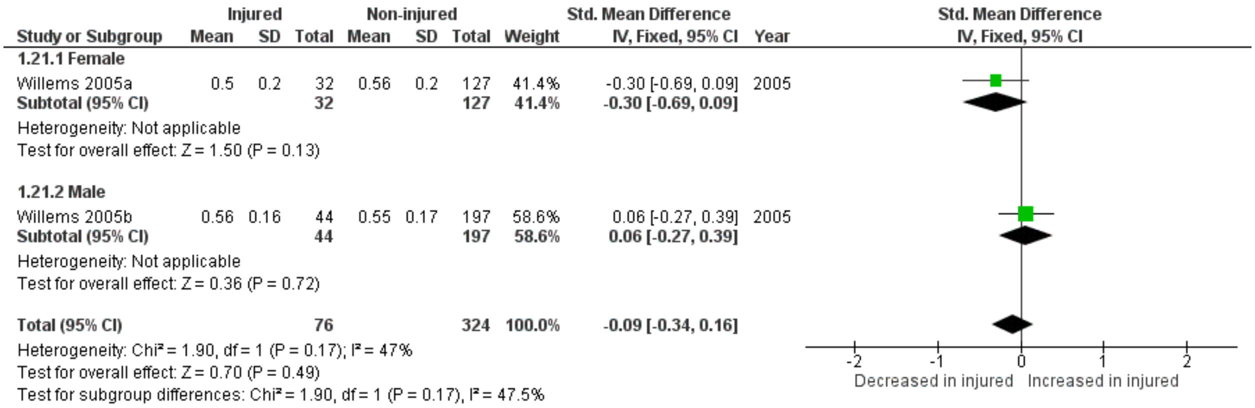


Figure 3.21: Forest plot: Association between ankle sprain and eccentric inversion at 120°

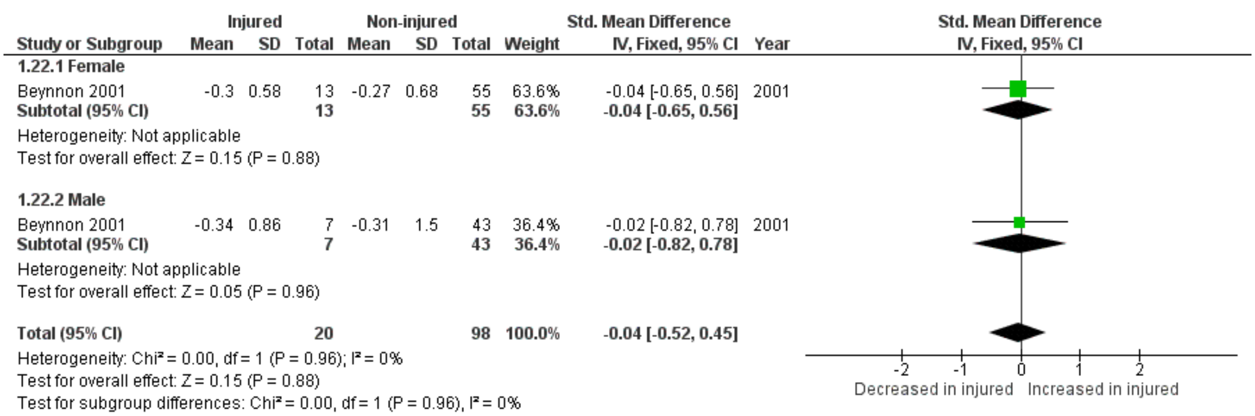


Figure 3. 22: Forest plot: Association between ankle sprain and eccentric inversion at a neutral angle

3.3.4.3. Range of motion (ROM)

ROM as a risk factor for LAS was examined in five studies, among which three were classified as high quality with an NOS score of 7, one was rated as moderate quality and one was classified as low quality. The high-quality studies were conducted by Beynnon et al. (2001), Willems et al. (2005a) and Willems et al. (2005b). The study by Hadzic et al. (2009) was of moderate quality, while Baumhauer et al. (1995) conducted the low-quality study. Below are the results from these studies.

- A total of 14 studies were reviewed in relation to ankle inversion and eversion, out of which only five examined the role of ROM in various anatomical positions. These studies were conducted by Baumhauer et al. (1995), Beynnon et al. (2001), Willems et al. (2005a), Willems et al. (2005b) and Hadzic et al. (2009). Baumhauer et al. (1995) reported a statistically significant difference between the injured and uninjured groups in subtalar inversion ROM and LAS ($p = 0.04$), as well as a statistically significant difference in the ratio of anatomical eversion to inversion ($p = 0.03$). The average anatomical ratio for the injured group's eversion to inversion (0.424) was lower than the average anatomical ratio.
- Ankle dorsiflexion with an extended knee: Heterogeneity was observed in male outcomes at 23% ($p > 0.05$), whereas no heterogeneity was observed for females ($p > 0.05$). The injured male groups showed lower ankle dorsiflexion with the knee extended compared with the uninjured groups, with an SMD of -0.39 (CI: -0.7 to -0.09) and a Z score of 2.52 ($p = 0.01$). However, no statistical difference was observed in the female group (Figure 3.23).

- Ankle dorsiflexion with a flexed knee: In the assessment of ankle dorsiflexion ROM with a flexed knee, no significant statistical difference was observed between the injured and uninjured groups in both males and females, as illustrated in Figure 3.24.

	Injured			Non-injured				Std. Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Fixed, 95% CI**	**Year**
1.6.1 Female only									
Beynnon 2001	5.3	1.8	13	4.9	1.9	55	11.6%	0.21 [-0.40, 0.82]	2001
Willems 2005a	32.5	8.1	32	30.14	6.39	127	27.9%	0.35 [-0.04, 0.74]	2005
Subtotal (95% CI)			**45**			**182**	**39.5%**	**0.31 [-0.02, 0.63]**	
Heterogeneity: Chi² = 0.14, df = 1 (P = 0.71); I² = 0%									
Test for overall effect: Z = 1.84 (P = 0.07)									
1.6.2 Male only									
Beynnon 2001	4.1	0.9	7	4	2.7	43	6.6%	0.04 [-0.76, 0.84]	2001
Willems 2005b	25.88	6.52	44	29.25	7.38	197	39.1%	-0.46 [-0.79, -0.13]	2005
Subtotal (95% CI)			**51**			**240**	**45.7%**	**-0.39 [-0.70, -0.09]**	
Heterogeneity: Chi² = 1.30, df = 1 (P = 0.25); I² = 23%									
Test for overall effect: Z = 2.52 (P = 0.01)									
1.6.3 Male and female									
Baumhauer 1995	15.63	4.5	15	14.74	4.49	130	14.8%	0.20 [-0.34, 0.73]	1995
Subtotal (95% CI)			**15**			**130**	**14.8%**	**0.20 [-0.34, 0.73]**	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.72 (P = 0.47)									
Total (95% CI)			**111**			**552**	**100.0%**	**-0.03 [-0.23, 0.18]**	
Heterogeneity: Chi² = 11.61, df = 4 (P = 0.02); I² = 66%									
Test for overall effect: Z = 0.27 (P = 0.79)									
Test for subgroup differences: Chi² = 10.17, df = 2 (P = 0.006), I² = 80.3%									

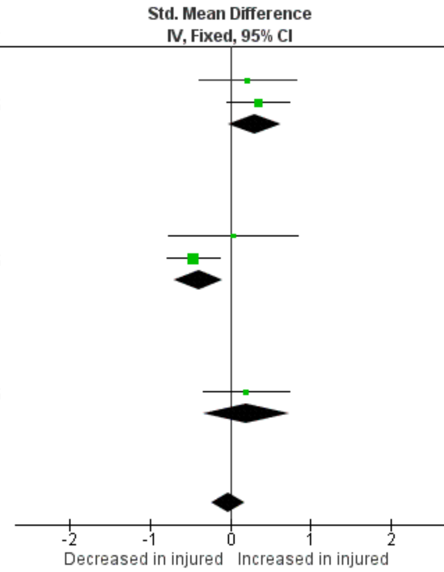


Figure 3.23: Forest plot: Association between ankle sprain and dorsiflexion ROM with knee extended

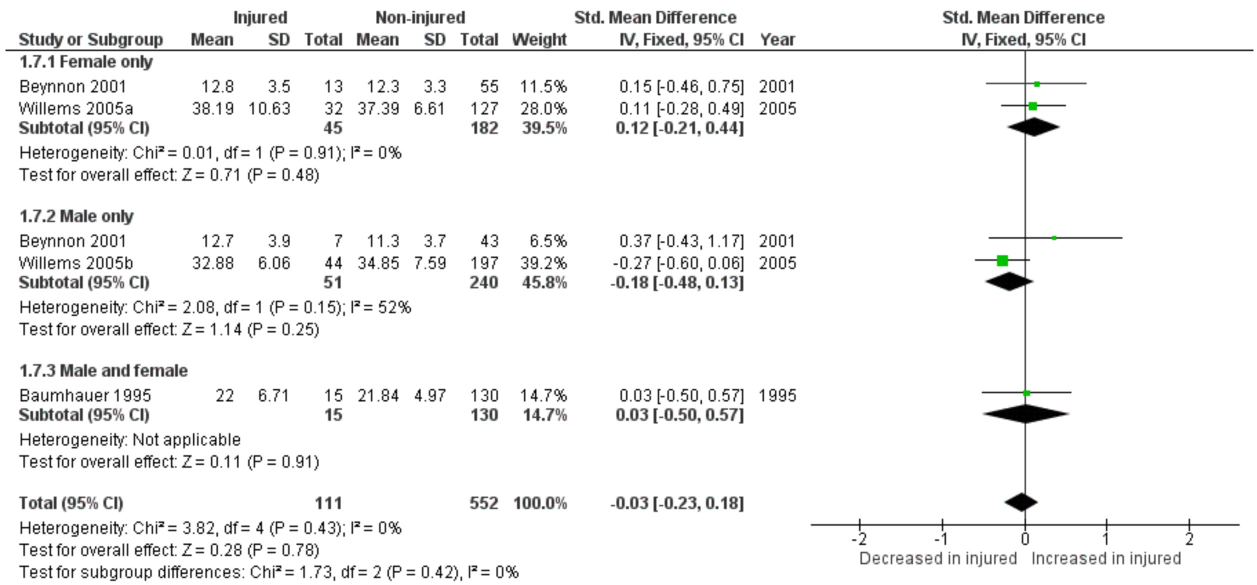


Figure 3.24: Forest plot: Association between ankle sprain and dorsiflexion ROM with knee flexed

3.3.4.4. Muscle reaction time

In this review, two high-quality studies (Beynnon et al., 2001; Willems et al., 2005b) were included to investigate the association between muscle reaction time and risk factors for LAS, with an NOS score of 7.

- Beynnon et al. (2001) employed a Neuro Test system to measure the time between joint perturbation and electromyographic signals from surface electrodes for muscle activation.
- Willems et al. (2005b) used surface electromyography (EMG) to capture the muscle activity of the peroneus brevis (PB), peroneus longus (PL) and anterior tibialis (AT); however, their results were conflicting. They used a unique platform that allowed either the foot to drop at 50° plantarflexion inversion from 15° adduction and 40° plantarflexion to measure the muscle reaction time after an

abrupt inversion perturbation. Willems et al. (2005b) found that males with reduced AT muscle ($p = 0.048$) and gastrocnemius ($p = 0.033$) were more at risk of LAS.

- The outcome of the AT muscle reaction time exhibited a high degree of heterogeneity among the studies, with a value of 76% ($p = 0.04$). The meta-analysis revealed a significant association between LAS and AT muscle reaction time, with the injured group demonstrating a significantly lower AT muscle reaction time, with an SMD -0.84 (CI: -1.15 to -0.53) and a Z score of 5.29 ($p < 0.01$), as illustrated in Figure 25.
- Similarly, the heterogeneity for PB muscle reaction time was 57% ($p > 0.05$). The injured group demonstrated a significantly lower PB muscle reaction time, with an SMD of -0.43 (CI: -0.74 to 0.13) and a Z score of 2.78 ($p < 0.05$), as shown in Figure 3.26.
- By contrast, the heterogeneity for PL muscle reaction time was not significant, with a value of 36% ($p > 0.05$). The injured group demonstrated a significantly lower PL muscle reaction time, with an SMD of -0.45 (CI: -0.75 to -0.14) and a Z score of 2.87 ($p < 0.05$), as illustrated in Figure 3.27.

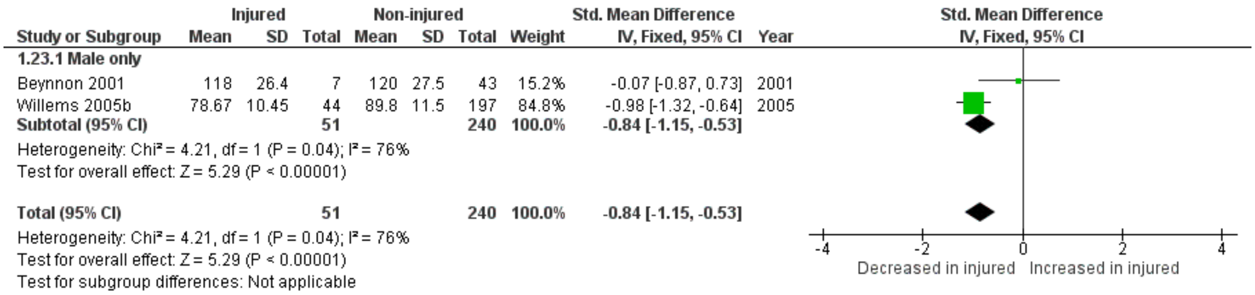


Figure 3.25: Forest plot: Association between ankle sprain and muscle reaction time for the AT muscle

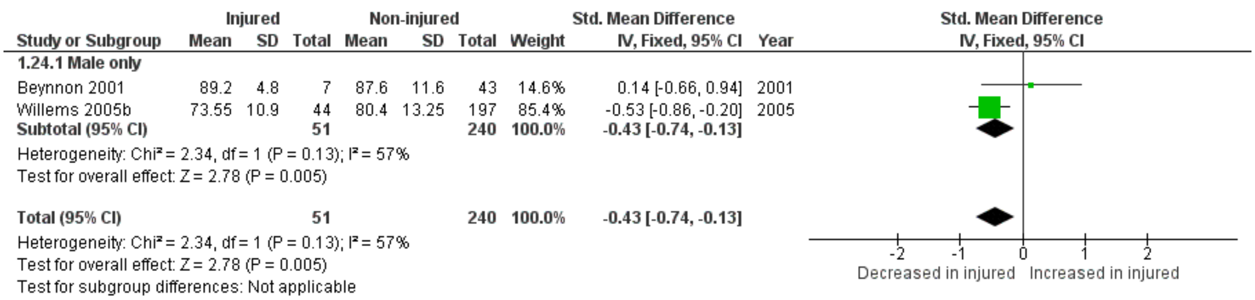


Figure 3.26: Forest plot: Association between ankle sprain and muscle reaction time for the PB muscle

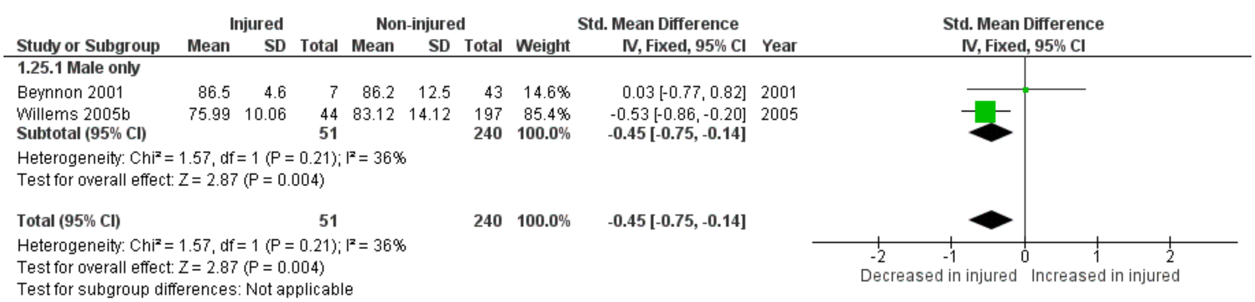


Figure 3.27: Forest plot: Association between ankle sprain and muscle reaction time for the PL muscle

3.3.4.5. Lower limb kinematics 'rearfoot angle'

Two prospective studies were conducted to investigate kinematic variables (Rice et al., 2017; Willems et al., 2004). Rice et al.'s (2017) study was of high quality, with an NOS score of 7, while Willems et al.'s (2004) study was of low quality, with an NOS score of 4. Kinematic variables were measured using a 3D model (CodaMotion, Charnwood Dynamics, UK) and seven infrared cameras (Proreflex) at 200 Hz and 240 Hz, respectively. Rice et al. (2017) found that the rearfoot angle in the frontal plane was not predictive of LAS during barefoot running (p = 0.753). On the other hand, Willems et al. (2004) reported a delayed maximum inversion velocity and knee flexion velocity during running.

The meta-analysis showed a 94% heterogeneity for the outcomes of the rearfoot angle between the two studies (p < 0.01). The injured group did not demonstrate a significant association compared with the uninjured group in the pooled data for the two studies, as shown in Figure 3.28.

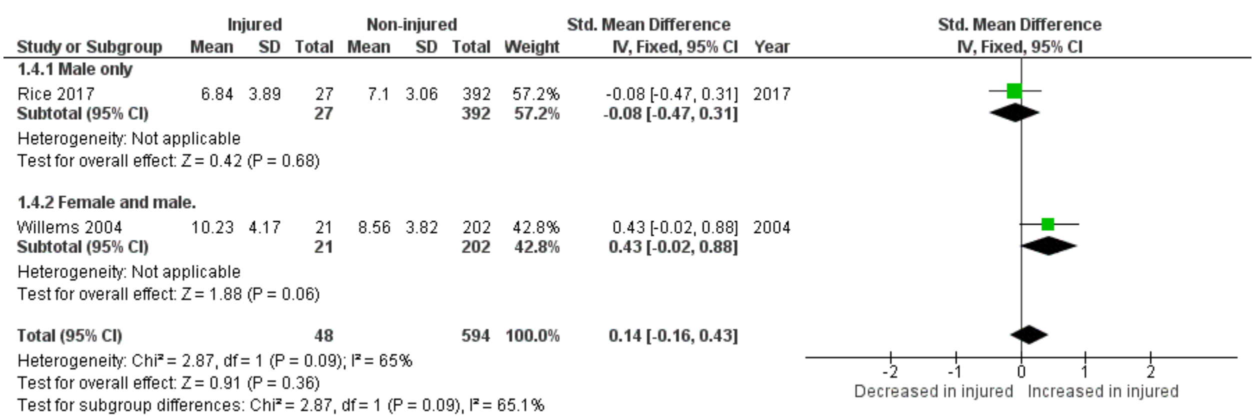


Figure 3.28: Forest plot: Association between ankle sprain and rearfoot angle

3.3.4.6. Joint laxity

The incidence of LAS has been investigated in four studies with regards to its association with joint laxity. Among these studies, one was classified as high quality with an NOS score of 7 (Beynnon et al., 2001), one was moderate quality with an NOS score of 5 (Attenborough et al., 2016) and two were low quality with an NOS score of 4 (Baumhauer et al., 1995; Fousekis et al., 2012).

- Two studies (Baumhauer et al., 1995; Beynnon et al., 2001) evaluated joint laxity using the modified Beighton method, and both reported no significant association with LAS incidence. However, Baumhauer et al. (1995) found that an anterior drawer test, which is a provocative test, demonstrated a predictive trend ($p = 0.078$) for LAS occurrence, whereas a talar tilt test did not show such a trend ($p = 0.473$). By contrast, Beynnon et al. (2001) reported a trend for the anterior drawer test in women ($p = 0.1$) and found an association between LAS incidence and the talar tilt test.
- Another study using the anterior drawer method reported controversial results, indicating that joint laxity is a factor in LAS occurrence ($p = 0.093$) (Fousekis et al., 2012).
- In a recent study, Attenborough et al. (2016) measured ankle joint laxity during inversion–eversion using an ankle arthrometer (BlueBay Research, Milton FL) and found no association with LAS incidence ($p = 0.41$). Overall, the evidence suggests that joint laxity may not be a significant risk factor for LAS, although provocative tests, such as the anterior drawer test, may show some predictive trends.

3.3.4.7. Joint position sense (proprioception)

Three studies were conducted to investigate the association between joint position sense and LAS incidence, with two studies being high quality with an NOS score of 7 (Willems et al., 2005a; Willems et al., 2005b) and one study being low quality with an NOS score of 4 (Fousekis et al., 2012).

- The two high-quality studies employed the Biodex System Isokinetic Dynamometer to assess ankle joint position sense. Willems et al. (2005b) reported that individuals with a maximum inversion of -5º in a passive joint position sense had a higher susceptibility to ankle sprain ($p = 0.037$).
- However, Willems et al. (2005a) found no significant difference in joint position sense between the injured and non-injured groups. By contrast, the low-quality study by Fousekis et al. (2012) reported that the proprioception characteristics of ankle joints were not significantly associated with LAS incidence.

3.3.4.8. Postural control

According to the systematic review, six studies investigated postural control as a predictive factor for LAS. Among them, two were high quality with an NOS score of 7 (Willems et al., 2005a; Willems et al., 2005b), three were moderate quality (Henry et al., 2015; Attenborough et al., 2016; Hadzic et al., 2009) and one was low quality with an NOS score of 4 (Noronha et al., 2013).

Two studies employed the star excursion balance test (SEBT) (Noronha et al., 2013; Attenborough et al., 2016). Noronha et al. (2013) showed that only the postero-lateral position of SEBT was a predictor of LAS incidence ($p = 0.03$), with scores below 80%. Attenborough et al. (2016) also found that leg length SEBT-PM scores of less than or equal to 77.5% provided protection against LAS in active students (OR = 4.04). In addition, Attenborough et al. (2016) reported that a poor score in a demi-pointe static balance test ($p = 0.06$) and a high number of foot lifts during a unilateral stance could be predictive of LAS. Henry et al. (2016) indicated that their injured group had lower scores for balance ($p = 0.024$) and reduced power output ($p = 0.038$) in the lower limb using a computer-interfaced contact mat for non-contact ankle injury among amateur football players. Willems et al. (2005a) conducted postural control tests using the limits of stability (LOS) test and found that the injured group had reduced maximal endpoint excursion ($p = 0.020$). By contrast, Willems et al. (2005b) demonstrated that they had reduced directional control in a LOS test ($p = 0.037$), and injured individuals had poorer scores on a flamingo balance test ($p = 0.001$). Lastly, Hadzic et al. (2009) utilised a Biodex balance system on a circular platform that moved simultaneously on the axis of the posterior (AP) and medial-lateral (ML). The results indicated that it was not a statistically significant predictor of LAS.

3.3.4.9. Clinical examinations

According to the systematic review, clinical examinations were conducted in four studies. Among these studies, one received a high-quality score of 7 on the NOS (Rice et al., 2017), two studies received moderate quality scores of 5 on the NOS (Milgrom et al., 1991; Mei-Dan et al., 2005) and one received a low-quality score of 4 on the NOS (Fousekis et al., 2012).

- Mei-Dan et al. (2005) utilised a Harris mat device to measure the foot arch and showed that a low arch is only associated with LAS in female military personnel ($p < 0.05$). In a recent military study, Rice et al. (2017) demonstrated that LAS risk factors are linked to a bimalleolar width ≤70.5 mm ($p = 0.001$), while a wider foot is linked to an increased risk of LAS (Milgrom et al., 1991).

- Milgrom et al. (1991) found significant differences in leg length ($p = 0.006$), foot length ($p = 0.037$) and foot width ($p = 0.003$) in the incidence of LAS among military individuals, while Fousekis et al. (2012) reported that lower limb length asymmetry is an LAS factor.
- The two studies exhibited substantial heterogeneity with regards to the outcomes of leg circumference, with a statistically significant I^2 value of 94% ($p < 0.01$). Milgrom et al. (1991) also demonstrated a significant association between a larger gastrocnemius circumference and LAS (SMD: 0.42; CI: 0.16 to 0.68), while Rice et al. (2017) had opposite findings, with the injured subjects having a smaller calf circumference (SMD: -0.57; CI: -0.96 to -0.18). However, the meta-analysis revealed that in the pooled data, the calf circumference demonstrated no significance between the injured and uninjured groups in the two male studies (Z score of 1.04, $p > 0.05$), as illustrated in Figure 3.29.

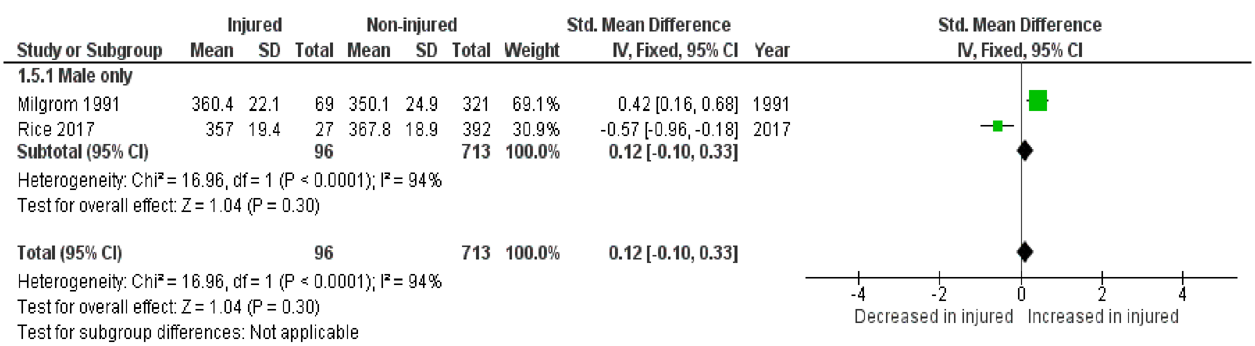


Figure 3.29: Forest plot: Association between ankle sprain and calf muscle circumference

3.3.4.10. Plantar pressure

The systematic review reported that two studies comprising one high-quality study with an NOS score of 7 (Rice et al., 2017) and one low-quality study with an NOS score of 4 (Willems et al., 2004) investigated plantarflexion as a predictor of LAS.

- Rice et al. (2017) utilised pressure trials with RSscan International Belgium sensors to assess peak pressure while running in a military population. The injured group exhibited earlier peak pressure under the fifth metatarsal and the furthest lateral metatarsal, with peak pressure in the forefoot reinversion occurring just before midstance rather than during initial metatarsal contact ($p = 0.030$).
- By contrast, Willems et al. (2004) conducted a foot scan of eight anatomical areas using a foot scan pressure plate (RSScan International, 2 m × 0.4 m, 16384 sensors, 480 Hz) during running by educational students. The injured group exhibited medially directed pressure at first metatarsal contact, with a flat forefoot and off-loading of the heel.
- The medio-lateral ratios indicated less lateral-to-medial pressure displacement during the initial contact phase, suggesting earlier supination and more time spent in supination, which increase the risk of excessive inversion. However, there were no significant differences in foot pressure distribution between the injured and non-injured groups across the eight anatomical areas.
- In terms of the centre of pressure (COP), the X-component was located more laterally in injured individuals at the last foot contact, leading to greater impact on the moment arm during vertical reaction force (Willems et al., 2004).

Moreover, during the forefoot push-off phase, the COP displacement was more laterally oriented. However, there were no significant differences in the Y-component of COP between the injured and non-injured groups.

3.3.4.11. Peroneus tertius muscle

Witvrouw et al. (2006) ascertained through a high-quality study with an NOS score of 7 that the occurrence or non-occurrence of the peroneus tertius muscle did not exhibit any significant correlation with the incidence of LAS (p=0.335). In addition, the study revealed that the strength of dorsiflexors was not influenced by the presence or absence of the peroneus tertius muscle.

3.4. Discussion

In this systematic review of 14 prospective studies, the methodological quality of each study was assessed using the NOS scoring system. Among these studies, five were rated as high quality with scores between 7–9, four were rated as moderate quality with scores between 5–6 and five were rated as low quality with scores between 0–4. The review aimed to investigate the intrinsic risk factors associated with LAS and examine the potential differences in risk factors between males and females. Despite conflicting evidence regarding the specific risk factors for LAS, the findings from this review reject the null hypothesis that intrinsic risk factors are not associated with LAS, as previous studies have reported inconsistent results.

The present study supports some of the findings of a previous systematic review and meta-analysis conducted by Kobayashi et al. (2016), such as the association between LAS and concentric plantarflexion. However, the current study has several advantages over the previous one as it included data from a larger number of prospective studies (14 vs. 8) and examined a wider range of intrinsic factors, including height, body mass and kinematics, separately in males and females. In other words, Kobayashi et al. (2016) conducted a systematic review that included eight prospective studies. The review did not report the use of a formal systematic review guideline, such as PRISMA, to structure the methodology. The risk of bias in the encompassed studies was assessed using a modified quality index, with all studies up to January 2015 included. The outcomes examined only BMI, ROM, muscle strength, postural stability, proprioception and muscle reaction time. The authors acknowledged the limitation that some relevant studies may have been missed.

In comparison, this systematic review and meta-analysis followed the PRISMA guideline and used the NOS to assess the risk of bias across the 14 prospective studies. The date range was expanded to include studies published until January 2022, allowing for the inclusion of more recently conducted research. A broader range of comprehensive outcomes was examined, including demographic characteristics, kinematics, malleolar width, plantar pressure, clinical examinations, previous injury history, centre-of-gravity measures and more.

There are several potential explanations for these methodological differences. First, following best practice guidelines, such as PRISMA, and utilising a validated risk of bias assessment tool strengthened the methodological rigour of this review compared with Kobayashi et al. (2016), who did not report the use of such methods. Expanding the date range from January 2015 to Jan 2022 allowed the capture of an additional four years of research publications, thereby increasing the evidence base. The assessment of a more comprehensive set of seven outcomes provided scope for inclusion of studies not considered by Kobayashi et al.'s criteria. Finally, it is possible that the search strategy and sensitivity of inclusion/exclusion criteria differed between reviews, with the current study's aim being to maximise the identification of all relevant literature.

These methodological improvements resulted in a substantially larger evidence base for this review. The 14 studies that were included represented a total of 2,445 participants compared with only eight included studies and 1,101 participants in Kobayashi et al.'s review. The larger pool of higher-quality evidence lends greater statistical power and generalisability to the conclusions drawn in this systematic review compared with the earlier review (Kobayashi et al., 2016).

In summary, by following best practice systematic review guidelines, expanding the scope of dates and outcomes assessed and implementing a rigorous search methodology, this systematic review was able to provide a more robust and up-to-date synthesis of the evidence than Kobayashi et al.'s earlier review through the inclusion of additional higher-quality studies and a larger sample of research participants.

The meta-analysis identified significant risk factors for LAS, with variations observed between males and females. In males, significant increases in height, body mass and concentric plantarflexion strength at 30° and 120°/s, as well as a decrease in concentric dorsiflexion strength at 30°, ankle dorsiflexion ROM with knee extended and muscle reaction time of the AT, PB and PL muscles, were observed among those who had sustained an LAS compared with those who had not. The association of these risk factors with LAS varied in females, with only dorsiflexion strength at 30° and plantarflexion strength at 120° being significant. This approach is consistent with that of Doherty et al. (2014b), who concluded that the prevalence of LAS differs between males and females due to various factors.

The findings suggest that body mass may be a factor in the occurrence of injury, particularly in males (Figure 3.2). Among the studies analysed, those that examined male participants showed greater heterogeneity in injury outcomes compared with those that investigated females. Male participants who were injured tended to have higher body mass than those who were not (SMD: 2.41, $p < 0.05$), while no significant difference was observed in body mass between the injured and non-injured females (SMD: 0.13, $p > 0.05$). However, it is important to note that the quality of the studies varied, with some rated as high quality and others as low quality.

Despite the lack of association found between BMI and LAS in the meta-analysis (Figure 3.3), a low-quality study on football players reported a significant association ($p = 0.018$), with heavier athletes and those with higher BMI at greater risk due to increased forces acting on the ankle during the support phase of heavy skills (Fousekis et al., 2012). Conversely, a high-quality study among students by Willems et al. (2005a) found no significant association between BMI and LAS incidence ($p = 0.930$). Moreover, Willems et al. (2005b) found similar results regarding the lack of association between BMI and LAS occurrence. However, their study only included students, who are a heterogeneous group in terms of high-intensity activities compared with athletic or military populations. Notably, in physically active populations like military recruits, BMI may reflect muscle mass rather than fat mass due to their high training and low body fat (Davey et al., 2011), which could contribute to an increased risk of losing balance when changing direction due to centre of mass imbalance rather than muscle imbalance (Rice et al., 2017). The conflicting evidence regarding the association between BMI and LAS highlights the need for further investigation of this potential risk factor in prospective studies.

In terms of height, the findings suggest a difference in the level of heterogeneity between male and female participants. The male participants had a higher level of heterogeneity compared with the female participants. Overall, the studies showed a low level of heterogeneity (Figure 3.4). A moderate statistically significant difference was observed in the male injured group compared with the uninjured group. However, no significant difference in height was noted between the injured and uninjured female groups. When the results of all the studies were pooled together, no significant difference in height between the injured and uninjured groups was observed. These findings suggest that body mass may play a role in injury outcomes in male participants, but height may not be a significant factor in injury outcomes in both male and female participants. However, it is important to note that these conclusions are drawn from the studies included in the analysis and may not necessarily apply to all populations.

The systematic review found no significant difference in leg dominance between the injured and uninjured participants. However, studies that examined the association between previous LAS history yielded conflicting results. Some studies, including those of Milgrom et al. (1991), Baumhauer et al. (1995) and Noronha et al. (2013), reported that a prior LAS history could predict future LAS. However, others, such as those of Attenborough et al. (2016) and Henry et al. (2016), found no association between LAS history and LAS risk.

The studies that examined muscle strength had inconsistent results due to differences in methodology, such as the type of muscle contraction (concentric, eccentric or isometric) and the position of the subject during the test. Baumhauer et al. (1995), who had a low-quality study, found no significant difference ($p < 0.05$) in ankle muscle strength between the injured and non-injured participants. In addition, the findings suggest that individuals who have suffered injuries have lower concentric dorsiflexion strength compared with those who have not. This applies to both male ($Z = 3.91$, $p < 0.05$) and female participants ($Z = 2.41$, $p < 0.05$). The meta-analysis showed a significant difference between the injured and uninjured groups. This study also found that only one research reported on concentric dorsiflexion at 30° for females (Willems et al., 2005a) and males (Willems et al., 2005b); hence, heterogeneity was not applicable (Figure 3.5).

However, the study found no association between concentric dorsiflexion strength and LAS at 120° (Figure 3.6). A high-quality study by Beynnon et al. (2001) investigated concentric dorsiflexion strength in both males and females at the neutral angle, while Hadzic et al. (2009) studied only males. There was no heterogeneity between the male studies ($p > 0.05$). Overall, the findings suggest that no association exists between concentric dorsiflexion strength and LAS at the neutral angle ($Z = 0.05$, $p > 0.05$) (Figure 3.7).

A low-quality study concluded that asymmetry in eccentric ankle plantar and dorsal flexor muscle strength could lead to LAS (Fousekis et al., 2012).

Willems et al. (2005a) investigated concentric plantarflexion strength at various angles in females, while Willems et al. (2005b) examined the same in males. The male participants in the injured group exhibited a significant decrease in concentric plantarflexion strength at 30° compared with the uninjured group ($Z = 2.37$, $p < 0.05$), as depicted in Figure 3.8. Conversely, no significant difference was observed in females ($Z = 0.80$, $p > 0.05$). However, both male ($Z = 2$, $p = 0.05$) and female ($Z = 2.15$, $p < 0.05$) participants in the injured group demonstrated increased concentric plantarflexion strength at 120° compared with the uninjured group, as shown in Figure 3.9. No significant difference was observed at the neutral angle between the injured and uninjured groups ($Z = 0.11$, $p > 0.05$) (Figure 3.10).

Willems et al. (2005a) (population of females) and Willems et al. (2005b) (population of males) investigated concentric eversion (Figures 3.11 and 3.12) and eccentric eversion strength (Figures 3.14 and 3.15) at 30° and 120°. Meanwhile, Beynnon et al. (2001) studied both genders' concentric eversion (Figure 3.13) and eccentric eversion (Figure 3.16) strength at a neutral angle. In addition, Willems et al. (2005a) (females) and Willems et al. (2005b) (males) examined concentric inversion (Figures 3.17 and 3.18) and eccentric inversion (Figures 3.20 and 3.21) at 30° and 120°. Beynnon et al. (2001) analysed concentric inversion (Figure 3.19) and eccentric inversion (Figure 3.22) strength at a neutral angle. The meta-analysis showed no significant differences ($p > 0.05$) in concentric and eccentric eversion and inversion muscle strength between individuals with and without a history of LAS.

The conflicting results of previous studies may be due to the high heterogeneity between the different populations and the methods used, as well as some studies scoring low in quality assessments. For instance, some studies used different regimes or training systems to assess exposure, had a follow-up of less than 6 months or had outcomes available less than 12 months before the study. Therefore, although ankle joint muscles are critical in determining the incidence of LAS, further research is needed to investigate the association between lower limb muscle strength and LAS, considering factors such as sample size, type, sex or subjects' exposure to potential injury mechanisms.

The systematic review identified five studies of varying quality that examined the ROM at the ankle joint through clinical examinations. These studies were conducted by Baumhauer et al. (1995), Beynnon et al. (2001), Willems et al. (2005a), Willems et al. (2005b) and Hadzic et al. (2009). The findings suggest a difference in ankle dorsiflexion strength between the injured and uninjured males, with the injured group showing lower ankle dorsiflexion ($Z = 2.52$, $p < 0.05$) with a knee extended compared with the uninjured group (Figure 2.23). However, this difference was not observed in females ($Z = 1.84$, $p > 0.05$). Moreover, there was no significant difference in ankle dorsiflexion ROM with a flexed knee between the injured and uninjured groups in both males and females, as reported by Baumhauer et al. (1995) ($Z = 0.11$, $p > 0.05$) (Figure 3.24). These results suggest that ankle dorsiflexion strength may play a role in the incidence of ankle sprains in males, but further research is needed to fully understand the association between ankle dorsiflexion and ankle sprains.

A moderate-quality study conducted by Hadzic et al. (2009) on athletes suggested that a reduction in dorsiflexion could decrease their capacity to absorb shock during landing, which, in turn, could lead to improper positioning of the ankle and consequently result in ankle sprains. However, the study's limited sample size may have reduced its statistical power. Wright et al. (2000) stated that touching the ground with the lateral part of the foot increases the risk of LAS. Willems et al. (2005b) found that decreased dorsiflexion ROM with straight knees and increased extension motion range at the first metatarsophalangeal joint (MTPJ) are risk factors for LAS. This may be due to the decreased support of the first MTPJ, leading individuals to compensate with increased ROM to allow for appropriate movement in the late stance, potentially resulting in LAS. On the other hand, a low-quality study by De Noronha et al. (2013) found that dorsiflexion ROM was not a predictor of ankle sprains.

Further investigation is needed for other ROM outcomes due to the limited evidence available, particularly in measuring ankle eversion/inversion and plantarflexion ROM.

Therefore, this thesis decided to include these ROM measurements in the prospective study (Chapter 5).

Muscle reaction time was studied only in males by Beynnon et al. (2001) and Willems et al. (2005b). They measured muscle activity using the Neuro Test and surface EMG, respectively, with conflicting results. Willems et al. (2005b) found that males with reduced AT and gastrocnemius muscle were more at risk of LAS. The meta-analysis revealed a significant association between LAS and decreased reaction time of the AT (SMD: -0.84, $p < 0.01$), PB (SMD -0.43, $p < 0.05$) and PL (SMD -0.45, $p < 0.05$) muscles.

Moreover, previous research on muscle reaction time (Fong et al., 2009) suggests that LAS may result from a delay in the muscle reaction time of the lateral ankle joint muscles, particularly the peroneal muscles. According to Ashton-Miller et al. (1996), ankle sprains occur within 40 milliseconds (ms) of maximum vertical ground reaction force during landing or jumping activities. However, various studies on healthy individuals reported sudden response times of the peroneal muscles ranging from 57 ms to 69 ms, which could explain the importance of muscle reaction time in LAS occurrence (Fong et al., 2009; Hopkins et al., 2007; Vaes et al., 2002). The current evidence on muscle reaction time is inconsistent. Meanwhile, Beynnon et al. (2001) and Willems et al. (2005b) demonstrated a delay in muscle reaction time in the injured group among male students. Therefore, for individuals at high risk of LAS injury, the enhanced muscle reaction time of the AT, PB and PL may be due to an altered musculoskeletal system, compromising the protective effect of leg muscles on ankle joint stability. However, previous findings by Willems et al. (2005b) showed that the primary muscles that are functionally unfit to prevent LAS are in the lateral aspect of the ankle joint, not the medial. Delayed muscle reaction can reduce ankle joint control, which limits the ability to counteract rapid inversion and increases the risk of LAS. However, there is limited and conflicting evidence regarding muscle reaction time as the meta-analysis was conducted on male subjects only, and only two studies with high NOA scores were available (Beynnon et al., 2001; Willems et al., 2005b).

In addition, Hartley et al. (2018) found that poor performance on the anterior reach of the SEBT in male collegiate athletes was associated with an increased risk of ankle sprain injury. De Noronha et al. (2013) and Attenborough et al. (2016) reported that only scores in the posterolateral position predicted LAS occurrence. Moreover, Hadzic et al. (2009) investigated the impact of postural control defects independent of the participants' BMI and found that these defects could lead to increased LAS occurrence after acute ankle injury. Meanwhile, Henry et al. (2015) showed that single-leg balance tests did not predict outcomes; thus, further prospective studies that include postural control outcomes are needed, particularly dynamic balance using an SEBT or Y-balance three directions.

LAS may also occur due to a decrease in proprioceptive function, which could be associated by PL muscle fatigue (Mei-Dan et al., 2005). Willems et al. (2005a) explained that poor passive ankle joint position sense could lead to inappropriate foot positioning and lateral shifting of the centre of pressure, causing ankle sprain during the contact phase. Therefore, they recommended including proprioception training in strategies to prevent ankle sprains. However, Willems et al. (2005b) found no association between joint position sense and LAS risk among male athletes.

Rice et al. (2017) conducted a barefoot running task among military personnel, which is not a typical activity associated with LAS mechanisms, such as cutting, hopping or landing, that involve changing direction or vertical force. A limitation of the study was the reluctance of recruits to report injuries and the effect of injury history. In addition, some recruits wore military boots during the assessment. Previous research suggests that LAS occurs when the ankle experiences maximum stress in inversion and plantarflexion during activities like hopping, cutting and landing. Moreover, landing or touching the ground with the lateral foot part increases the chances of LAS due to improper landing or cutting techniques (Bahr & Bahr, 1997; Fong et al., 2011; Fong et al., 2009; Wright et al., 2000).

Only two low-quality studies examined lower limb kinematics. Rice et al. (2017) investigated rearfoot kinematics during a running task in the military, with participants wearing shoes or being barefoot. They found that frontal plane rearfoot kinematic variables did not predict LAS. Willems et al. (2004) also investigated rearfoot kinematics during a running task and found that delayed maximal inversion velocity and maximum knee flexion velocity increased the risk of LAS. However, the study had limitations in its kinematics, and alignment measurements of the midfoot and forefoot were poor. Both studies suggest a delay in kinematic maximal inversion of the rearfoot in athletes during running.

The meta-analysis revealed a shortage of kinematic variables, and the outcomes for the rearfoot angle were insignificant and inconsistent, indicating a lack of prospective exploration of biomechanics studies, possibly due to implementation difficulties. In addition, kinematics should be assessed in a variety of tasks, such as cutting, jumping, single-leg landing, hopping and roping, to gain a comprehensive understanding of lower limb kinematics and injury mechanisms. Therefore, future research should focus on gathering kinematic data to enhance understanding of these factors.

Another outcome not related to LAS was observed in three studies of varying quality (Baumhauer et al., 1995; Beynnon et al., 2001; Fousekis et al., 2012; Attenborough et al., 2016), although their methods were different. Only Fousekis et al. (2012) reported that an anterior drawer test showed a trend of predictive laxity and LAS; however, their study had limitations in clinical practice and sample size.

With respect to the clinical variables, a high-quality study by Rice et al. (2017) found that smaller bimalleolar width could predict LAS. Military personnel carrying loads during training activities have a higher centre of gravity and decreased stability, and a bimalleolar width of ≤70.5 mm may indicate a reduced ability of the evertor muscles to prevent LAS injury. However, further research is needed to confirm or refute Rice's findings. Moreover, Milgrom et al. (1991) associated a wider foot width measured at the calcaneus point with a higher risk of LAS injury. Mei-Dan et al. (2005) linked a lower arch to a permanent everted position, leading to a shorter and weaker peroneus muscle and a delayed muscle reaction, which could lead to ankle sprains.

Milgrom et al. (1991), Baumhauer et al. (1995) and Noronha (2013) reported that a previous history of LAS is a risk factor, whereas Attenborough et al. (2016) and Henry et al. (2016) did not find any such association. Noronha (2013) explained that a history of LAS is considered a risk factor as it affects postural control. However, Attenborough et al. (2016) suggested that the inconsistent findings could be due to various factors, such as the severity of the injury, the time elapsed since the previous injury and the effect of the rehabilitation protocol on the rate of re-sprain. The use of ankle bracing may also provide additional support and affect the risk of re-injury.

Research has shown that individuals participating in high-intensity activities are more prone to LAS on the first occasion compared with the normal inactive population (Beynnon et al., 2005). Military personnel and athletes are two to three times more likely to experience recurrent sprains compared with the general non-athletic population (Mei-Dan et al., 2005). High-intensity activities, including military training, had the highest proportion of training injuries at 35.2%, followed by athletes at 28.5%, with ankle sprain and foot injuries ranking second at 15.1% after lower back pain (Strowbridge & Burgess, 2002). Exposure times for various physical activities among students have been reported to be 15.33 ± 4.33 hours per week and 15.63 ± 3.67 hours per week (Willems et al., 2005a; Witvrouw et al., 2006). A moderate-quality study of the military found that recruits usually trained for 18 or more hours per day and slept between four and five hours, which may have affected their ability to prevent LAS occurrence using muscle strength, such as the peroneal muscles that play an important role in preventing LAS, as well as other risk factors such as dynamic imbalance (Milgrom et al., 1991). However, changes to training programmes and footwear might affect the quality of evidence.

Several limitations were identified in the studies reviewed, including variations in the exposure regimes or training systems used, incoherence among the selected studies and differences in external environments and age groups of the populations studied (de Vries et al., 2016). In addition, some studies had outcomes available at the start that were less than 12 months prior or a follow-up less than six months later.

Participants younger than 15 years were excluded from the study, limiting the generalisation of the findings to active adult individuals (de Vries et al., 2016). The review only compiled 13 studies, and the variability in the outcomes assessed limited the number of studies pooled for specific outcomes. Furthermore, the studies only focused on intrinsic risk factors and did not explore or control extrinsic risk factors such as footwear, ground surface and contact injuries in sports, which may also contribute to LAS. Therefore, further research is needed to fully understand the risk factors for LAS in physically active individuals and develop effective prevention strategies. Changes to training programmes and footwear may also affect the quality of evidence in future studies.

Further research is needed to identify specific intrinsic risk factors associated with LAS in physically active adults. Prospective studies that incorporate a variety of risk factors, such as kinematics, bimalleolar width, muscle weakness, postural control, ROM and postural balance, would provide a more comprehensive understanding of the underlying association or causes of LAS. Identifying the intrinsic risk factors associated with LAS in physically active individuals can provide valuable insights to clinicians and exercise planners in developing more effective injury prevention strategies aimed at reducing the incidence and severity of LAS in physically active individuals. For example, if a particular muscle weakness or postural imbalance is found to be a significant risk factor for LAS, specific exercises and interventions can be designed to target these areas and improve overall injury prevention. In addition, understanding the specific kinematic and biomechanical factors associated with LAS can inform the design of appropriate footwear and other equipment for athletes and military personnel. Overall, further research in this area has the potential to improve the understanding of LAS and help develop effective injury prevention strategies. This information can ultimately help reduce the incidence of LAS in physically active populations, leading to improved performance and overall quality of life.

3.5. Conclusion

The systematic review conducted in this study identified several outcomes associated with the risk of LAS, such as body mass and height in males, muscle weakness and ranges of motion. However, there were some conflicts between the results of these studies, suggesting a lack of consensus regarding the risk factors for LAS. The literature has several limitations, such as small sample sizes, heterogeneous age groups and physical activity levels and different methods for measuring dynamic balance, muscle strength and ROM. These limitations underscore the need for further high-quality prospective research to better understand the intrinsic risks of LAS. This systematic review has an increased number of studies resulting in greater sample sizes than the previous study by Kobayashi, as a result an increase in the number of the LAS risk factors involved in the forest plots between male and female. Furthermore, in terms of military studies, this systematic review has three military prospective studies compared to Kobayashi who has only one study. Therefore, this reflects a comprehensive result to explore the most risk factor related to LAS.

Previous research has shown that increased height, body mass, muscle strength imbalance between agonists and antagonists of the ankle and disturbed balance play crucial roles in predicting LAS. Therefore, future research should focus on exploring these and other potential intrinsic risk factors for LAS in physically active individuals.

Clinicians and exercise planners can benefit from the findings of such research, as they can use the knowledge gained to develop effective prevention strategies for LAS. Specifically, a better understanding of the intrinsic risk factors for LAS can help clinicians and exercise planners identify individuals at high risk for LAS and tailor interventions accordingly.

Thus, this study proposes a prospective research design to explore intrinsic LAS risk factors among military recruits in Saudi Arabia. This research will benefit from a controlled environment during military training, reducing the effects of extrinsic risk factors and biases, and will focus on the biomechanical and clinical aspects of military training. The results of this study could improve the understanding of LAS risk factors and facilitate the development of effective prevention strategies for physically active individuals.

3.6. Learnings From This Systematic Review and Meta-Analysis

The systematic review found several outcomes linked to the risk of LAS. However, the literature has some limitations, including small sample sizes, non-homogeneous groups based on age and physical activity, using different methods for measuring dynamic balance, muscle strength or ROM, and testing kinematics during tasks that may not be related to injury. As a result, there is no consensus on LAS risk factors.

Moreover, prior studies on students and athletes have reported conflicting results regarding the association between LAS and its incidence. These conflicting results may be due to external factors that were not controlled, such as training exposure, shoe-surface interaction and sample population heterogeneity. To overcome these limitations, a prospective study was designed to explore the intrinsic risk factors of ankle sprain in a carefully controlled military population. This will foster a better understanding of the risk factors that are intrinsic to LAS by minimising the impact of external factors.

Furthermore, the results of this study can provide valuable information to clinicians and exercise planners who can design interventions to reduce the incidence of LAS in physically active individuals.

CHAPTER 4

Repeatability and Validity of Measurement Tools

This chapter focuses on the selected tools for measuring the intrinsic risk factors associated with lateral ankle sprains. The repeatability and validity of these tools will be examined in comparison to the standard tools.

4.1. Introduction

As demonstrated by the literature review, identifying and understanding the risk factors associated with lateral ankle sprains (LAS) is critical for developing effective prevention strategies. Biomechanical, functional and clinical factors have all been shown to be important risk factors for LAS, with landing biomechanics of the lower limb joints being a particular focus in recent research (Doherty et al., 2015). Various tools are available to assess these risk factors; however, it is important to consider factors such as practicality and accuracy when selecting the appropriate tools for screening and evaluation.

Repeatability is a measure of the consistency of multiple measurements of the same variable under the same conditions by the same examiner (Reinstein et al., 2012). Meanwhile, reliability refers to the consistency of measurements, and a high level of reliability means that the measure produces consistent results under the same conditions.

The repeatability of a measurement indicates its reliability, which could be inter-rater or intra-rater. Reliability is demonstrated when measurements show consistency across different raters, while intra-rater (intra-tester) reliability is demonstrated when measurements show consistency across the same rater (Koo & Li, 2016).

Validity, on the other hand, refers to the accuracy of a measurement or tool. Thus, assessing the reliability and validity of all clinical and biomechanical tools is crucial to ensure the quality of research and should be done before conducting large-scale studies.

Several tools are available for assessing the clinical, functional and biomechanical risk factors associated with LAS, including the following:

1. Goniometer: A goniometer is used to assess the active joint range of motion (ROM) in the ankle, such as dorsiflexion and plantarflexion.
2. Hand-held dynamometer (HHD): This tool is used to assess muscle strength in the ankle, such as dorsiflexion and plantarflexion strength.
3. Y-Balance Test (YBT): The YBT is used to assess dynamic balance in the ankle. The test requires the participant to stand on one leg and reach out as far as possible with the other leg in different directions.
4. Sliding breadth calliper: This tool is used to measure the bimalleolar width, which is the distance between the inner and outer ankle bones.
5. Motion analysis: Biomechanical factors can be assessed using two-dimensional (2D) and 3D kinematics analysis during activities such as single-leg landing (SLL) and lateral hopping (LH). The 3D analysis is considered the optimum method for biomechanical measurement but can be time-consuming and expensive.

For screening large populations, it is important to use tools that are quick, simple and portable. Therefore, 2D motion analysis and an HHD can be proposed as quick ways to determine the biomechanical and muscle weakness risk factors for LAS. However, it is important to establish the repeatability and validity of these tools prior to the main study to ensure the accuracy of the outcome measures.

Before collecting data from a large cohort, it is important to assess the repeatability and reliability of all tools, including the goniometer, HHD, YBT, sliding breadth calliper and 2D motion analysis, in a population similar to the one that the research will be focusing on. In this study, the intra-rater reliability of these tools is established. Therefore, this chapter is divided into two sections: the first section addresses the repeatability and reliability assessment of the biomechanical, clinical and functional tools, while the second section discusses the validity of the 2D motion analysis compared with the 3D motion analysis.

Aims and objectives

The objectives of this chapter are as follows:

A. To assess the repeatability and reliability of a universal goniometer, HHD, YBT, sliding breadth calliper and kinematic 2D motion analysis.
B. To assess the validity of the 2D motion analysis with the 3D kinematics.

Research questions

A. Are the selected tools reliable for clinical, functional and biomechanical examinations?
B. Is 2D motion analysis valid compared with 3D kinematics?

4.2. Reliability and Repeatability of Tools

An accurate assessment of the biomechanical risk factors for LAS requires the use of reliable and valid tools. This section will outline the data collection methods and assessment protocols to ensure the accuracy of the results.

4.2.1 Materials and Methods

4.2.1.1. Ethical approval

Ethical clearance was obtained from the Research, Enterprise and Engagement Ethical Approval Panel of the University of Salford prior to the commencement of the study (HSR1819-083, Appendix B). All reliability studies were conducted at the University of Hail.

4.2.1.2 Instruments

The following instruments were used for clinical and biomechanical measures:

1. A manual goniometer was used for ROM measurement.
2. A MicroFet F2 HHD was used for muscle strength measurement.
3. The Y-Balance Test (YBT) was used in three dimensions, namely, anterior (ANT), posteromedial (PM) and posterolateral (PL), for balance assessment.
4. A sliding breadth calliper was used for bimalleolar width measurement.
5. The 2D motion analysis was used for biomechanical assessment and then compared with the 3D kinematics assessment for 2D motion analysis validity.

For biomechanical assessment by 2D analysis, three high-speed cameras were used for sampling at 100 frames per second (fps), each equipped with USB 3.0, CMOS, 60 to 300 fps, resolution of 1280 × 1024 pixels, one-megapixel capacity, and utilising a 1/2” e2v Sensor with a global shutter (Quintic Consultancy Ltd., Sutton Coldfield, UK). The cameras were located three metres from the strike point (the predetermined reference point where the participants were asked to land on foot during the assessment) and from each other.

4.2.1.3. Participants

Twelve healthy, physically active participants with an average age of 22.41 ± 0.6 years, average height of 174.16 ± 5.88 (cm) and average mass of 68.7 ± 7.7 (kg) were recruited for the repeatability and validity study after they signed the informed consent form (Appendix C). Upon initial acceptance to participate in this study, the participants were provided with a participant information sheet outlining the details of the study. Prior to data collection, all participants were screened for any pre-existing injuries. The participants were then scheduled for an appointment, and any questions related to the study were addressed before data collection commenced. All participants were healthy and clear of any lower limb injury or musculoskeletal surgery during the past year prior to this study. All the participants were students who had almost the same physical routine. However, as this information was collected to assess the repeatability and reliability of tools, the participants' activity levels were not accounted for in detail. All assessments were undertaken in the movement analysis laboratory.

The rationale behind opting for a smaller sample size in this study stemmed from a strategic consideration of the prevailing circumstances, particularly the challenges posed by the coronavirus disease 2019 (COVID-19) pandemic. With restrictions in place and the availability of individuals becoming a limiting factor, a careful decision was made to strike a balance between ensuring data collection accuracy and accommodating the exigencies imposed by the pandemic. While a larger sample size might have provided more comprehensive insights, it would have necessitated a prolonged data collection period, potentially hampering the feasibility of the prospective study within the constraints of the COVID-19 environment.

However, it is important to acknowledge that the choice of a smaller sample size, influenced by COVID-19 restrictions, could potentially be a limitation of this study. The reduced number of participants may impact the generalisability of the findings and potentially introduce biases that arise from a limited representation. The constrained sample size may also influence the statistical power of the analysis, potentially affecting the ability to detect subtle or nuanced effects. Despite this limitation, it is worth noting that previous studies, such as the one conducted by Lachaine et al. (2017), have also employed a smaller number of subjects (e.g. 12) when assessing repeatability (Lachaine et al., 2017). This choice was grounded in the need to account for factors like examiner error and maintain the integrity of results. The decision to capture data at a single time point between sessions was initially motivated by a plan to conduct follow-up assessments after injury. Unfortunately, the persistent impact of the COVID-19 pandemic disrupted these intentions, underscoring the significance of this decision in light of the unforeseen challenges presented by the global health crisis.

4.2.2. Data Collection Procedure

In this study, each participant was scheduled for two appointments, with a one-week gap between them. This interval between appointments was based on the recommendation of Thorborg et al. (2010). Prior to data collection, the researcher thoroughly explained each measurement procedure to the participants to ensure their understanding.

During the examination, the participants were instructed to wear shorts and be barefoot. This choice of attire allowed for easy access to the relevant anatomical landmarks and facilitated accurate measurements. By standardising the clothing requirement, this study aimed to minimise any potential confounding factors that could arise from different types of clothing or footwear. The use of two appointments and the adherence to specific instructions regarding clothing and footwear were deliberate choices in the current study design. These measures were implemented to enhance consistency and reliability in data collection, ensuring that the participants had a clear understanding of the procedures and were appropriately prepared for the examination.

To address the source of error related to lack of consistency, this study specifically considered two potential sources: examiner error and participant error (within or between sessions). First, regarding examiner error, this study implemented rigorous training and standardisation procedures for the examiner involved in data collection to ensure consistency in the assessment techniques, measurements and variabilities in result interpretation, such as the angles obtained using the Quintic tool. By minimising examiner error, this study aimed to enhance the reliability and accuracy of the data, for example, using a goniometer and a video system. To ensure consistency and reliability, a single examiner conducted the assessments for all participants in both examination sessions. This approach allowed for the evaluation of the intra-tester reliability of all clinical and biomechanical measures.

By having the same examiner perform the assessments, this study aimed to avoid the potential sources of variability that could arise from different examiners with varying techniques or interpretations. This consistency in the examiner ensured that the measurements were conducted in a standardised manner, reducing the likelihood of examiner-related biases.

Participant error within sessions refers to variability in performance or response from the participants during a single session. To mitigate this source of error, this study provided clear instructions and demonstrations to the participants, emphasising the correct execution of the tests or tasks. In addition, the participants were closely monitored during data collection to address any potential errors or deviations from the prescribed protocol. Participant error between sessions refers to inconsistencies in performance or response by the participants across multiple sessions. To minimise this source of error, the current study implemented standardised protocols and procedures for each session, ensuring consistency in the testing environment, equipment setup and instructions provided to the participants.

By assessing both examiner error and participant error (within and between sessions), this study aimed to identify and control for potential sources of inconsistency. This approach helps improve the reliability and validity of the findings, enhancing the overall quality of the research outcomes.

At both visits, comprehensive clinical, functional and biomechanical measurements were conducted to gather a comprehensive set of data. These measurements were carefully selected to capture various aspects relevant to the study objectives. By conducting a comprehensive set of clinical, functional and biomechanical measurements at both visits, this study also aimed to obtain a comprehensive understanding of the participants' conditions and their impact. In addition, this approach allowed for a more robust and multifaceted analysis, enabling us to explore potential associations, identify trends and draw meaningful conclusions from the collected data. The same methodology would be applied to the prospective study, given that twice the number of participants should be tested during the end of the prospective study baseline. However, due to COVID-19 circumstances and the subsequent lockdowns, the participants were tested only at the beginning of the training at baseline; a re-test of the injured participants at the end of the baseline of the training was not performed.

4.2.2.1. Clinical and functional examinations

Active range of motion of the ankle joint

For the measurement of ROM in the ankle joints, a manual goniometer was employed in this study. The active ROM of the ankle joint was assessed in both the sagittal and frontal planes according to the respective movement plane. The foot's postural orientation during the ROM measurements is presented in Table 4.1.

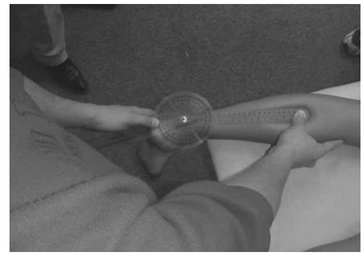
To measure the subtalar eversion and inversion ROM, the participants were asked to be in a prone position, with their ankles hanging off the edge of the bed. The goniometer was placed with its axis on the rear foot, at the middle point proximal to the insertion of the Achilles tendon. The stationary arm was aligned with the midline of the lower leg, while the movement arm was aligned with the midline of the calcaneus.

For dorsiflexion and plantarflexion ROM assessment, the participants were seated near the end of the clinical bed, with their hips flexed at 90° and their knees slightly flexed at 15°. A knee pillow was used as a support to maintain a consistent position of the knee during the repeated trials. The other reason for opting for 15° of knee flexion following (DiGiovanni et al., 2002) is to eliminate the effect of the gastrocnemius muscle, which could restrict or interfere with the actual dorsiflexion and plantarflexion ROM, as this constitutes two joint muscles. The foot was allowed to hang from the bed, positioning the ankles at the edge of the bed for ROM measurement. This could enhance the functionality of dorsiflexion using goniometer such as lunge test. However, functionally this study was evaluated dorsiflexion ROM by kinematics during most functional tasks correlated to LAS occurrence. Furthermore, as a limitation of this study due to timing of data collection, this study couldn’t include lunge test. Moreover, ROM using goniometer and lunge tests were reliable and according to the systematic review (chapter 3), five previous prospective studies used goniometer (Baumhauer et al 1995; Beynonn et al 2001; Willems et al 2005a; Willems et al 2005b and Fousekis et al 2012) versus two studies used lunge test (Noronha et al 2013 and Henry et al 2016). The manual goniometer’s axis was centred on the intersection point of the lines drawn through the lateral midline of the fibula and the fifth metatarsal. The stationary arm was placed on the lateral aspect of the leg (fibula), while the moving arm was placed on the lateral aspect of the foot along the fifth metatarsal.

These standardised measurement techniques were adapted from the guidelines proposed by Norkin and White (2016). Three readings were obtained for each motion, and the average was calculated to ensure accurate and reliable measurements of ankle joint ROM.

Table 4.1: Postural orientations to measure the range of motion (ROM) of the participants in the joints (Norkin and White 2016)

Measurement Type	Position	Image
Subtalar Eversion ROM	**Axis:** Midline point proximal to the Achilles tendon insertion **Stationary arm**: Midline of the lower leg **Moving arm**: Midline of the calcaneus	

Subtalar Inversion ROM	**Axis:** Midline point proximal to the Achilles tendon insertion **Stationary arm**: Midline of the lower leg **Moving arm**: Midline of the calcaneus	
Dorsiflexion ROM	**Axis**: The point of intersection of the lines through the lateral midline of the fibula and the fifth metatarsal **Stationary arm**: Parallel to the fibula **Moving arm**: Parallel to the 5th metatarsal	
Plantarflexion ROM	**Axis**: The point of intersection of the lines through the lateral midline of the fibula and the 5th metatarsal **Stationary arm**: Parallel to the fibula **Moving arm**: Parallel to the 5th metatarsal	

Bimalleolar width

A sliding breadth calliper was used to measure the bimalleolar width of the participant while standing. The examiner stood behind the participant and located the protuberance of the malleoli through palpation. The outer jaws of the sliding breadth calliper were then positioned around the malleoli, and the measurement was taken where the inner surfaces of the calliper jaws made contact with the outer surface of the malleoli protuberance, as depicted in Figure 4.1. The main scale of the calliper was used to measure the distance between the outer and inner malleoli, known as the bimalleolar width, and was recorded in centimetres. The measurement was taken three times from each participant, and an average of the readings was calculated.

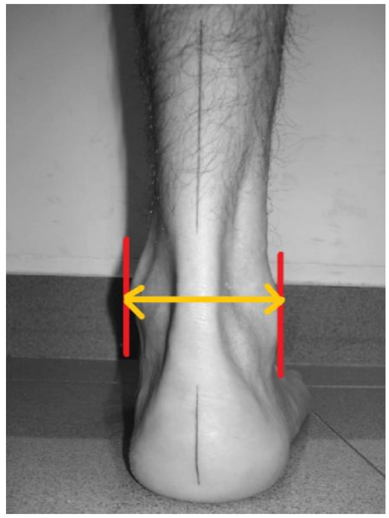


Figure 4.1: Bimalleolar width: Transverse line showing the readings on the main scale of the calliper; the red lines indicate the jaws of the calliper

Dynamic balance (YBT)

The YBT is a valuable functional test for evaluating postural stability and balance. The dynamic YBTs selected for this study were chosen based on their ability to identify individuals at risk of ankle sprains and their sensitivity to previous ankle injuries, as established in previous research that utilised three specific directions: ANT, PL and PM (Hartley et al., 2018; Plisky et al., 2009). These variations were chosen to assess balance and postural stability, as lower scores on these test directions have been associated with an increased risk of ankle sprains, as noted by Hartley et al. (2018).

To ensure accurate and comparable measurements, an important step was taken before conducting the YBT. The true limb length of each participant was measured using a tape measure. This measurement served as a normalisation factor for the data obtained during the YBT. The reference points for limb length measurement were identified as the anterior superior iliac spine (ASIS) and the medial malleoli protuberance, as illustrated in Figure 4.2. The reach distance was initially recorded (in cm), normalised with the true leg length (in cm), and then multiplied by 100. Thus, YBT was assessed in percentage (%).

Normalising the data based on true limb length allows for better comparisons across participants, accounting for variations in individual leg lengths. This normalisation step helps ensure that the measurements taken during the YBT are not influenced by differences in limb length among the participants, enabling a more accurate assessment of postural stability and balance. By utilising the YBT and incorporating the normalisation process for true limb length, this study aimed to obtain reliable and meaningful data on the participants’ postural stability performance and balance. This information will contribute to the understanding of the association between balance scores and the risk of ankle sprains, providing valuable insights for injury prevention and rehabilitation strategies.

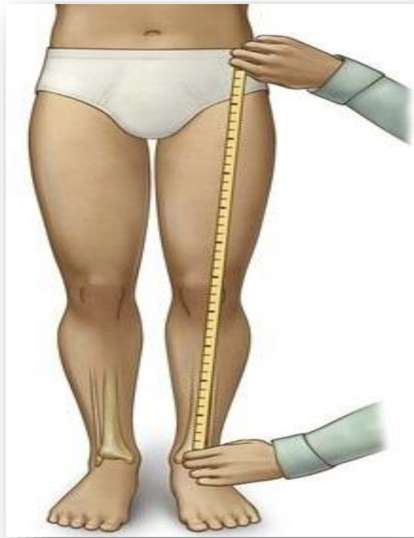


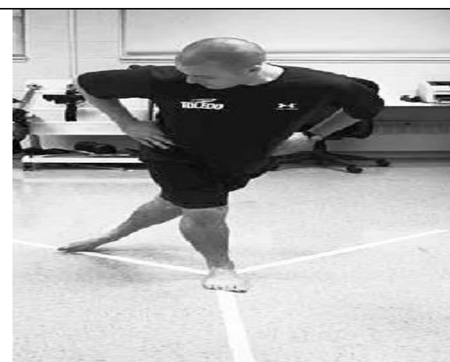
Figure 4.2: Limb length measurement using a measuring tape (Google search)

During the assessment, the examiner played a crucial role in ensuring standardised administration of the tests. Verbal instructions and demonstrations were provided to the participants to ensure proper understanding and execution of the test procedures. For example, the examiner provided instructions on the placement of the participants' hands on their hips, as well as guidance on the positioning of both feet and legs.

The instructions and demonstrations given by the examiner were based on established guidelines and best practices in the field. Reference was made to Table 4.2 from the study conducted by Powden et al. (2019), which provided detailed information on the recommended positions and techniques for the tests. By providing clear instructions, practice and demonstrations, the examiner aimed to minimise potential errors or variations in test execution that could arise from differences in the participants' interpretations or techniques. Standardising these aspects of the test administration helped ensure the reliability and validity of the measurements obtained, allowing for a more accurate and meaningful assessment of the participants' clinical and biomechanical characteristics.

Overall, the examiner's role in providing consistent and standardised instructions and demonstrations was essential for maintaining the integrity and reliability of the assessment process, contributing to the overall quality of the data collected.

Table 4.2: Reach in three different directions: ANT, PL and PM (Powden et al., 2019)

Direction of Reach	Image
Anterior (ANT) Reach	
Posterolateral (PL) Reach	
Posteromedial (PM) reach	

During the YBT, the participants were given specific instructions on how to perform the test. They were instructed to reach out in three directions, namely, ANT, PL and PM, using one foot while keeping the other foot firmly planted at the centre of the YBT setup.

The instructions and technique for the test were based on Table 4.2 from the study conducted by Hartley et al. (2018).

To ensure that the participants understood the test procedure and could perform it correctly, they were given the opportunity to practice the YBT three to five times. This practice helped them become familiar with the task and allowed them to refine their movements and balance control. During the test, the examiner also provided additional instructions to prevent false movements that could affect the validity of the trial. The participants were instructed to avoid lifting their heel or the lateral aspect of their foot from the floor, as these movements could lead to an unsuccessful trial. In such cases, the trial was repeated to ensure accurate measurements.

Each participant performed three trials of each test after a familiarisation period. Both legs were tested, and data from all tests were analysed. This ensured that sufficient data points were obtained to assess their reach distance and postural stability in each direction. By providing clear instructions, allowing practice time and guiding the participants on proper technique, the examiner aimed to minimise potential errors and variations in the test performance. This standardised approach contributed to the reliability and validity of the YBT measurements and enhanced the overall quality of the assessment process.

Hartley et al. (2018) and Hertel et al. (2000) conducted measurements three times using a similar approach. In addition, Gribble et al. (2013) investigated inter-rater reliability and reported excellent results, with intraclass correlation coefficient (ICC) values ranging from 0.86 to 0.92 for normalised maximum excursion distances. Furthermore, Hertel et al. (2000) compared different numbers of trials (ranging from 1–3, 4–6, 7–9 and 10–12) and found high estimates of intratester and intertester reliability. However, adequate practice trials should be performed before taking baseline measures, as recommended by Hertel et al. (2000). In line with this recommendation, the participants in this prospective study were instructed to practice the specific test before the actual recordings were made.

Thus, the average of normalised recordings was calculated. This approach allows for more accurate comparisons and interpretation of the data across participants. By adhering to established protocols, considering reliability studies and implementing practice trials, this study aimed to minimise measurement errors and enhance the reliability and validity of the recorded data. These efforts contribute to the overall quality and reliability of the findings related to dynamic balance and postural stability assessments.

Examination of muscle strength

The muscle strength of the ankle dorsiflexors, plantarflexors, subtalar inverters, subtalar evertors, hip abductors and hip extensors was evaluated using an HHD, which has been established as a reliable tool for measuring muscle strength around the ankle by Spink et al. (2010) and hip joints by Chamorro et al. (2017). In this study, the participants' muscle strength was assessed using a MicroFet F2 HHD (Hoggan Scientific, LLC, Salt Lake City, UT, USA).

The MicroFet F2 HHD is capable of measuring forces ranging from 0 to 300 lbs, as well as newton, with an accuracy of 1% of the reading. Figure 4.3 illustrates the HHD used during the measurements.

Figure 4.3: MicroFet F2 hand-held dynamometer (HHD)

Payne et al., (1997) suggested two distinct methodologies that can be employed for HHD strength measurements. The first approach, known as the ‘make test’, involves the examiner stabilising the dynamometer while the subject applies maximal force against it. The second method, referred to as the ‘break test’, requires the examiner to surpass the maximum force exerted by the subject, resulting in a minor limb movement opposing the patient’s force. Notably, both the ‘make test’ and the ‘break test’ have demonstrated reliability and repeatability, provided that the examiner possesses sufficient force to counteract the patient’s exertion (Bohannon, 1988). This study chose to utilise the ‘make test’ method for HHD strength measurements. This decision was based on considerations of participant comfort, ease of execution and robustness of the chosen method within the context of this research objectives. The ‘make test’ aligns with the focus on obtaining accurate and consistent measurements while minimising any potential discomfort for the participants.

It is important to acknowledge that the efficacy of the chosen ‘make test’ method is contingent on the examiner’s ability to exert adequate force to counteract the subject’s efforts. This requirement underscores the significance of the examiner’s strength and control, which this was help in addressed through standardised training and consistent protocols. By opting for the ‘make test’ method in this study, this study aimed to maximise the precision and reliability of the collected HHD strength measurements.

For the hip muscle strength, points were marked for consistent placement of the HHD to maintain consistency of the procedure throughout the study population. For the placement of the HHD while assessing hip extensor strength, the point was marked posteriorly at two-thirds of the distance between the femur greater trochanter and the lateral femoral condyle and marked laterally on the same distance from the greater trochanter to the lateral femur condyle while assessing hip abductor strength (Kawaguchi & Babcock, 2010).

Prior to conducting the muscle strength assessments, each participant’s body mass was measured in kilograms to normalise the muscle strength data. The muscle strength measurements were recorded in newton per kilogram (N/kg).

During the assessment of the ankle and hip muscles, the examiner securely held the dynamometer in place while the participants exerted a maximal voluntary isometric contraction against it, applying their maximum effort in a specific position and direction relevant to the targeted muscle. Each participant performed three trials of maximum contraction, with each trial lasting for five seconds. A 10-second relaxation period was provided between trials to prevent muscle fatigue. The first two trials were considered practice trials to allow the participants to get familiar with the procedure, while the last three trials were recorded for analysis purposes.

Ankle strength was assessed according to recommendations by Carroll et al. (2013). The strength of the ankle inverters, evertors, dorsiflexors and plantarflexors was assessed in the following position:

Position of subject: Fowler's position on the examination table, as shown in Table 4.3.

Position of the hip: 25° of hip flexion

Position of knee: Extended knee

Position of foot: Over the edge of the examination table (Table 4.3)

The placement of the dynamometer for ankle strength measurement is shown in Table 4.3:

1. **Evertor strength:** The HHD was positioned at the lateral border of the foot distal to the base of the fifth metatarsal head.
2. **Invertor strength:** The HHD was positioned on the medial border of the foot near the base of the first metatarsal head.
3. **Dorsiflexion strength:** The HHD was positioned on the dorsal aspect of the foot proximal to the metatarsal heads.
4. **For Plantarflexion strength: The** HHD was positioned against the metatarsal heads on the plantar surface of the foot.

The isometric strength (in newton) was assessed for subtalar eversion, inversion, ankle dorsi flexion and plantarflexion and then normalised to body mass (N/kg).

Table 4.3: Postural orientation for the strength measurements of the various muscle groups surrounding the ankle joint

Measurement type	Position
Evertor strength	The HHD was positioned at the lateral border of the foot distal to the base of the 5th metatarsal head. The participant was secured with a belt just above ankle joint for stabilisation.
Invertor strength	The HHD was positioned to the medial border of the foot near the base of the 1st metatarsal head. The participant was secured with a belt just above ankle joint for stabilisation.
Plantarflexion strength	The HHD was positioned against the metatarsal heads on the plantar surface of the foot. The participant was secured with a belt just above ankle joint for stabilisation.
Dorsiflexion strength	The HHD was positioned on the dorsal aspect of the foot proximal to the metatarsal heads. The participant was secured with a belt just above ankle joint for stabilisation.

In a previous prospective study by Ridder et al. (2017), they specifically examined the correlation between hip muscle strength and the risk of sustaining LAS in youth soccer players. Their findings indicated that reduced hip extension muscle strength was an independent risk factor for LAS in this particular population. In addition, a recent study by Powers et al 2017 and Kawaguchi et al. (2021) investigated the association between hip abductor weakness and LAS. Their results demonstrated a significant association between hip abductor weakness and the occurrence of LAS.

Based on these two previous studies, the current study includes the assessment of hip muscle strength to determine whether this weakness could be considered a risk factor for individuals who experienced LAS compared with those who did not.

The position of the subject for the hip muscle strength measurement was consistent with the study of Kawaguchi and Babcock (2010), as shown in Table 4.4:

1. **Hip abductor isometric strength:** The approach employed for hip abduction strength testing was meticulously designed to ensure both accuracy and replicability. The participants were positioned lying on their side, with the targeted limb positioned on top. This arrangement allowed for a controlled and stable testing environment. To further enhance stability, the lower limb was flexed at the hip and knee, effectively minimising extraneous movements that could affect the measurement.

   Positioning pillows between the legs was another crucial aspect of the methodology. This placement served the purpose of maintaining the hip at a consistent angle of approximately 30° of abduction, a parameter that was carefully assessed using a hand-held goniometer. The use of this device provided an objective and standardised means of measuring the hip angle, contributing to the precision of the test outcomes, as depicted in Table 4.4 (Kawaguchi et al., 2010).

   Furthermore, the participants were secured with a waist strap to prevent unintended movements during the strength-testing process. This fixture ensured that the subjects' position remained consistent throughout the testing procedure, in line with established protocols from prior research (Ireland et al., 2003;

Kawaguchi & Babcock, 2010; Thorborg et al., 2010; Powers et al 2017). The decision to adopt this approach is grounded in its proven efficacy across multiple studies, which lends credibility to its application in the present research.

In summary, the comprehensive methodology for hip abduction strength testing was carefully crafted to optimise accuracy, reliability and alignment with established best practices. The thoughtful use of pillows, goniometry and a waist strap collectively contributed to a controlled testing environment that minimised confounding factors and enhanced the validity of the study's findings (Ireland et al., 2003; Kawaguchi & Babcock, 2010; Thorborg et al., 2010).

2. **Hip extensor strength:** Based on the methodology illustrated in Table 4.4, the participants were instructed to be in the prone position, with their trunk supported on the edge of the examination couch. By strategically fixing one knee in a slightly flexed position to stabilise the testing leg foot on the ground, the testing leg was extended to facilitate force application. A pillow will be placed under the anterior thigh to maintain the hip in 30° extension, which was assessed with a hand-held goniometer. However, the significance of the Velcro strap lies in its ability to firmly secure the subject's back to the table.

   This fixation of the trunk serves multiple essential purposes. First, it isolates the muscle group under examination, mitigating any unintended compensatory movements or contributions from the upper body. This isolation ensures that the force generated is predominantly attributed to the targeted muscle, thereby enhancing the accuracy and validity of the measurement. Second, the use of the Velcro strap aligns with established protocols recommended in prior research

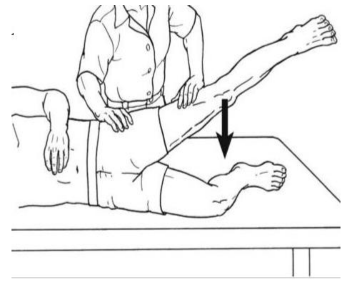
(Elizabeth et al., 2011; Kawaguchi & Babcock, 2010; Thorborg et al., 2010). This consistency in methodology across multiple studies further validates the appropriateness of employing the Velcro strap to achieve trunk fixation.

In essence, the Velcro strap was a critical component of the study's design, functioning as a tool to enhance the precision and reliability of muscle testing. Its application aligns with established best practices, contributes to the validity of the results and ensures that the targeted muscle group's contribution to the applied force remains the primary focus of the investigation (Elizabeth et al., 2011; Kawaguchi & Babcock, 2010; Thorborg et al., 2010).

Position of the dynamometer:

1. **Hip abductor isometric strength:** The central part of the HHD force pad was placed on a lateral mark that was two-thirds of the imaginary line from the greater trochanter of the femur to the lateral condyle (Table 4.4).
2. **Hip extensor strength:** The central part of the HHD force pad was placed on a posterior mark that was two-thirds of the imaginary line from the greater trochanter of the femur to the lateral condyle (Table 4.4).

Table 4.4: Postural orientation for the strength measurements of the hip abductors and hip extensors (Kawaguchi et al., 2010)

Measurement Type	Position	Image
Abductor strength	The participant was lying on their side, with the limb to be tested on top; the knee of the testing leg was extended; the participant was secured with a strap at the lower back	
Extensor strength	The subject leaned with his trunk supported on the edge of the examination couch, as shown in Figure 4.6B, such that his one leg was flexed slightly to support the foot on the ground and the testing leg was extended under the force. the participant was secured with a strap at the lower back	

4.2.2.2. Biomechanical examination

Screening tasks

Both 2D and 3D motion capture techniques were used to collect data during SLL and LH tasks. The tasks were performed by the participants in a randomised order. Prior to the trials, the participants were given time to become familiar with the tasks to prevent any self-conscious movements that could affect the data. A total of five successful trials were recorded for each participant and for both limbs. This approach ensured that an adequate amount of data was captured for analysis, allowing for a comprehensive assessment of the participants' movement patterns during the specified tasks.

Single-leg landing

The SLL task in this study followed a protocol previously used by Weinhandl et al. (2011) and Delahunt et al. (2013). During the task, the participants stood on a 40-cm step and were instructed to land on one limb positioned on the force plate and step off without touching the force plate with the other leg or taking a second step. They were also instructed to maintain their balance for 10 seconds after landing, with their hands on their waist throughout the entire trial.

If a participant did not follow these instructions during a trial, it was considered unsuccessful and repeated. To prevent the impact of fatigue, a minimum rest period of one minute was provided between trials for the participants. Similar to the previous task, five successful trials were recorded for each participant in a consistent manner.

By using a standardised protocol and ensuring the participants followed specific instructions, the study aimed to collect reliable and comparable data on SLL performance. This methodology allows for a detailed analysis of the participants' ability to maintain balance and execute controlled movements during the task.

Lateral hopping

The LH test is a functional assessment commonly used to evaluate ankle joint stability and lateral movement ability following an LAS injury. During the test, the individual stood on one leg and hops laterally for a specific distance before landing on the same leg. Both the injured and uninjured legs are tested, and the results were compared. The test provides valuable information about the individual's functional capacity, dynamic balance, proprioception and ankle muscle power after LAS. It helps determine their readiness to return to sports activities and identifies any potential deficits that should be addressed before resuming sports participation.

The protocol for the LH task was adapted based on the established methodology outlined in the study by Delahunt et al. (2007) and Ridder et al., (2015). The participants were instructed to stand on their designated test leg, positioned 30 cm away from the edge of the force plate. Subsequently, the participants were provided explicit instructions to execute an LH manoeuvre, effortlessly surmounting an obstacle set at a height of 15 cm and skilfully alighting at the precise centre of the force plate. This meticulous approach was undertaken for a multitude of logical and methodological reasons, each contributing to the efficacy and precision of the study design. Furthermore, this deliberate choice of 15 cm as the obstacle height, grounded in empirical research on biomechanics and sports science (Ridder et al., 2015; Delahunt et al., 2007).

By standardising the obstacle height, the potential influence of fatigue on performance was effectively minimised. Varying obstacle heights could introduce confounding variables that obscure the true impact of the LH manoeuvre on the measured outcomes. The main reason is to ensure consistency of hopping as if this is a barrier individuals need to hop over whereas without the barrier they could hop without as much effort for example, and ensured that each participant faced an equivalent challenge, enhancing the reliability and validity of the results.

Moreover, the deliberate use of a consistent obstacle height also served to establish a uniform protocol for all participants. Such uniformity is paramount in research settings as it reduces the potential for bias and discrepancies that might arise from individual variations or fluctuations in performance. By adhering to the same obstacle height for every participant, the study maintains a stringent adherence to scientific rigour and eliminates the possibility of procedural inconsistencies that could undermine the study's integrity (Delanhunt et al., 2007). In summary, the strategic choice of a 15-cm obstacle height for the LH task reflects a nuanced understanding of the experimental design. It ensures not only a consistent and standardised environment across repeated measures but also guards against the introduction of confounding variables related to fatigue and procedural variability. This thoughtfully selected obstacle height, backed by established research principles, forms a critical component of the study's methodological robustness and contributes to the accurate interpretation of the obtained results.

After each landing, the participants were required to maintain their balance for a duration of 10 seconds, keeping their hands on their waist throughout the entire trial. To ensure consistency and accuracy, line markings on the floor were utilised to ensure that each LH commenced from a distance of 30 cm away from the edge of the force plate (Delahunt et al., 2007).

Trials in which the participants deviated from the specified protocols were considered unsuccessful and subsequently excluded from the analysis. To mitigate the potential effects of fatigue, a rest period of one to one-and-a-half minutes was provided between trials for all participants. Following these guidelines, five successful trials were recorded for each subject.

By employing a standardised and rigorous approach, the study aimed to collect precise and comparable data regarding the participants' performance in the LH task. This meticulous methodology allows for a comprehensive evaluation of balance, control and landing techniques during the task, ensuring the reliability and validity of the findings.

Two-dimensional camera setup and calibration

Three high-speed cameras were utilised in the study, each equipped with USB 3.0 connectivity and capable of capturing footage at a range of 60 to 300 fps. The cameras had a resolution of 1280 × 1024 pixels and a one-megapixel capacity, utilising a ½" e2v Sensor with a Global Shutter (Quintic Consultancy Ltd, Sutton Coldfield, UK). The cameras were positioned at a distance of 3 meters from the strike point, which served as the reference point for the participants' foot landings during the task.

Figure 4.4 illustrates the placement of the cameras in relation to the central force platform. Camera 1 was mounted on a tripod at a height of 5 cm from the ground. Camera 2 was positioned on a tripod at a height of 30 cm from the ground, strategically positioned to capture the sagittal reflective markers during IC, as well as the maximum and minimum angles of the ankle, knee and hip throughout the task. Camera 3, located at the same distance from the centre as Camera 1, was positioned on the opposite side, as depicted in Figure 4.4.

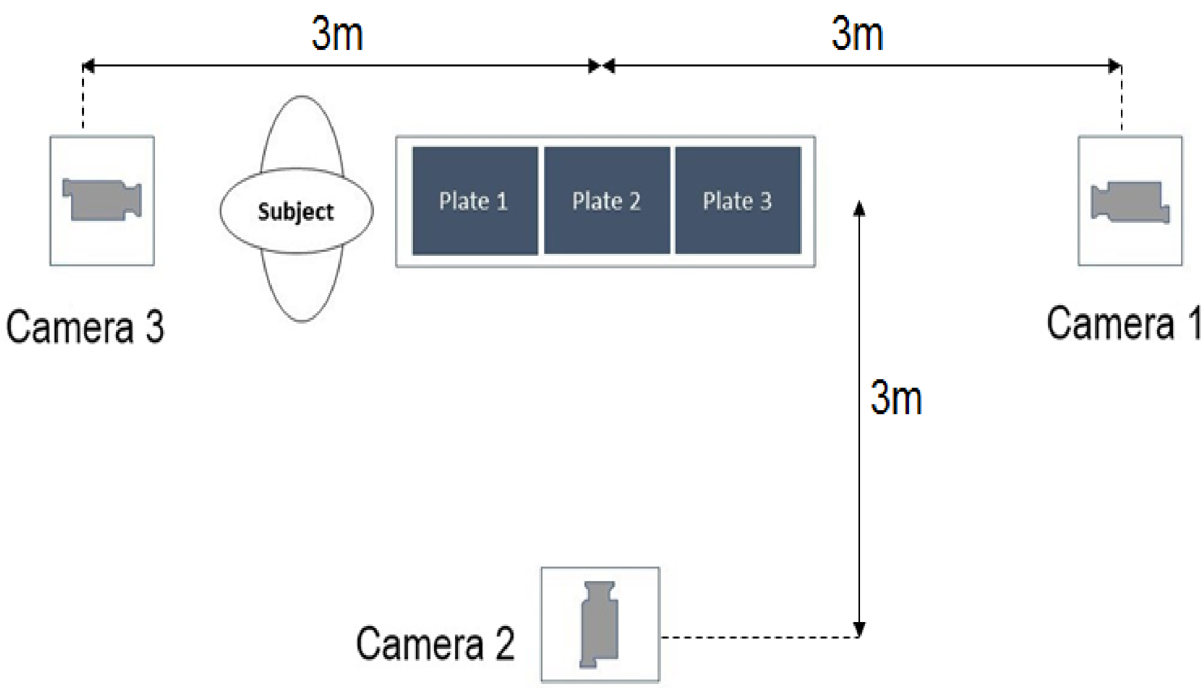


Figure 4.4: Placement of the 2D cameras

Cameras 1 and 3 alternated between capturing the frontal plane views (anterior and posterior) by switching sides for each task. To ensure consistency, a standard zoom setting was employed to maintain a standardised distance and zoom level across all participants. Prior to the trials, a calibration process was conducted using a 60-cm L-frame equipped with three reflective markers. This frame was placed at the centre of the force plate and captured by each camera to establish accurate spatial reference points.

The meticulous setup and calibration procedures employed in the study aimed to ensure accurate and reliable data collection from the high-speed cameras. By positioning the cameras strategically and standardising their settings, the study aimed to capture detailed and precise movements during task performance, providing valuable insights into the kinematics of the ankle, knee and hip joints.

Two-dimensional marker placement and preparation

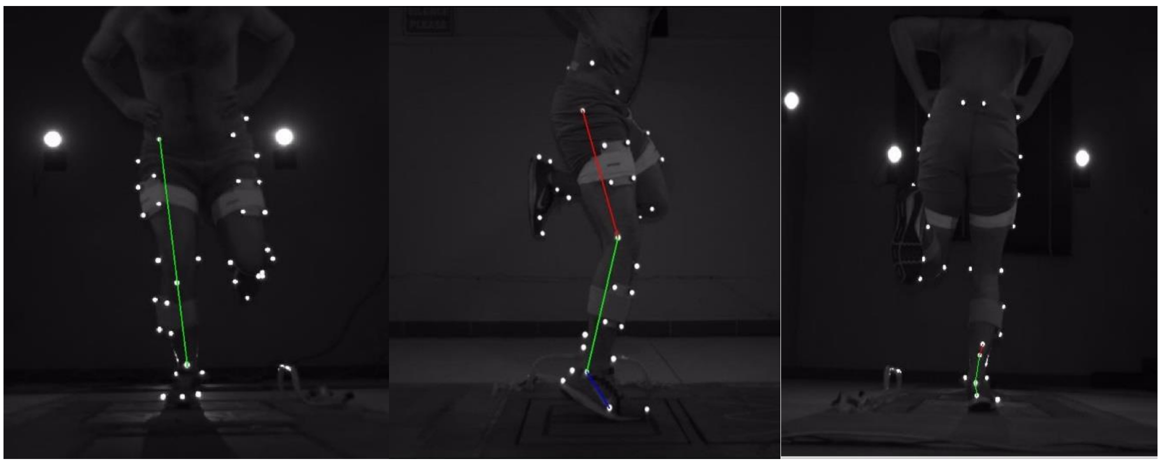
To facilitate the 2D motion analysis, reflective markers were strategically placed on anatomical reference points representing the centres of rotation for various joints. Prior to commencing the trials, the participants had 14.5-mm diameter reflective markers (Figure 4.5) affixed to their lower extremities at specific anatomical landmarks, enabling the assessment of motion in different planes.

The anterior landmarks were targeted for frontal plane motion assessment. These included the midpoint of the anterior ankle between the two malleoli to represent the centre of the ankle joint, the centre of the knee joint at the tibial tuberosity and the ASIS. To ensure accuracy, a standard tape measure was used to manually determine the midpoints of the knee and ankle.

Markers were placed at key locations for sagittal plane motion assessment. These included the greater trochanter, midpoint of the lateral knee joint, lateral malleoli and the lateral aspect of the fifth toe.

Four markers were positioned in descending order to evaluate the rear foot angle. They were placed at the midpoint of the calf muscle, the top of the Achilles tendon, the top of the heel and the bottom of the heel.

By strategically placing the reflective markers on these anatomical landmarks, the study aimed to capture precise motion and assess the kinematics of the ankle, knee and hip joints in different planes. This detailed analysis provides valuable insights into the movement patterns and biomechanics of the lower extremities during the tasks performed by the participants.



(A) (B) (C)

Figure 4.5: Two-dimensional marker position combined with 3D markers: (A) anterior markers (frontal plane), (B) lateral markers (sagittal plane) and (C) posterior markers on the rear foot (frontal plane)

Two-dimensional data processing

The videos recorded during the baseline kinematic assessment were analysed using the Quintic Biomechanics software package (Version 31). This system offered a digital chronometer (non-physical stopwatch offered by the software as time tool in quintic) feature that proved instrumental in selecting an IC as the reference point at 0 ms. To capture the desired time interval, the video was carefully analysed by moving through frames. First, the video was moved back frame by frame until the 20-ms mark was reached, which served as the starting point for the analysis. The video was then forwarded until 300 ms was reached, marking the endpoint for the analysis. The stopwatch feature was synchronised with the video, enabling precise time measurements at each frame. The technical properties of the Quintic system will be detailed as a point of reference in this study.

In this study, the initial time point was determined by observing the participant's ground contact in the video and selecting a time of 20 ms before contact and 300 ms after contact using the Quintic system. Calibration files for each camera were then uploaded to ensure accurate data collection.

Subsequently, automatic digitisation was performed, and the frame template was selected based on the specific plane required for the analyses. A frame template in the Quintic software was used to define the coordinate system and marker positions for calculating the kinematic angles of the lower limbs. The frame template works by defining a set of markers that will be tracked during motion capture. For the lower limbs, this typically includes markers on the hip, knee and ankle joints in the sagittal plane, as well as the rearfoot and frontal plane projection angle (FPPA) in the frontal plane. This defines the axes of rotation for calculating joint angles. Therefore, the sagittal plane had a template with four points: the first point is for the hip joint, the second is for the knee joint, the third is for the ankle joint and the fourth is for the fifth metatarsal joint. While the frontal plane in this study had two templates, the first template for the rearfoot includes four points of angles in the posterior part of the foot and lower leg. Meanwhile, the FPPA contained the following points: the ASIS, the middle of tibia tuberosity and the last point located in the lower anterior shank of the tibia just above the front ankle joint (see Figure 4.6).

The 2D data obtained were subsequently filtered using optimal smoothing techniques, which reduce random noise while preserving the integrity of the signal. From the trials conducted, the maximum, minimum and average values for each variable in one limb were determined based on the first five successful trials. Proper anatomical landmarks were identified in the marker data, and the corresponding data were extracted to calculate the relative joint angles for the ankle, knee and hip using specialised software (see Figure 4.6).

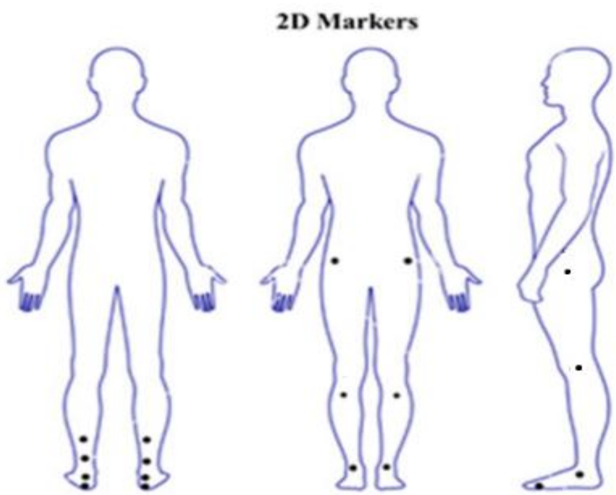


Figure 4.6: Two-dimensional marker positions

Initial Contact (IC): This refers to the moment when the foot makes contact with the ground during landing.

Pre-Initial Contact (Pre-IC): In this study, the pre-IC is defined as the time point of 20 ms prior to the IC.

Post-Initial Contact (Post-IC): The post-IC in this study is defined as the time period of 300 ms after the IC.

Following the identification of IC, automatic digitisation was performed, and the appropriate frame template corresponding to the specific plane of interest was selected for subsequent analyses. To ensure data quality, the 2D data were filtered using the optimal Butterworth filter in the Quintic Biomechanics v31 software. This filtering process aims to reduce random noise without compromising the overall integrity of the data (Ellis, 2012).

For each variable, including the rearfoot, FPPA, knee and ankle angles, calculations were performed based on the data points in the pre-IC, IC and post-IC regions. These values were then extracted and recorded in an Excel spreadsheet for each of the five successful trials conducted (Figure 4.6).

4.3. Validity of 2D Motion Analysis by 3D Kinematics

To evaluate the validity of the 2D motion analysis, a comparison was made with the gold standard 3D motion capture assessment. Specifically, the data obtained from the 2D assessment of ankle function during SLL and LH were compared with the corresponding data acquired through 3D motion capture. This comparison allowed for the assessment of the validity of the 2D kinematics.

The use of the gold standard 3D motion capture provided standard errors of measurement (SEM), which were crucial in determining whether any observed differences in measurements were statistically significant and accounted for the inherent sources of measurement error. This information greatly enhanced one’s confidence in utilising 2D motion analysis for measuring various biomechanical variables.

During the initial visit, in addition to the clinical measures, both 2D and 3D motion capture systems were employed to record the kinematic data simultaneously. This was done for the SLL and LH tasks. The trials for these tasks were carefully collected, and their specific details are presented below.

4.3.1. Two-Dimensional Camera Setup and Calibration

The 2D camera setup and calibration have been discussed in Section 4.1.2.2

4.3.2. Three-Dimensional Camera Setup and Calibration

A comprehensive motion capture system was utilised to collect kinematic and kinetic data during the various tasks. The system consisted of a 10-camera setup from VICON Motion Systems Ltd., located on the laboratory walls and a force platform (AMTI BP400600, USA) embedded on the floor. The cameras had a high sampling frequency of 240 Hz, while that of the force platform was recorded at 1200 Hz, ensuring accurate and detailed data capture. The setup of the cameras surrounding the force platform at the laboratory's centre is illustrated in Figure 4.7A.

Before the testing commenced, a dynamic calibration procedure was conducted using VICON's infrared five-point active wands. The T-shaped hand-held wand, featuring fixed reflective markers at a distance of 750.43 mm, was used for calibration, as depicted in Figure 4.7C. The dynamic calibration involved capturing the calibration volume for a duration of 45 seconds, ensuring that all markers were visible to the camera system. This calibration process defined the 3D testing volume and optimised marker visibility for accurate data collection during the dynamic trials.

4.3.3. Three-Dimensional Marker Placement and Preparation

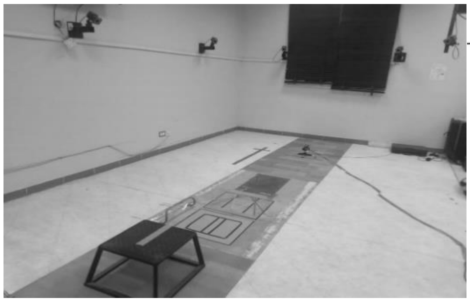
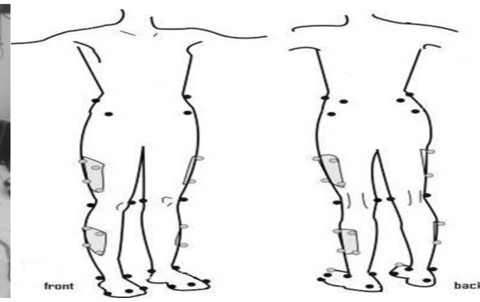
Anatomical reference frames were established using reflective markers placed on specific anatomical landmarks. These markers, which had a diameter of 14.5 mm, were attached to both lower limbs using double-sided tape. The markers were positioned on the ankle, knee and hip joints based on the defined anatomical landmarks (cast marker set) shown in Figure 4.7B.

For the pelvis and hip joints, the markers were placed bilaterally on the ASIS, posterior superior iliac spine, iliac crest, greater trochanters and medial and lateral femoral condyles.

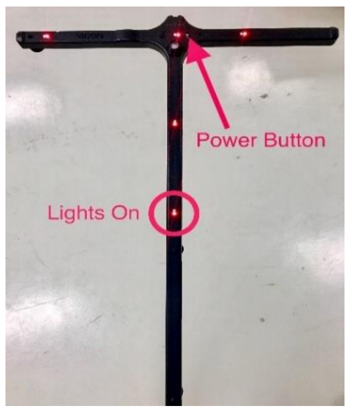
For the ankle joints, the markers were positioned on the medial and lateral malleoli, posterior calcanei and the head of the first, second and fifth metatarsals on both limbs. Since the participants wore shoes, the markers representing the foot segment's anatomical landmarks were placed at the estimated locations on their shoes.

Cluster plates, consisting of four reflective markers each, were attached to the anterolateral part of the shank and thigh using double-sided tape. Elastic bands were used to secure the cluster plates in place. Two cluster plates were attached to each limb. To ensure accurate tracking of the 3D motion of each segment, it was recommended to have at least three non-collinear markers visible in a single frame covered by two cameras (Payton & Bartlett, 2007).

Before data collection, a static trial position was recorded to calibrate the alignment of the participant's limbs while standing on the force plate with equal distribution of body weight on both lower limbs.

(4) (B)



©

Figure 4.7: (A) The 3D motion capture setups within the laboratory with the experimental arrangement; (B) The anatomical landmarks for 3D marker positioning; (C) The calibration wand

4.3.4. Three-Dimensional Data Processing

The trials were recorded using the Vicon software, with the appropriately named markers corresponding to the anatomical locations for each trial. The raw data were then exported into Visual 3D (v6.1.36.0) for further analysis. The biomechanical model was scaled according to the participants' anthropometry using data from the static calibration trials. Mass and height were normalised during the scaling process.

To ensure data quality, a fourth-order bi-directional Butterworth filter was applied to both the motion and force plate data. A low-pass filter with cut-off frequencies of 12 Hz was used for the motion plate data, while a 25-Hz variant was used for the force plate data, effectively reducing random noise and obtaining smooth data without compromising the force and motion signals.

Joint angles were calculated using the Euler rotation sequence of X-Y-Z, where X represents flexion and extension, Y represents abduction and adduction and Z represents internal and external rotation (Figure 4.8). This calculation was performed for the ankle, knee and hip joints in the frontal, sagittal and transverse planes using the software. The resulting plots were analysed to determine the minimum and maximum values corresponding to the IC, pre-IC and post-IC points, as explained in the section discussing 2D data processing.

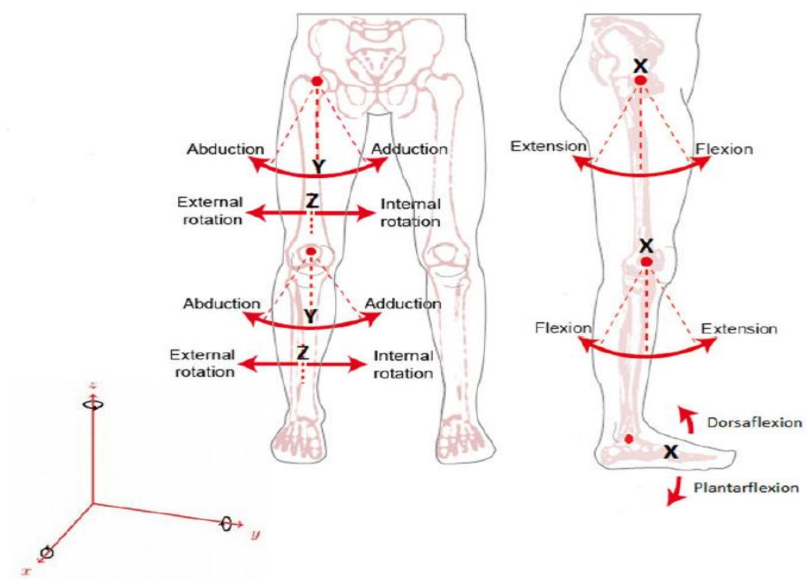


Figure 4.8: XYZ Euler rotation sequence, X (flexion and extension), Y (abduction and adduction) and Z (internal rotation and external rotation)

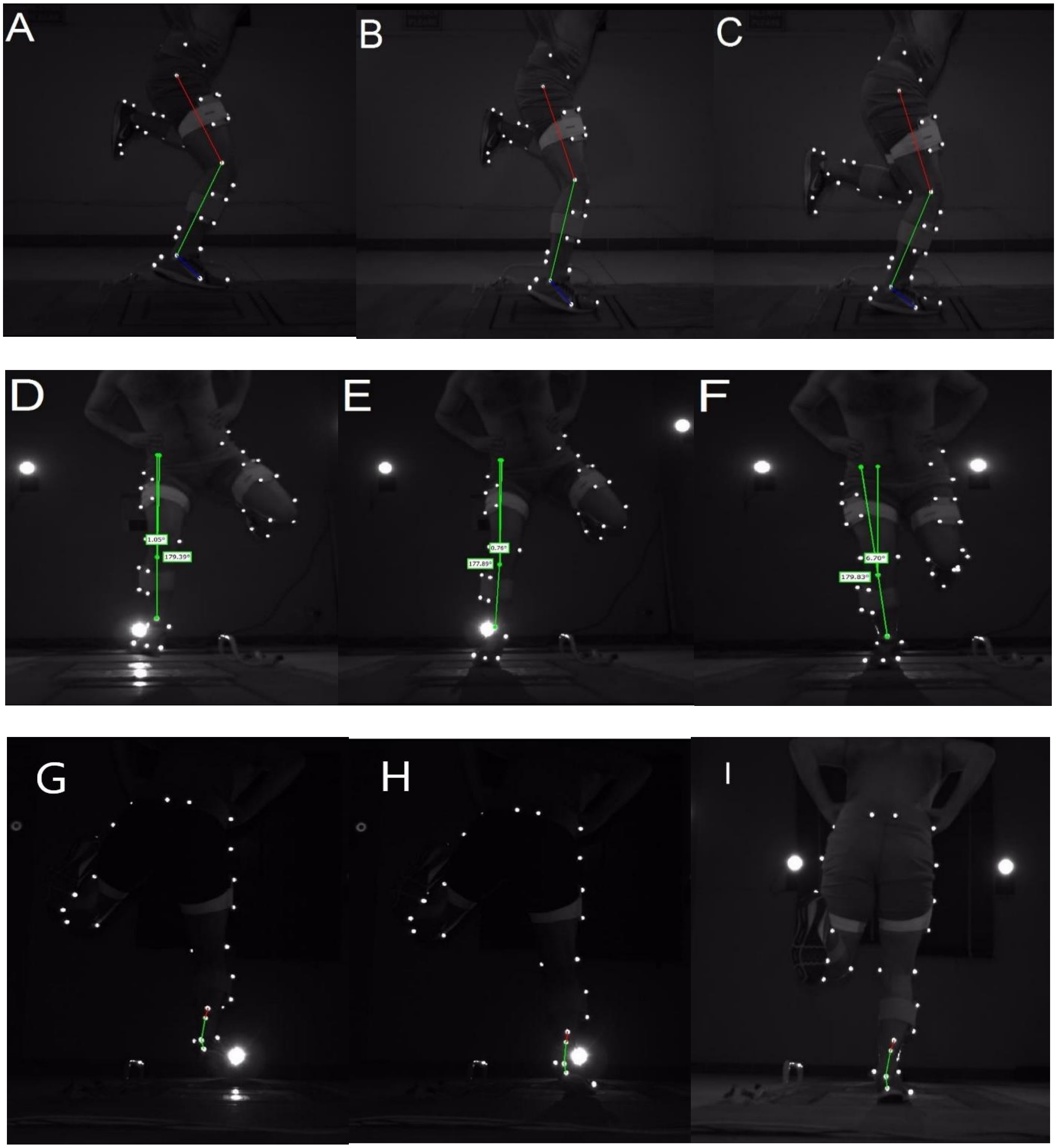


Figure 4.9: Kinematics capturing in the sagittal and frontal planes

Sagittal plane: (A) 20 ms pre-IC, (B) IC, (C) 300 ms post-IC

Frontal plane (FPPA): (D) 20 ms pre-IC, (E) IC, (F) 300 ms post-IC

Frontal plane (rearfoot): (G) 20 ms pre-IC, (H) IC, (I) 300 ms post-IC

4.4. Statistical Analysis for Repeatability and Validity of Tools

The data points for statistical analysis were initially recorded considering joint positions at 200 ms pre-IC, IC and 300 ms post-IC. However, to improve the accuracy of the joint trajectory data and reduce parallax error, the time window was reduced from 200 ms pre-IC to 20 ms pre-IC. This adjustment resulted in more precise results by minimising the parallax error. In addition, all data were normalised to prevent any skewness in the analysis.

All statistical analyses were performed using SPSS for Windows (version 27.0). The repeatability test involved calculating the mean, maximum and minimum values of the kinematic variables. These values were obtained from the mean of five trials for the screening tasks conducted on all participants at pre-IC, IC and post-IC. For clinical measurements, such as muscle strength, ROM, bimalleolar width and dynamic balance, the mean value was derived from three trials.

The between-days repeatability was assessed using the coefficient of variation (CV). The CV is a measure of relative variability expressed as a percentage. It represents the ratio of the standard deviation to the mean. A lower CV indicates less variability and less accurate repeatability, while a higher CV indicates greater variability. In this case, lower CV values indicate less variability in the measurements, suggesting greater consistency and repeatability. Conversely, higher CV values indicate greater variability, which may suggest less consistency or precision in the measurements. To calculate the CV, the standard deviation (SD) and the mean (M) of the measurements are needed. The formula for calculating CV is as follows:

$$CV = (SD / M) * 100$$

When evaluating the CV in research, different ranges are often used to assess the repeatability and reliability of measurements. These ranges can help interpret the CV values and determine the acceptability of the results.

- CV < 10%: This range indicates very good/excellent repeatability, demonstrating high precision and consistency in the measurements. It suggests that the variation within the data is minimal, and the measurement tool or device is highly reliable.
- 10% ≤ CV ≤ 20%: Within this range, the repeatability is considered good. It implies that the measurements have reasonable precision and show acceptable variation, indicating a reliable measurement tool.
- 20% ≤ CV ≤ 30%: In this range, the repeatability is deemed acceptable. It suggests some variability within the measurements, but they remain within an acceptable range for certain research applications. However, some ways to improve repeatability may be worth considering.
- CV > 30%: CV values exceeding 30% are generally considered unacceptable. Such high variability indicates potential problems in the data or experimental procedure. It may also suggest a lack of precision and reliability in the measurements, making the results less reliable or meaningful (Brown, 1998).

The between-session intra-rater reliability was assessed and analysed from the ICC with 95% confidence intervals (CI), SEM and minimal detectable difference (MDD).

The ICC range between 0 to 1, and its values were interpreted according to the following criteria: less than 0.5 indicates poor, between 0.5 and 0.75 indicates moderate, between 0.75 and 0.9 indicates good and greater than 0.90 indicates excellent reliability (Koo & Li, 2016). Only an ICC greater than 0.90 was acceptable for this study, so the results will not be subjected to doubts in terms of reliability (Bobak et al., 2018; Koo & Li, 2016). The ICC values itself cannot provide a clear account of reliability as it does not indicate the amount of disagreement between the measurements. Thus, SEM was calculated using the following formula:

$$\boldsymbol{SEM} = SD_{pooled} \times \sqrt{(1 - ICC)}$$

where a lower SEM value indicates better reliability**,** (Baumgartner et al., 1989; Tighe et al., 2010). In addition, the MDD or minimal detectable change (MDC) was calculated. MDD is the smallest and real change in any outcome (Kropmans et al., 1999; Wu et al., 2015). MDD was calculated using the following formula:

$$\boldsymbol{MDD} = 1.96 \times \sqrt{2 \times SEM}$$

The value of 1.96 corresponds to the Z-score for a 95% confidence level, while the SEM represents the standard error of measurement. The threshold for MDC is established by employing a confidence level. With a confidence level of 95%, the probability of a modification above this threshold being due to chance variability in an unaltered patient is only 5% (Stratford & Riddle, 2012). While a change exceeding the MDC suggests that the alteration is improbable to be caused by chance variability, it does not indicate whether the degree of modification has clinical significance (Beninato & Portney, 2011).

The study used the mean difference between the 2D and 3D measurements of kinematic variables, as well as Pearson's correlation coefficient (r) with a significance value of $p = 0.05$, to evaluate the correlation between the two methods and establish the validity of the 2D kinematics.

The mean difference between the measurements indicates the average difference between the measurements obtained by the two tools, which can determine whether the two tools are measuring the same thing or if they differ systematically. A mean difference of zero indicates perfect agreement between the two tools. A small mean difference between the measurements indicates that the two tools are measuring the same construct or attribute consistently. However, a large mean difference suggests that the two tools are measuring different aspects of the construct or attribute or that there is systematic bias in one or both of the tools. Bland–Altman plots were used between the 2D and 3D data to assess the differences and range of error with average mean difference and 95% limits of agreement (LOA). The LOA provides a visual assessment of the agreement between the two instruments. The criteria and one common approach for accepting the mean difference in validity studies is to use the LOA, which is defined as the mean difference plus or minus two standard deviations of the differences between the two measurements. The LOA provides an interval within which 95% of the differences between the two measurements are expected to fall. If the LOA is clinically acceptable (i.e. within an acceptable range of measurement error), then the mean difference may be considered acceptable.

The Pearson correlation coefficient, on the other hand, provides information about the direction and strength of the linear relationship between the measurements obtained by the two tools. A correlation coefficient of 1 indicates a perfect positive correlation, while a correlation coefficient of -1 indicates a perfect negative correlation. A correlation coefficient of 0 indicates no correlation between the measurements. Generally, a correlation coefficient of 0.7 or higher indicates a strong correlation. The correlation grades are classified as 0 to 0.3 = small, 0.3 to 0.5 = moderate, 0.5 to 0.7 = large, 0.7 to 0.9 = very large and > 9 to 1 = perfect, according to Hopkins et al. (2009).

However, it is important to note that a high correlation coefficient does not necessarily mean that the two tools are measuring the same thing, and a low correlation coefficient does not necessarily mean that the two tools are measuring different things.

Therefore, in a validity study, a small mean difference between the measurements and a high Pearson's correlation coefficient would suggest that the two tools are measuring the same construct or attribute consistently and are, therefore, valid measures. However, a large mean difference and a low correlation coefficient may suggest that the two tools are not measuring the same construct or attribute or that there is systematic bias in one or both of the tools, indicating that the measures are not valid.

In summary, a validity study with a mean difference and Pearson correlation can provide information about the agreement and corelation between two measurement tools and can help researchers and clinicians decide whether the tools can be used interchangeably or if one tool is preferred over the other for a particular application. In terms of type 1 and type 2 errors, the advantage of using corrections for multiple testing is a reduction in false positive conclusions, while the primary disadvantage is an elevated risk of false negatives and decreased power. The optimal balance is context-dependent and relies on weighing the relative costs of each type of inferential error in the given research setting and scientific field. Researchers must consider these trade offs carefully when making methodological decisions involving multiple pairwise statistical tests.

4.5. Results

4.4.1. Between-Days Repeatability

4.4.1.1. Clinical and functional data

Table 4.5: Summary of the clinical outcomes of muscle strength, ankle ROM, dynamic balance and bimalleolar width. Between-day coefficient of variation ranges, intra-rater repeatability, intraclass correlation coefficients (ICC), (Mean 1 and Mean 2), standard deviations pooled, SEM and MDD for the clinical measurements

Variable	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Hip Extensors N/kg	11.54	0.97	2.86	2.89	0.03	0.33	–0.20	0.06	0.16
Hip Abductors N/kg	9.35	0.96	2.45	2.48	0.03	0.23	0.05	0.05	0.13
Ankle dorsiflexors N/kg	13.45	0.98	2.23	2.25	0.02	0.30	–0.36	0.04	0.11
Ankle plantarflexors N/kg	10.78	0.98	4.05	4.08	0.03	0.44	–0.296	0.06	0.16
Evertors N/kg	11.93	0.98	1.76	1.77	0.01	0.21	–0.16	0.03	0.08
Invertors N/kg	9.57	0.96	1.88	1.90	0.02	0.18	–0.17	0.04	0.11
Ankle dorsiflexion ROM (°)	19.44	0.98	12.33	12.67	0.34	2.40	–0.09	0.34	0.94

Variable	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Ankle plantarflexion ROM (°)	6.04	0.98	39.81	40.17	0.36	2.41	–0.66	0.34	0.94
Inversion ROM (°)	10.62	0.97	16.67	15.67	1.00	1.77	–0.04	0.31	0.85
Eversion ROM (°)	15.29	0.97	14.00	13.67	0.33	2.14	–0.27	0.37	1.02
Anterior YBT (%)	8.81	0.96	77.05	78.08	1.03	6.79	–0.35	1.36	3.76
Posteromedial YBT (%)	9.45	0.98	81.78	81.82	0.04	7.72	–0.06	1.09	3.02
Posterolateral YBT (%)	5.91	0.98	86.66	87.45	0.79	5.15	–1.21	0.73	2.02
Bimalleolar width(cm)	7.42	0.99	6.60	6.60	0.00	0.49	–0.34	0.05	0.13

Note: ***YBT:*** *Y-balance test****, ROM:*** *Range of motion,* ***IC: (°)****: Degree,* ***N/Kg:*** *Newton per kilogram and* ***%:*** *percentage.*

The hip extensors (N/kg), hip abductors (N/kg), ankle dorsiflexors (N/kg), ankle plantarflexors (N/kg), evertors (N/kg), invertors (N/kg), ankle dorsiflexion ROM (°), ankle plantarflexion ROM (°), inversion ROM (°), eversion ROM (°), AN TYBT (%), PM YBT (%), PL YBT (%) and bimalleolar width (cm) were measured. The bimalleolar width demonstrated a maximum ICC of 0.99, with 95% CI and 0.05 (cm) SEM. The hip abductor strength and ankle invertor strength demonstrated a minimum ICC of 0.96, with 0.05 SEM and 0.04 N/kg, respectively. The coefficient of variation for all clinical outcomes were less than 19.44, which demonstrated excellent to good repeatability overall (Table 4.5).

4.4.1.2. Biomechanical data

The results for the biomechanical variables during the LH at 20 ms pre-IC and 300 ms post-IC (Table 4.6) demonstrated an ICC ranging between 0.67 to 0.98 and an SEM between 0.64 (°) to 3.25 (°). The peak of knee° towards extension at pre-IC (°) and the peak of knee° towards flexion at pre-IC (°) demonstrated the highest ICC of 0.98, with SEM of 1.45 (°) and 1.64 (°), respectively. The coefficient of variation ranges from 6.99 (%) at (peak of FPPA° towards adduction at post-IC (°)) to 18.1 (%) at (peak of ankle° towards dorsiflexion at pre-IC (°)), demonstrating excellent to good repeatability.

Table 4.6: The results for the lateral hop (LH) data at 20 ms pre-IC to 300 ms post-IC

2D during LH (º)	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Peak of ankle° towards dorsiflexion pre-IC (°)	18.1	0.90	–15.33	–14.99	0.34	2.19	–0.27	0.69	1.91
Peak of ankle° towards plantarflexion pre-IC (°)	14.20	0.89	–13.49	–13.89	0.40	1.94	0.34	0.64	1.77
Ankle° dorsi/plantarflexion at IC (°)	15.32	0.87	–16.53	–15.57	0.96	7.37	–0.19	2.66	7.37
Peak of ankle° towards dorsiflexion post-IC (°)	13.11	0.85	–13.69	–12.51	1.18	6.96	–0.24	2.70	7.4
Peak of ankle° towards plantarflexion post-IC (°)	18.01	0.73	18.47	20.32	1.85	5.63	–0.36	2.93	8.12
Peak of ankle° towards eversion pre-IC (°)	9.44	0.96	–0.04	–0.33	0.29	4.58	0.15	0.92	2.55
Peak of ankle° towards inversion pre-IC (°)	11.21	0.96	1.58	1.31	0.27	4.58	0.17	0.92	2.55
Ankle° eversion/inversion at IC (°)	11.13	0.75	3.25	1.56	1.69	5.42	0.35	2.71	7.51

2D during LH (°)	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Peak of ankle° towards eversion post-IC (°)	14.21	0.82	–1.82	–3.36	1.54	5.18	0.39	2.20	6.09
Peak of ankle° towards inversion post-IC (°)	9.63	0.84	9.82	8.57	1.25	4.89	0.35	1.95	5.4
Peak of knee° towards extension pre-IC (°)	8.90	0.98	27.39	26.95	0.44	10.24	0.14	1.45	4.01
Peak of knee° towards flexion pre-IC (°)	13.42	0.98	31.39	30.68	0.71	11.63	0.21	1.64	4.54
Knee° flexion/extension angle at IC (°)	17.01	0.97	24.95	24.80	0.15	8.91	0.08	1.54	4.26
Peak of knee° towards extension post-IC (°)	9.88	0.92	22.54	22.02	0.52	7.08	1.13	2.00	5.54
Peak of knee° towards flexion post-IC (°)	10.11	0.90	45.26	45.61	0.35	7.49	0.08	2.37	6.56
Peak of FPPA° towards adduction pre-IC (°)	9.43	0.88	–4.08	–4.48	0.40	2.82	0.21	0.98	2.71
Peak of FPPA° towards abduction pre-IC (°)	8.76	0.87	–2.80	–3.16	0.36	2.76	0.19	0.99	2.74
FPPA° adduction/abduction at IC (°)	8.32	0.92	–7.34	–6.02	1.32	5.68	–0.45	1.61	4.46
Peak of FPPA° towards adduction post-IC (°)	6.99	0.86	–10.44	–12.30	1.86	6.57	0.45	2.46	6.81
Peak of FPPA° towards abduction post-IC (°)	10.21	0.67	–0.49	–2.52	2.03	5.66	0.37	3.25	9.00

Note: ***LH:*** *Lateral hopping,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plane projection angle,* ***IC:*** *Initial contact,* ***(°)****: Degree and (cm)****:*** *Centimetre.*

The results of the biomechanical variables during SLL at 20 ms pre-IC and 300 ms post-IC (Table 4.7) demonstrated an ICC ranging between 0.64 to 0.97 and an SEM between 0.75 (°) to 3.00 (°). The knee° flexion/extension angle at IC (°) demonstrated a maximum ICC of 0.97, with an SEM of 0.75 (°), while the peak of ankle° towards inversion at post-IC (°) demonstrated the lowest ICC of 0.64, with an SEM of 2.83 (°). The coefficient of variation ranges from 8.45 (%) at ankle° eversion/inversion at IC (°) to

15.01 (%) at peak of ankle° towards plantarflexion at pre-IC (°), demonstrating excellent to good repeatability.

Table 4.7: The results for the single-leg landing (SLL) data at 20 ms pre-IC to 300 ms post-IC

2D during SLL (º)	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Peak of ankle° towards dorsiflexion pre-IC (°)	12.11	0.92	–22.32	–21.16	1.16	6.65	–0.33	1.88	5.21
Peak of ankle° towards plantarflexion pre-IC (°)	15.01	0.91	31.25	29.73	1.52	6.57	0.43	1.97	5.46
Ankle° dorsi/plantarflexion at IC (°)	9.43	0.88	18.91	16.69	2.22	6.21	0.61	2.15	5.95
Peak of ankle° towards dorsiflexion post-IC (°)	10.32	0.87	–12.94	–10.70	2.24	5.81	–0.62	2.10	5.82
Peak of ankle° towards plantarflexion post-IC (°)	9.665	0.84	22.28	22.78	0.50	5.12	0.19	2.05	5.68
Peak of ankle° towards eversion pre-IC (°)	8.92	0.91	5.46	5.27	0.19	2.72	0.12	0.82	2.27
Peak of ankle° towards inversion pre-IC (°)	11.23	0.91	6.86	6.50	0.36	2.97	0.21	0.89	2.46
Ankle° eversion/inversion at IC (°)	8.45	0.68	5.10	3.48	1.62	5.30	0.31	3.00	8.31
Peak of ankle° towards eversion post-IC (°)	11.15	0.85	–10.89	–12.10	1.21	6.77	–0.25	2.62	7.26
Peak of ankle° towards inversion post-IC (°)	14.02	0.64	1.67	–0.21	1.46	4.71	0.39	2.83	7.84
Peak of knee° towards extension pre-IC (°)	11.34	0.96	7.67	8.11	0.44	3.94	–0.28	0.79	2.18
Peak of knee° towards flexion pre-IC (°)	10.32	0.95	8.80	9.33	0.53	3.98	–0.32	0.89	2.46
Knee° flexion/extension angle at-IC (°)	8.91	0.97	10.57	10.69	0.12	4.36	–0.07	0.75	2.07
Peak of knee° towards extension post-IC (°)	12.98	0.96	13.17	13.23	0.06	4.44	–0.04	0.89	2.46
Peak of knee° towards flexion post-IC (°)	11.23	0.93	51.93	52.67	0.74	6.46	–0.22	1.71	4.73

2D during SLL (º)	CV (%)	ICC	Mean 1	Mean 2	Mean Diff.	SD	Effect Size	SEM	MDD
Peak of FPPA° towards adduction pre-IC (°)	10.89	0.87	–2.26	–2.88	0.62	3.92	0.23	1.41	3.9
Peak of FPPA° towards abduction pre-IC (°)	12.76	0.86	–1.78	–2.46	0.68	3.79	0.26	1.42	3.93
FPPA° adduction/abduction at IC (°)	11.98	0.82	–2.34	–2.32	0.02	4.18	–0.01	1.77	4.90
Peak of FPPA° towards adduction post-IC (°)	12.89	0.82	–6.80	–7.32	0.52	5.57	0.12	2.36	6.54
Peak of FPPA° towards abduction post-IC (°)	9.43	0.78	2.21	2.05	0.16	4.77	0.04	2.24	6.2

Note: ***SLL:*** *Single-leg landing,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plane projection angle,* ***IC:*** *Initial contact,* ***(°)****: Degree and (cm)****:*** *Centimetre.*

4.4.2. Validity of 2D Motion Analysis with 3D Kinematics

The validity results of the 2D motion analysis during SLL demonstrated high statistical significance ($p \leq 0.05$) and a strong correlation ranging from 0.989 to 0.582 ($r = 0.989$ to 0.582). This indicates that the 2D motion analysis method used in assessing SLL was highly valid, showing a consistent and significant correlation between the measured variables.

Table 4.8: The validity results for the ankle and knee joint angles at the sagittal plane (x) and frontal plane (y) between 2D and 3D, with the Pearson correlation coefficients (r), mean for 2D and 3D and $p < 0.05$ during SLL in three phases at 20 ms pre-IC, the angle of IC and 300 ms post-IC

Validity between 2D and 3D during SLL (º)	2D		3D		Mean Diff.	R	p-value
	Mean	SD	Mean	SD			
Peak of ankle° towards dorsiflexion pre-IC (°)	–21.74	6.92	–22.15	6.84	0.41	0.951**	0.01
Peak of ankle° towards plantarflexion pre-IC (°)	30.49	6.41	24.82	7.57	5.67	0.888**	0.01
Ankle° dorsi/plantarflexion at IC (°)	17.8	7.23	17.47	7.17	0.33	0.996**	0.01
Peak of ankle° towards dorsiflexion post-IC (°)	–11.82	6.89	–13.67	6.70	1.85	0.991**	0.01
Peak of ankle° towards plantarflexion post-IC (°)	22.53	5.28	20.79	5.47	1.74	0.911**	0.01
Peak of ankle° towards eversion pre-IC (°)	5.36	10.93	–2.93	5.09	8.3	0.801**	0.01
Peak of ankle° towards inversion pre-IC (°)	6.68	8.32	3.69	4.17	2.99	0.426	
Ankle° eversion/inversion at IC (°)	4.29	6.34	1.32	4.76	2.97	0.680*	0.05
Peak of ankle° towards eversion post-IC (°)	–12.71	7.83	–7.49	4.39	5.22	0.669*	0.05
Peak of ankle° towards inversion post-IC (°)	0.73	5.62	–0.63	4.45	1.36	0.709**	0.01
Peak of knee° towards extension pre-IC (°)	7.89	5.03	7.37	4.93	0.52	0.959**	0.01

Validity between 2D and 3D during SLL (º)	2D		3D		Mean Diff.	R	p-value
	Mean	SD	Mean	SD			
Peak of knee° towards flexion at pre-IC (°)	9.06	8.58	4.14	11.87	4.92	0.964**	0.01
Knee° flexion/extension angle at IC (°)	10.83	4.56	10.62	4.48	0.21	0.984**	0.01
Peak of knee° towards extension post-IC (°)	13.2	4.57	12.72	4.69	0.48	0.989**	0.01
Peak of knee° towards flexion post-IC (°)	52.3	6.36	50.7	7.79	1.60	0.942**	0.01
Peak of FPPA° towards adduction pre-IC (°)	–2.57	3.98	–4.1	5.06	1.53	0.630*	0.05
Peak of FPPA° towards abduction pre-IC (°)	–2.12	3.70	–3.29	4.72	1.17	0.582*	0.05
FPPA° adduction/abduction at IC (°)	–2.33	3.81	–2.81	4.11	0.48	0.932**	0.01
Peak of FPPA° towards adduction post-IC (°)	–7.06	4.99	–8.36	5.03	1.3	0.849**	0.01
Peak of FPPA° towards abduction post-IC (°)	2.13	4.93	1.1	5.45	1.03	0.709**	0.01

Note: ***SLL:*** *Single-leg landing,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plane projection angle,* ***Pre:*** *Before,* ***Post:*** *After,* ***IC:*** *Initial contact* ***and (°)****: Degree.*

The Bland–Altman test demonstrates no significant difference between the two observations, as supported by a Cohen's d value of –0.290 (95% CI: –0.734 to 0.161). This indicates that the two observation methods are in close agreement, with minimal variations between them.

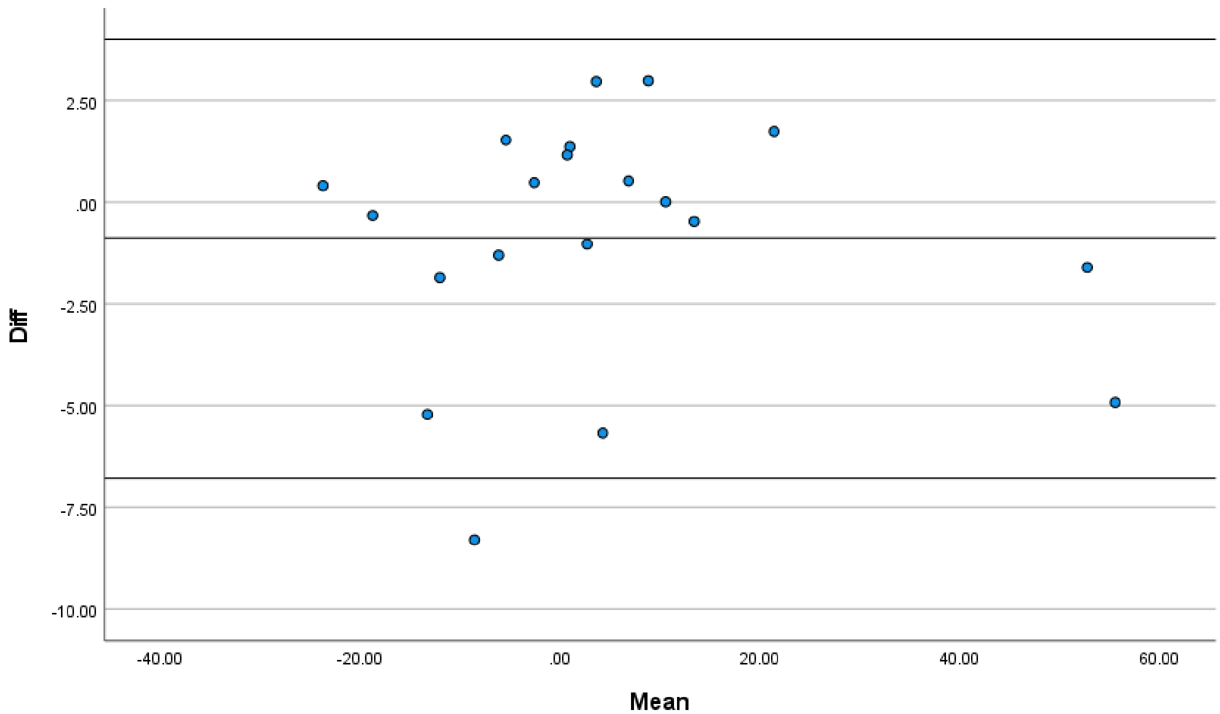


Figure 4.10: Bland–Altman plot between 2D and 3D observations during SLL

The validity results of the 2D motion analysis in LH indicated statistical significance ($p \leq 0.05$) and a range of correlations from 0.521 to 0.989 ($r = 0.521$ to 0.989). These findings suggest that the 2D motion analysis method used in assessing LH was valid, showing a consistent and significant correlation between the measured variables.

Table 4.9: The validity results for the ankle and knee joint angles at the sagittal plane (x) and frontal plane (y) between 2D and 3D, with the Pearson correlation coefficients ®, mean for 2D and 3D and $p < 0.05$ during LH in three phases at 20 ms pre-IC, the angle of IC and 300 ms post-IC

Validity between 2D and 3D during LH (°)	**2D**		**3D**		**Mean Diff.**	**R**	**p-value**
	Mean	**SD**	**Mean**	**SD**			
Peak of ankle° towards dorsiflexion pre-IC (°)	–15.16	6.00	–19.27	6.08	4.11	0.711**	0.01
Peak of ankle° towards plantarflexion pre-IC (°)	–13.69	6.30	–19.42	5.80	5.73	0.910**	0.01
Ankle° dorsi/plantarflexion at IC (°)	–16.05	7.09	–16.93	7.38	0.88	0.989**	0.01
Peak of ankle° towards dorsiflexion at post-IC (°)	–13.1	6.61	–13.31	6.82	0.21	0.979**	0.01
Peak of ankle° towards plantarflexion post-IC (°)	19.39	5.22	16.72	4.38	2.67	0.813**	0.01
Peak of ankle° towards eversion pre-IC (°)	–0.185	13.52	–2.70	5.61	2.52	0.695*	0.05
Peak of ankle° towards inversion pre-IC (°)	1.44	7.83	–3.08	6.41	4.53	0.770**	0.05
Ankle° eversion/inversion at IC (°)	2.40	5.87	1.58	4.84	0.82	0.967**	0.01
Peak of ankle° towards eversion post-IC (°)	–2.59	4.93	–5.15	3.36	2.56	0.644*	0.05
Peak of ankle° towards inversion post-IC (°)	9.19	5.06	8.92	4.59	0.27	0.894**	0.01
Peak of knee° towards extension pre-IC (°)	27.17	8.47	27.01	8.08	0.16	0.962**	0.01
Peak of knee° towards flexion pre-IC (°)	31.03	10.69	22.13	10.36	8.9	0.923**	0.01
Knee° flexion/extension angle at IC (°)	24.87	8.55	22.79	7.41	2.08	0.949**	0.01
Peak of knee° towards extension post-IC (°)	22.28	6.93	21.21	7.37	1.07	0.974**	0.01

Validity between 2D and 3D during LH (°)	2D		3D		Mean Diff.	R	p-value
	Mean	SD	Mean	SD			
Peak of knee° towards flexion post-IC (°)	45.43	6.62	43.71	7.73	1.72	0.949**	0.01
Peak of FPPA° towards adduction pre-IC (°)	–4.28	8.81	–6.14	6.31	1.86	0.521	
Peak of FPPA° towards abduction pre-IC (°)	–2.98	7.55	–3.1	5.03	0.12	0.585*	0.05
FPPA° adduction/abduction at IC (°)	–6.68	5.84	–7.33	6.21	0.65	0.912**	0.01
Peak of FPPA° towards adduction post-IC (°)	–11.37	7.73	–12.21	6.17	0.84	0.805**	0.01
Peak of FPPA° towards abduction post-IC (°)	–1.50	5.77	–2.43	3.77	0.93	0.730**	0.01

Note: ***LH:*** *Lateral hopping,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plane projection angle,* ***Pre:*** *Before,* ***Post:*** *After,* ***IC:*** *Initial contact and* ***(°)****: Degree.*

The Bland–Altman test revealed a high level of agreement between the two measurements, supported by low effect size. The Cohen's d value of –0.156 (95% CI: –0.595 to 0.287) indicates a minimal difference between the two measurement methods. This suggests that the measurements are in close agreement and the observed differences are not clinically significant.

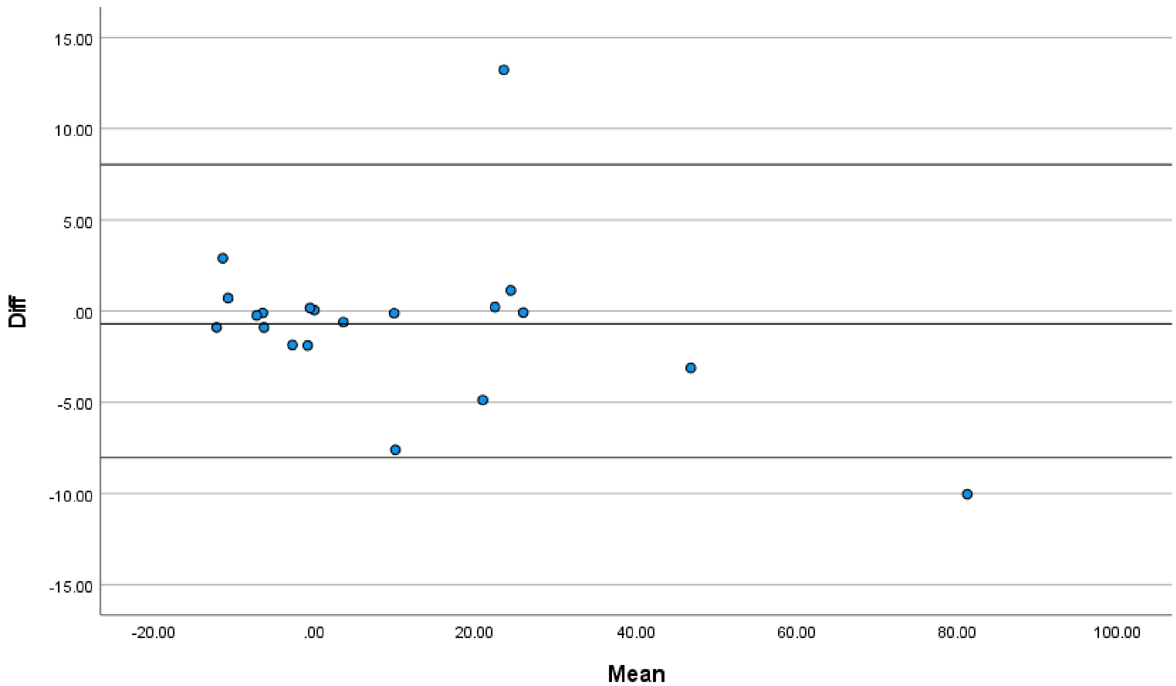


Figure 4.11: Bland–Altman plot between the 2D and 3D observations during LH

4.4.3. Guidelines for Reporting Reliability and Agreement Studies (GRRAS) Checklist

Table 4.10: Guidelines for Reporting Reliability and Agreement Studies (GRRAS) checklist for reporting of reliability and agreement studies (version based on Table I in Kottner et al., 2011))

Section	**Item #**	**Checklist Item**	**Reported on Page # / Section / Chapter**
Title/Abstract	1	Identify in the title or abstract that inter-rater/intra-rater reliability or agreement was investigated.	Page 143
Introduction	2	Name and describe the diagnostic or measurement device of interest explicitly.	Page 151, Section 4.2.2.1.
	3	Specify the subject population of interest.	Military population was the population of interest; however, this study could not be applied to them due to the COVID-19
	4	Specify the rater population of interest (if applicable).	N/A
	5	Describe what is already known about reliability and agreement and provide a rationale for the study (if applicable).	Page 147

Methods	6	Explain how the sample size was chosen. State the determined number of raters, subjects/objects and replicate observations.	Pages 145 - 151
	7	Describe the sampling method.	Section 4.2.2
	8	Describe the measurement/rating process (e.g. time interval between repeated measurements, availability of clinical information, blinding).	Section 4.2.2
	9	State whether the measurements/ratings were conducted independently.	Yes
	10	Describe the statistical analysis.	Section 4.4
Results	11	State the actual number of raters and subjects/objects included and the number of replicate observations conducted.	One rater examined between session repeatability; Observations were made in two sessions
	12	Describe the sample characteristics of the raters and subjects (e.g. training, experience).	A physiotherapist and academic lecturer at the University of Hail
	13	Report estimates of reliability and agreement, including measures of statistical uncertainty.	Section 4.3
Discussion	14	Discuss the practical relevance of the results.	Chapter 5
Auxiliary material	15	Provide detailed results if possible (e.g. online).	Section 4.4

4.6. Discussion

In this study, the repeatability of the clinical, functional and biomechanical measures, along with the validity of 2D motion analysis compared with 3D kinematics, was evaluated. The findings of the study reject the null hypothesis and support the alternate hypothesis. The evaluation of the clinical and biomechanical data collected in the study demonstrates generally moderate to high repeatability for all the tools used, according to the ICC criteria by Koo and Li (2016). In addition, the validity of 2D kinematics was found to be high, as indicated by the Bland–Altman test showing a strong agreement between the observations (Koo & Li, 2016).

To strengthen the study and ensure comprehensive reporting, the checklist for the GRRAS was included in Table 4.10. The GRRAS checklist serves as a valuable resource for researchers, providing guidance on the important aspects to consider and report when conducting reliability and agreement studies in the field of health research (Kottner et al., 2011). By including the GRRAS checklist in the results section, readers and reviewers can easily access the specific criteria recommended by the guidelines. This promotes transparency and facilitates a thorough assessment of the study's methodology, data collection procedures, statistical analysis and interpretation of results.

Therefore, by reporting the GRAAS checklist in the results section, the researcher has taken deliberate steps to demonstrate the rigour of the research methodology. The inclusion of the GRRAS checklist in the study's appendix serves as a testament to the commitment to transparency and methodological precision. This strategic placement allows readers and reviewers to readily access the detailed criteria outlined in the guidelines.

This study aligns closely with the principles laid out in the GRRAS checklist, reflecting a conscious effort to adhere to the recommended standards. By incorporating this checklist into the research framework, the current study has proactively addressed essential aspects of the study design, data collection procedures, statistical analysis and result interpretation, which not only reinforces the study's internal validity but also presents an opportunity for readers to comprehensively assess the reliability and agreement of the measured variables.

Furthermore, the presence of the GRRAS checklist serves as a valuable tool for fellow researchers seeking guidance in enhancing the quality and credibility of their own investigations. By highlighting the adherence to these established standards. Also, this study underscore that sound information is provided to evaluate the reliability and agreement of the measured variables.

HHD is a cost-effective, portable and user-friendly method for assessing isometric strength. Due to its numerous advantages, including its popularity, many studies have investigated the reliability and validity of HHD (Keep et al., 2016; Kelln et al., 2008; Rnold et al., 2010). In the present study, the results of the isometric strength assessment using HHD demonstrated excellent reliability for ankle dorsiflexors, plantarflexors, evertors and invertors, as well as hip extensors and abductors.

The repeatability of the ankle plantarflexor strength (N/kg) in the supine position was assessed for between-day measurements. Excellent to good repeatability was achieved, as demonstrated by the coefficient of variation. The results indicated high reliability, with consistent measurements observed across different testing sessions, which presented an ICC value of 0.98. The mean values for the first and second conditions were 4.05 and 4.08 N/kg, respectively. The mean difference was 0.03 N/kg, indicating a small change between the two conditions. The SD was 0.44 N/kg, reflecting the variability of data points around the mean. The SEM was 0.06 N/kg, representing the precision of the mean estimate. The MDD was 0.16 N/kg, suggesting that a change of at least 0.16 N/kg is considered minimally detectable for ankle plantarflexor strength. Similarly, a study conducted by Davis et al. (2017) also assessed the muscle strength of the same muscle group in the supine position. Their findings showed a high level of reliability, as indicated by an ICC of 0.98. In addition, the SEM value reported in their study was 3.2 Nm, without normalisation. These results further support the consistent and reliable measurement of muscle strength in the supine position for the specific muscle group examined (Davis et al., 2017).

For ankle dorsiflexor strength (N/kg), the ICC value of 0.98 indicates high reliability. The mean values for the first and second conditions were 2.23 and 2.25 N/kg, respectively. The mean difference was 0.02 N/kg, indicating a small change between the two conditions. The SD was 0.30 N/kg, reflecting the variability of data points around the mean. The SEM was 0.04 N/kg, representing the precision of the mean estimate. The MDD was 0.11 N/kg, suggesting that a change of at least 0.11 N/kg was minimally detectable for ankle dorsiflexor strength. By contrast, Kelln et al. (2008) reported ICCs ranging from 0.87 to 0.94 for three trials in a supine position. In addition, the SEM values in their study ranged from 0.7 to 0.15. These results suggest that the measurements of muscle strength in the supine position had good to excellent reliability (Kelln et al., 2008).

Moreover, Kelln et al. (2008) also demonstrated excellent reliability in measuring invertor strength, with a high level of consistency (Kelln et al., 2008). In the current study, the ICC value of 0.96 for invertor strength (N/kg) suggests high reliability in measuring invertor strength. The mean values for the first and second conditions were 1.88 and 1.90 N/kg, respectively. The mean difference was 0.02 N/kg, indicating a small change between the two conditions. The SD was 0.18 N/kg, reflecting the variability of data points around the mean. The SEM was 0.04 N/kg, representing the precision of the mean estimate. The MDD was 0.11 N/kg, suggesting that a change of at least 0.11 N/kg was minimally detectable for invertor strength. Furthermore, for evertors (N/kg), an ICC value of 0.98 suggests high reliability in measuring evertor strength. The mean values for the first and second conditions were 1.76 and 1.77 N/kg, respectively. The mean difference was 0.01 N/kg, indicating a small change between the two conditions. The SD was 0.21 N/kg, reflecting the variability of data points around the mean. The SEM was 0.03 N/kg, representing the precision of the mean estimate. The MDD was 0.08 N/kg, suggesting that a change of at least 0.08 N/kg was minimally detectable for evertor strength.

By contrast, the present study focused on the reliability of the HHD in assessing the invertor and evertor muscle groups. The results revealed excellent reliability for both muscle groups, with an ICC of 0.96 for the invertor muscle group and 0.98 for the evertor muscle group. The SEM values were also low, with 0.03 N/kg for the evertor muscle group and 0.04 N/kg for the invertor muscle group. These findings indicate that the measurements of muscle strength in the invertor and evertor muscle groups are highly reliable in this study.

For hip extensors (N/kg), the ICC value of 0.97 suggests high reliability in measuring hip extensor strength. The mean values for the first and second conditions were 2.86 and 2.89 N/kg, respectively. The mean difference was 0.03 N/kg, indicating a small change between the two conditions. The SD was 0.33 N/kg, reflecting the variability of data points around the mean. The SEM was 0.06 N/kg, representing the precision of the mean estimate. The MDD was 0.16 N/kg, indicating that a change of at least 0.16 N/kg was minimally detectable for hip extensor strength.

For hip abductors (N/kg), an ICC value of 0.96 suggests high reliability in measuring hip abductor strength. The mean values for the first and second conditions were 2.45 and 2.48 N/kg, respectively. The mean difference was 0.03 N/kg, indicating a small change between the two conditions. The SD was 0.23 N/kg, reflecting the variability of data points around the mean. The SEM was 0.05 N/kg, representing the precision of the mean estimate. The MDD was 0.13 N/kg, suggesting that a change of at least 0.13 N/kg was minimally detectable for hip abductor strength.

The findings from various studies indicate consistent and reliable measurements when using a goniometer to assess joint ROM, including that of Clapper et al. (1998). In the current study, the reliability of ankle joint ROM measurements was examined using a universal goniometer. The results demonstrated excellent reliability, with ICCs ranging from 0.97 to 0.98 (Table 4.5). In addition, the SEM values for ankle joint ROM measurements ranged from 0.31º to 0.37º, indicating minimal measurement error.

These results provide further support for the reliability of using HHD and goniometry to assess joint ROM.

For ankle dorsiflexion ROM (°), the ICC value of 0.98 indicates high reliability in measuring ankle dorsiflexion ROM. The mean values for the first and second conditions were 12.33° and 12.67°, respectively. The mean difference was 0.34°, indicating a small change between the two conditions. The SD was 2.40°, reflecting the variability of data points around the mean. The SEM was 0.34°, representing the precision of the mean estimate. The MDD was 0.94°, suggesting that a change of at least 0.94° was minimally detectable for ankle dorsiflexion ROM. A study examining the reliability of a goniometer for assessment of dorsiflexion ROM was found to have a high ICC of 0.96, indicating good agreement between measurements. The SEM for dorsiflexion ROM was reported as 1.8°, suggesting minimal measurement error. Another study also reported a favourable ICC score of 0.92 for dorsiflexion ROM. These findings collectively suggest that the measurement of dorsiflexion ROM was reliable and consistent across different studies. However, further research in this area is warranted to validate and expand upon these findings (Clapper & Wolf, 1988).

For ankle plantarflexion ROM (°), the ICC value of 0.98 suggests high reliability in measuring ankle plantarflexion ROM. The mean values for the first and second conditions were 39.81° and 40.17°, respectively. The mean difference was 0.36°, indicating a small change between the two conditions. The SD was 2.41°, reflecting the variability of data points around the mean. The SEM was 0.34°, representing the precision of the mean estimate. The MDD was 0.94°, suggesting that a change of at least 0.94° was minimally detectable for ankle plantarflexion ROM. In a previous study by Clapper and Wolf (1988), the reliability of plantarflexion measurements was assessed, yielding an ICC score of 0.96. In the current study, plantarflexion measurements were also evaluated, and the results demonstrated excellent ICC agreement (0.98), indicating a high level of consistency and reliability. The SEM value for plantarflexion was calculated as 0.34º, suggesting minimal measurement error. These findings further support the reliability of plantarflexion measurements and underscore the consistency of the results across different studies.

For inversion ROM (°), the ICC value of 0.97 suggests high reliability in measuring inversion ROM. The mean values for the first and second conditions were 16.67° and 15.67°, respectively. The mean difference was 1.00°, indicating a relatively larger change between the two conditions. The SD was 1.77°, reflecting the variability of data points around the mean. The SEM was 0.31°, representing the precision of the mean estimate. The MDD was 0.85°, suggesting that a change of at least 0.85° was minimally detectable for inversion ROM.

For eversion ROM (°), the ICC value of 0.97 suggests high reliability in measuring eversion ROM. The mean values for the first and second conditions were 14.00° and 13.67°, respectively. The mean difference was 0.33°, indicating a small change between the two conditions. The SD was 2.14°, reflecting the variability of data points around the mean. The SEM was 0.37°, representing the precision of the mean estimate. The MDD was 1.02°, suggesting that a change of at least 1.02° was minimally detectable for eversion ROM.

The measurement of subtalar eversion ROM between days has been subject to limited research and conflicting findings. However, in the present study, excellent ICC scores of

0.97 were achieved for both measures, indicating a high level of agreement and consistency. The SEM for subtalar eversion ROM ranged from 0.31° to 0.37°, suggesting minimal measurement error. By contrast, a single study using the same method reported moderate ICC scores ranging from 0.53 to 0.64 and SEM values between 2.1° to 3.8° when three different examiners were involved (Gwynne et al., 2014). This discrepancy highlights the importance of standardised measurement protocols and the potential influence of examiner variability on the repeatability of subtalar eversion ROM measurements.

The dynamic balance assessment using the YBT evaluated balance in three directions: ANT, PL and PM. The results were normalised to limb length to account for individual variations. The repeatability analysis demonstrated excellent ICC scores ranging from 0.96 to 0.98, indicating a high degree of consistency in the measurement of dynamic balance. The SEM values ranged from 0.73 cm to 1.36 cm, suggesting minimal measurement error. These findings suggest that the present study has established a high level of repeatability for both subtalar eversion ROM and the YBT, providing valuable insights into the reliability of these measurements. It highlights the importance of standardised protocols and skilled examiners to ensure accurate and consistent assessment of dynamic balance and subtalar eversion ROM.

For ANT YBT (%), the ICC value of 0.96 indicates high reliability in measuring ANT reach on the YBT. The mean values for the first and second conditions were 77.05 and 78.08 cm, respectively. The mean difference was 1.03 cm, indicating a small change between the two conditions. The SD was 6.79 cm, reflecting the variability of data points around the mean. The SEM was 1.36 cm, representing the precision of the mean estimate. The MDD was 3.76 cm, suggesting that a change of at least 3.76 cm was minimally detectable for ANT reach on the YBT.

For PM YBT (%), the ICC value of 0.98 suggests high reliability in measuring PM reach on the YBT. The mean values for the first and second conditions were 81.78 and 81.82 cm, respectively. The mean difference was 0.04 cm, indicating a small change between the two conditions. The SD was 7.72 cm, reflecting the variability of data points around the mean. The SEM was 1.09 cm, representing the precision of the mean estimate. The MDD was 3.02 cm, suggesting that a change of at least 3.02 cm was minimally detectable for PM reach on the YBT.

For PL YBT (%), the ICC value of 0.98 suggests high reliability in measuring PL reach on the YBT. The mean values for the first and second conditions were 86.66 and 87.45 cm, respectively. The mean difference was 0.79 cm, indicating a small change between the two conditions. The SD was 5.15 cm, reflecting the variability of data points around the mean. The SEM was 0.73 cm, representing the precision of the mean estimate. The MDD was 2.02 cm, suggesting that a change of at least 2.02 cm was minimally detectable for PL reach on the YBT.

The findings of the study conducted by Hyouk & Kim (2014) provide valuable information about the reliability of the measurements. The intra-rater SEM values indicate the amount of error expected in the measurements taken by the same examiner. The reported values ranging from 2.41 to 3.30 suggest that the measurements in Hyouk's study had relatively low measurement error. The MDD values represent the smallest change in measurement that can be considered beyond measurement error. The range of MDD values from 7.16 to 8.99 indicates that any observed differences in measurements beyond these thresholds are likely to be real and not due to measurement error alone. The ICC values assess the consistency and agreement of measurements made by the same examiner. The range of ICC values from 0.88 to 0.96 suggests a high level of agreement and consistency in the measurements taken by Hyouk & Kim (2014).

The consistency between the findings of Hyouk's study and the current study suggests that both studies have observed similar levels of reliability in their measurements. This strengthens the confidence in the reliability of the measurements obtained in the current study and enhances the overall validity of the findings.

In addition to the repeatability of the 2D analysis, the repeatability of the YBT has also been investigated in previous studies. These studies have shown promising results with good to excellent ICC scores. For example, in a study conducted by Hyong and Kim (2014), the ICC scores for the YBT ranged from 0.88 to 0.94. The SEM was reported to be between 2.41 cm and 3.3 cm. Similarly, Hertel et al. (2000) conducted a study that also reported favourable ICC results ranging from 0.81 to 0.96 for the YBT. These findings highlight the reliability and consistency of the YBT as a measurement tool for assessing balance and functional stability. The high ICC scores indicate that the YBT can provide reproducible results, making it a valuable assessment tool in research and clinical settings (Hertel et al., 2000; Hyouk & Kim 2014).

For bimalleolar width (cm), the ICC value of 0.99 suggests high reliability in measuring bimalleolar width. The mean values for the first and second conditions were 6.60 cm in both cases. The mean difference was 0.00 cm, indicating no change between the two conditions. The SD was 0.49 cm, reflecting the variability of data points around the mean. The SEM was 0.05 cm, representing the precision of the mean estimate. The MDD was 0.13 cm, suggesting that a change of at least 0.13 cm was minimally detectable for bimalleolar width.

Prior research investigating the risk factors for ankle sprains has predominantly utilised 3D analysis methods, as demonstrated in studies conducted by Rice et al. (2017) and Willems et al. (2004). However, the use of 2D video analysis has gained popularity due to its advantages in screening a larger number of participants quickly, its simplicity and its portability. The viability of incorporating 2D analysis in clinical research relies on its repeatability and the validity of its kinematic variables as outcomes for lower limb assessments. In terms of the repeatability of the 2D analysis across multiple days, several studies have reported positive findings. Specifically, studies examining FPPA through video analysis have indicated good to excellent repeatability. This is evident in the research conducted by Herrington et al. (2017), Gwynne and Curran (2014) and Munro et al. (2012). These studies have demonstrated the potential of 2D analysis to yield consistent and reliable measurements for FPPA using video recordings (Gwynne & Curran, 2014; Herrington et al., 2017; Munro et al., 2012).

The analysis of between-day repeatability in the 2D analysis during LH (º) demonstrated a high reliability of measurement, supported by a strong ICC and a lower SEM. The results indicate consistent and reliable measurements across different days. The following variables were assessed for repeatability between days.

The peak of ankle° towards dorsiflexion at pre-IC (°) demonstrates high reliability with an ICC of 0.90. The average difference between Mean 1 and Mean 2 was 0.34 units.

The SD was 2.19, indicating the variability of data points around the mean. The SEM was 0.69, representing the precision of the mean estimate. The MDD was 1.91.

The peak of ankle° towards plantarflexion at pre-IC (°) also demonstrates high reliability with an ICC of 0.89. The average difference between Mean 1 and Mean 2 was 0.40 units. The SD was 1.94, indicating the variability of data points around the mean. The SEM was 0.64, representing the precision of the mean estimate. The MDD was 1.77.

The ankle° dorsi/plantarflexion at IC (°) demonstrates good reliability with an ICC of 0.87. The average difference between Mean 1 and Mean 2 was 0.96 units. The SD was 7.37, indicating the variability of data points around the mean. The SEM was 2.66, representing the precision of the mean estimate. The MDD was 7.37.

The peak of ankle° towards dorsiflexion at post-IC (°) demonstrates reasonable reliability with an ICC of 0.85. The average difference between Mean 1 and Mean 2 was 1.18 units. The SD was 6.96, indicating the variability of data points around the mean. The SEM was 2.70, representing the precision of the mean estimate. The MDD was 7.4.

The peak of ankle° towards plantarflexion at post-IC (°) demonstrates moderate reliability with an ICC of 0.73. The average difference between Mean 1 and Mean 2 was 1.85 units. The SD was 5.63, indicating the variability of data points around the mean. The SEM was 2.93, representing the precision of the mean estimate. The MDD was 8.12.

The peak of ankle° towards eversion at pre-IC (°) demonstrates excellent reliability with an ICC of 0.96. The average difference between Mean 1 and Mean 2 was 0.29 units. The SD was 4.58, indicating the variability of data points around the mean. The SEM was 0.92, representing the precision of the mean estimate. The MDD was 2.55.

The peak of ankle° towards inversion at pre-IC (°) demonstrates excellent reliability with an ICC of 0.96. The average difference between Mean 1 and Mean 2 was 0.27 units. The SD was 4.58, indicating the variability of data points around the mean. The SEM was 0.92, representing the precision of the mean estimate. The MDD was 2.55.

The ankle° eversion/inversion at IC (°) demonstrates moderate reliability with an ICC of 0.75. The average difference between Mean 1 and Mean 2 was 1.69 units. The SD was 5.42, indicating the variability of data points around the mean. The SEM was 2.71, representing the precision of the mean estimate. The MDD was 7.51.

The peak of ankle° towards eversion at post-IC (°) demonstrates good reliability with an ICC of 0.82. The average difference between Mean 1 and Mean 2 was 1.54 units. The SD was 5.18, indicating the variability of data points around the mean. The SEM was 2.20, representing the precision of the mean estimate. The MDD was 6.09.

The peak of ankle° towards inversion at post-IC (°) demonstrates good reliability with an ICC of 0.84. The average difference between Mean 1 and Mean 2 was 1.25 units. The SD was 4.89, indicating the variability of data points around the mean. The SEM was 1.95, representing the precision of the mean estimate. The MDD was 5.4.

The peak of knee° towards extension at pre-IC (°) demonstrates excellent reliability with an ICC of 0.98. The average difference between Mean 1 and Mean 2 was 0.44 units. The SD was 10.24, indicating the variability of data points around the mean. The SEM was 1.45, representing the precision of the mean estimate. The MDD was 4.01.

The peak of knee° towards flexion at pre-IC (°) demonstrates excellent reliability with an ICC of 0.98. The average difference between Mean 1 and Mean 2 was 0.71 units. The

SD was 11.63, indicating the variability of data points around the mean. The SEM was 1.64, representing the precision of the mean estimate. The MDD was 4.54.

The knee° flexion/extension angle at IC (°) demonstrates excellent reliability with an ICC of 0.97. The average difference between Mean 1 and Mean 2 was 0.15 units. The SD was 8.91, indicating the variability of data points around the mean. The SEM was 1.54, representing the precision of the mean estimate. The MDD was 4.26.

The peak of knee° towards extension at post-IC (°) demonstrates good reliability with an ICC of 0.92. The average difference between Mean 1 and Mean 2 was 0.52 units. The SD was 7.08, indicating the variability of data points around the mean. The SEM was 2.00, representing the precision of the mean estimate. The MDD was 5.54.

The peak of knee° towards flexion at post-IC (°) demonstrates good reliability with an ICC of 0.90. The average difference between Mean 1 and Mean 2 was 0.35 units. The SD was 7.49, indicating the variability of data points around the mean. The SEM was 2.37, representing the precision of the mean estimate. The MDD was 6.56.

The peak of FPPA° towards adduction at pre-IC (°) demonstrates good reliability with an ICC of 0.88. The average difference between Mean 1 and Mean 2 was 0.40 units. The SD was 2.82, indicating the variability of data points around the mean. The SEM was 0.98, representing the precision of the mean estimate. The MDD was 2.71.

The peak of FPPA° towards abduction at pre-IC (°) demonstrates good reliability with an ICC of 0.87. The average difference between Mean 1 and Mean 2 was 0.36 units. The SD was 2.76, indicating the variability of data points around the mean. The SEM was 0.99, representing the precision of the mean estimate. The MDD was 2.74.

The FPPA° adduction/abduction at IC (°) demonstrates good reliability with an ICC of 0.92. The average difference between Mean 1 and Mean 2 was 1.32 units. The SD was 5.68, indicating the variability of data points around the mean. The SEM was 1.61, representing the precision of the mean estimate. The MDD was 4.46.

The peak of FPPA° towards adduction at post-IC (°) demonstrates good reliability with an ICC of 0.86. The average difference between Mean 1 and Mean 2 was 1.86 units. The SD was 6.57, indicating the variability of data points around the mean. The SEM was 2.46, representing the precision of the mean estimate. The MDD was 6.81.

The peak of FPPA° towards abduction at post-IC (°) demonstrates moderate reliability with an ICC of 0.67. The average difference between Mean 1 and Mean 2 was 2.03 units. The SD was 5.66, indicating the variability of data points around the mean. The SEM was 3.25, representing the precision of the mean estimate. The MDD was 9.00.

Furthermore, the assessment of between-day repeatability in the 2D analysis during SLL (º) revealed a high level of measurement reliability. It was supported by a strong ICC and a lower SEM than MDD. These findings suggest that the measurements obtained using the 2D analysis method during SLL (º) are consistent and dependable across multiple days.

The peak of ankle° towards dorsiflexion pre-IC (°) demonstrates excellent reliability with an ICC of 0.92. The average difference between Mean 1 and Mean 2 was 1.16 units. The SD was 6.65, indicating the variability of data points around the mean. The SEM was 1.88, representing the precision of the mean estimate. The MDD was 5.21.

The peak of ankle° towards plantarflexion pre-IC (°) demonstrates good reliability with an ICC of 0.91. The average difference between Mean 1 and Mean 2 was 1.52 units.

The SD was 6.57, indicating the variability of data points around the mean. The SEM was 1.97, representing the precision of the mean estimate. The MDD was 5.46.

The ankle° dorsi/plantarflexion at IC (°) demonstrates good reliability with an ICC of 0.88. The average difference between Mean 1 and Mean 2 was 2.22 units. The SD was 6.21, indicating the variability of data points around the mean. The SEM was 2.15, representing the precision of the mean estimate. The MDD was 5.95.

The peak of ankle° towards dorsiflexion post-IC (°) demonstrates good reliability with an ICC of 0.87. The average difference between Mean 1 and Mean 2 was 2.24 units. The SD was 5.81, indicating the variability of data points around the mean. The SEM was 2.10, representing the precision of the mean estimate. The MDD was 5.82.

The peak of ankle° towards plantarflexion post-IC (°) demonstrates moderate reliability with an ICC of 0.84. The average difference between Mean 1 and Mean 2 was 0.50 units. The SD was 5.12, indicating the variability of data points around the mean. The SEM was 2.05, representing the precision of the mean estimate. The MDD was 5.68.

The peak of ankle° towards eversion pre-IC (°) demonstrates excellent reliability with an ICC of 0.91. The average difference between Mean 1 and Mean 2 was 0.19 units. The SD was 2.72, indicating the variability of data points around the mean. The SEM was 0.82, representing the precision of the mean estimate. The MDD was 2.27.

The peak of ankle° towards inversion pre-IC (°) demonstrates excellent reliability with an ICC of 0.91. The average difference between Mean 1 and Mean 2 was 0.36 units. The SD was 2.97, indicating the variability of data points around the mean. The SEM was 0.89, representing the precision of the mean estimate. The MDD was 2.46.

The ankle° eversion/inversion at IC (°) demonstrates fair reliability with an ICC of 0.68. The average difference between Mean 1 and Mean 2 was 1.62 units. The SD was 5.30, indicating the variability of data points around the mean. The SEM was 3.00, representing the precision of the mean estimate. The MDD was 8.31.

The peak of ankle° towards eversion post-IC (°) demonstrates good reliability with an ICC of 0.85. The average difference between Mean 1 and Mean 2 was 1.21 units. The SD was 6.77, indicating the variability of data points around the mean. The SEM was 2.62, representing the precision of the mean estimate. The MDD was 7.26.

The peak of ankle° towards inversion post-IC (°) demonstrates fair reliability with an ICC of 0.64. The average difference between Mean 1 and Mean 2 was 1.46 units. The SD was 4.71, indicating the variability of data points around the mean. The SEM was 2.83, representing the precision of the mean estimate. The MDD was 7.84.

The peak of knee° towards extension pre-IC (°) demonstrates excellent reliability with an ICC of 0.96. The average difference between Mean 1 and Mean 2 was 0.44 units. The SD was 3.94, indicating the variability of data points around the mean. The SEM was 0.79, representing the precision of the mean estimate. The MDD was 2.18.

The peak of knee° towards flexion pre-IC (°) demonstrates excellent reliability with an ICC of 0.95. The average difference between Mean 1 and Mean 2 was 0.53 units. The SD was 3.98, indicating the variability of data points around the mean. The SEM was 0.89, representing the precision of the mean estimate. The MDD was 2.46.

The knee° flexion/extension angle at IC (°) demonstrates excellent reliability with an ICC of 0.97. The average difference between Mean 1 and Mean 2 was 0.12 units. The SD was 4.36, indicating the variability of data points around the mean. The SEM was 0.75, representing the precision of the mean estimate. The MDD was 2.07.

The peak of knee° towards extension post-IC (°) demonstrates excellent reliability with an ICC of 0.96. The average difference between Mean 1 and Mean 2 was 0.06 units. The SD was 4.44, indicating the variability of data points around the mean. The SEM was 0.89, representing the precision of the mean estimate. The MDD was 2.46.

The peak of knee° towards flexion post-IC (°) demonstrates good reliability with an ICC of 0.93. The average difference between Mean 1 and Mean 2 was 0.74 units. The SD was 6.46, indicating the variability of data points around the mean. The SEM was 1.71, representing the precision of the mean estimate. The MDD was 4.73.

The peak of FPPA° towards adduction pre-IC (°) demonstrates good reliability with an ICC of 0.87. The average difference between Mean 1 and Mean 2 was 0.62 units. The SD was 3.92, indicating the variability of data points around the mean. The SEM was 1.41, representing the precision of the mean estimate. The MDD was 3.90.

The peak of FPPA° towards abduction pre-IC (°) demonstrates good reliability with an ICC of 0.86. The average difference between Mean 1 and Mean 2 was 0.68 units. The SD was 2.76, indicating the variability of data points around the mean. The SEM was 0.99, representing the precision of the mean estimate. The MDD was 3.93.

The FPPA° adduction/abduction at IC (°) demonstrates acceptable reliability with an ICC of 0.82. The average difference between Mean 1 and Mean 2 was 0.02 units, indicating minimal variation. The SD was 4.18, indicating the variability of data points around the mean. The SEM was 1.77, representing the precision of the mean estimate. The MDD was 4.90.

The peak of FPPA° towards adduction post-IC (°) demonstrates acceptable reliability with an ICC of 0.82. The average difference between Mean 1 and Mean 2 was 0.52 units. The SD was 5.57, indicating the variability of data points around the mean. The SEM was 2.36, representing the precision of the mean estimate. The MDD was 6.54.

The peak of FPPA° towards abduction post-IC (°) demonstrates acceptable reliability with an ICC of 0.78. The average difference between Mean 1 and Mean 2 was 0.16 units. The SD was 4.77, indicating the variability of data points around the mean. The SEM was 2.24, representing the precision of the mean estimate. The MDD was 6.20, suggesting the minimum change that was detectable in this measurement.

In this study, the ICC for FPPA varied between 0.78 for the peak of FPPA° towards abduction post-IC (°) and 0.87 for the peak of FPPA° towards adduction pre-IC (°). The SEM ranged from 1.41° to 2.23°. The MDD during the SLL task was between 3.9° and 6.5°. These findings are consistent with a previous study by Herrington et al. (2017), which reported an ICC value of 0.87 and SEM of 1.4°, although the MDD was not mentioned in the study.

Another study by Munro et al. (2012) presented ICC values ranging from 0.72 to 0.91, with an SEM of 2.72° and MDD of 7.54° for FPPA during SLL. The ICC and SEM values in that study demonstrate relative agreement with the present study. However, the corresponding MDD in the present study for FPPA of the knee was from 3.9° to 6.5°, slightly lower than those reported by Munro et al. (2012).

Dingenen et al. (2018) investigated the sagittal plane during running. Their results showed an ICC of 0.87 with an SEM of 1.0° for knee flexion and an ICC of 0.90 with an SEM of 0.8° for ankle dorsiflexion angle.

Comparatively, in the current study focusing on the sagittal plane during SLL, the results demonstrated good to excellent ICC values for knee flexion. The ICC ranged from 0.83 at the maximum angle of pre-IC to 0.97 at the IC angle, with SEM values ranging from 0.75° to 1.7°. For ankle dorsiflexion, the ICC ranged from 0.64 at the maximum post-IC angle to 0.91 at the minimum pre-IC angle, with SEM values ranging from 0.8° to 2.99°.

During the LH task, the study also demonstrated excellent ICC values for knee flexion kinematics, ranging from 0.90 at the peak of knee° towards flexion post-IC (°) to 0.98 at the peak of knee° towards flexion pre-IC (°). Excellent to good repeatability was achieved, as demonstrated by the coefficient of variation, with the SEM values for knee flexion ranging from 1.44º to 2.36º. In terms of ankle dorsiflexion, the ICC values ranged from 0.73 at the peak of ankle° towards plantarflexion post-IC (°) to 0.9 at the peak of ankle° towards dorsiflexion pre-IC (°), with SEM values ranging from 0.64º to 2.9º, in the analysis of clinical variables (Table 4.5) and biomechanical variables (Tables 4.6 and 4.7) at a 95% CI.

This finding suggests that the instruments employed in the study are capable of capturing realistic clinical changes. In other words, the measured changes in these variables were not only statistically significant but also exceeded the threshold that was considered clinically meaningful. This observation was important as it validates the reliability and sensitivity of the instruments used in assessing the variables under investigation.

By surpassing the MDD, the instruments used in this study demonstrated their utility in clinical practice and research, as they enabled the identification of changes that are not merely statistically significant but also clinically relevant. This information provides confidence in the accuracy and precision of the measurements obtained, enhancing the validity and reliability of the study's findings. Overall, the results of this analysis suggest that the selected instruments are reliable and effective tools for detecting clinically significant changes in both clinical and biomechanical variables. These findings contribute to the body of knowledge in the field and support the use of these instruments in future clinical studies and patient management scenarios.

The validity analysis comparing the measurements between the 2D and 3D methods during SLL (º) demonstrated a high level of agreement, as indicated by the Bland–Altman test. Furthermore, no significant difference was observed between the findings of the 2D and 3D methods, with a very small effect size (–0.290). The interpretations of each variable assessed using both the 2D and 3D methods are provided below.

For the peak of ankle° towards dorsiflexion pre-IC (°), 2D mean: –21.74 (SD: 6.92), 3D mean: –22.15 (SD: 6.84), mean difference: 0.41, r: 0.951 and p-value: 0.01. Therefore, the 2D and 3D measurements of the peak of ankle° towards dorsiflexion pre-IC (°) showed a small mean difference of 0.41 units. In addition, there was a strong positive correlation ($r = 0.951$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of ankle° towards plantarflexion pre-IC (°), 2D mean: 30.49 (SD: 6.41), 3D mean: 24.82 (SD: 7.57), mean difference: 5.67, r: 0.888 and p-value: 0.01. Hence, the 2D and 3D measurements of the peak of ankle° towards plantarflexion pre-IC (°) showed a larger mean difference of 5.67 units. However, there was a positive correlation ($r = 0.888$) between the two measurements, indicating a moderate level of agreement and consistency. Moreover, the correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For ankle° dorsi/plantarflexion at IC (°), 2D mean: 17.8 (SD: 7.23), 3D mean: –17.47 (SD: 7.17), mean difference: 0.33, r: 0.996 and p-value: 0.01. As a result, the 2D and 3D measurements of the ankle° dorsi/plantarflexion at IC (°) showed a small mean difference of 0.33 units. In addition, there was a strong positive correlation ($r = 0.996$) between the two measurements, indicating a high level of agreement. Moreover, the correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of ankle° towards dorsiflexion at post-IC (°), 2D mean: –11.82 (SD: 6.89), 3D mean: –13.67 (SD: 6.70), mean difference: 1.85, r: 0.991 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of ankle° towards dorsiflexion at post-IC (°) demonstrated a mean difference of 1.85 units. There was a strong positive correlation ($r = 0.991$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of ankle° towards plantarflexion post-IC (°), 2D mean: 22.53 (SD: 5.28), 3D mean: 20.79 (SD: 5.47), mean difference: 1.74, r: 0.911 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of ankle° towards plantarflexion post-IC (°) showed a mean difference of 1.74 units. There was a strong positive correlation ($r = 0.911$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of ankle° towards eversion pre-IC (°), 2D mean: 5.36 (SD: 10.93), 3D mean: –2.93 (SD: 5.09), mean difference: 8.3, r: 0.801 and p-value: 0.01. Hence, the 2D and 3D measurements of the peak of ankle° towards eversion pre-IC (°) showed a larger mean difference of 8.3 units. There was a strong positive correlation ($r = 0.801$) between the two measurements, indicating a moderate level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of ankle° towards inversion pre-IC (°), 2D mean: 6.68 (SD: 8.32), 3D mean: 3.69 (SD: 4.17), mean difference: 2.99, r: 0.426 and p-value: >0.05. Therefore, the 2D and 3D measurements of the peak of ankle° towards inversion pre-IC (°) showed a mean difference of 2.99 units, confirming that there was no correlation ($r = 0.426$) between the two measurements and indicating some level of agreement. The correlation between the 2D and 3D measurements was not significant ($p > 0.05$).

For ankle° eversion/inversion at IC (°), 2D mean: 4.29 (SD: 6.34), 3D mean: 1.32 (SD: 4.76), mean difference: 2.97, r: 0.680 and p-value: 0.05. Thus, the 2D and 3D measurements of ankle° eversion/inversion at IC (°) showed a mean difference of 2.97 units. There was a moderate positive correlation ($r = 0.680$) between the two measurements, indicating some level of agreement. The correlation between the 2D and 3D measurements was marginally significant ($p = 0.05$).

For the peak of ankle° towards eversion post-IC (°), 2D mean: –12.71 (SD: 7.83), 3D mean: –7.49 (SD: 4.39), mean difference: 5.22, r: 0.669 and p-value: 0.05. The 2D and 3D measurements of the peak of ankle° towards eversion post-IC (°) showed a mean difference of 5.22 units. There was a moderate positive correlation ($r = 0.669$) between the two measurements, indicating some level of agreement. The correlation between the 2D and 3D measurements was marginally significant ($p = 0.05$).

For the peak of ankle° towards inversion post-IC (°), 2D mean: 0.73 (SD: 5.62), 3D mean: –0.63 (SD: 4.45), mean difference: 1.36, r: 0.709 and p-value: 0.01. Hence, the 2D and 3D measurements of the peak of ankle° towards inversion at post-IC (°) showed a mean difference of 1.36 units. There was a moderate positive correlation ($r = 0.709^{**}$) between the two measurements, indicating some level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards extension pre-IC (°), 2D mean: 7.89 (SD: 5.03), 3D mean: 7.39 (SD: 4.93), mean difference: 0.52, r: 0.959 and p-value: 0.01. Therefore, the 2D and 3D measurements of the peak of knee° towards extension pre-IC (°) showed a mean difference of 0.52 units. There was a strong positive correlation ($r = 0.959$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards flexion pre-IC (°), 2D mean: 9.06 (SD: 8.58), 3D mean: 4.14 (SD: 11.87), mean difference: 4.92, r: 0.964 and p-value: 0.01. Therefore, the 2D and 3D measurements of the peak of knee° towards flexion pre-IC (°) showed a mean difference of 4.92 units. There was a strong positive correlation ($r = 0.964$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For knee° flexion/extension angle at IC (°), 2D mean: 10.83 (SD: 4.56), 3D mean: 10.62 (SD: 4.48), mean difference: 0.21, r: 0.984 and p-value: 0.01. As a result, the 2D and 3D measurements of knee° flexion/extension angle at IC (°) showed a negligible mean difference of 0.21 units. There was an extremely positive correlation ($r = 0.984$) between the two measurements, indicating a very high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards extension post-IC (°), 2D mean: 13.2 (SD: 4.57), 3D mean: 12.72 (SD: 4.69), mean difference: 0.48, r: 0.989 and p-value: 0.01. Therefore, the 2D and 3D measurements of the peak of knee° towards extension post-IC (°) showed a mean difference of 0.48 units. There was a very strong positive correlation ($r = 0.989$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards flexion at post-IC (°), 2D mean: 52.3 (SD: 6.36), 3D mean: 50.7 (SD: 7.79), mean difference: 1.60, r: 0.942 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of knee° towards flexion at post-IC (°) showed a mean difference of 1.60 units. There was a positive correlation ($r = 0.942$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards adduction pre-IC (°), 2D mean: –2.57 (SD: 3.98), 3D mean: –4.1 (SD: 5.06), mean difference: 1.53, r: 0.630 and p-value: 0.05. Therefore, the 2D and 3D measurements of the peak of FPPA° towards adduction pre-IC (°) showed a mean difference of 1.53 units. There was a moderate positive correlation ($r = 0.630$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements approaches statistical significance ($p = 0.05$).

For the peak of FPPA° towards abduction pre-IC (°), 2D mean: –2.12 (SD: 3.70), 3D mean: –3.29 (SD: 4.72), mean difference: 1.17, r: 0.582 and p-value: 0.05. Therefore, the 2D and 3D measurements of the peak of FPPA° towards abduction pre-IC (°) showed a mean difference of 1.17 units. There was a weak positive correlation ($r = 0.582$) between the two measurements, indicating limited agreement. The correlation between the 2D and 3D measurements was statistically significant ($p > 0.05$).

For FPPA° adduction/abduction at IC (°), 2D mean: –2.33 (SD: 3.81), 3D mean: –2.81 (SD: 4.11), mean difference: 0.48, r: 0.932 and p-value: 0.01. As a result, the 2D and 3D measurements of FPPA° adduction/abduction at IC (°) showed a mean difference of 0.48 units. There was a strong positive correlation ($r = 0.932$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards adduction post-IC (°), 2D mean: –7.06 (SD: 4.99), 3D mean: –8.36 (SD: 5.03), mean difference: 1.30, r: 0.849 and p-value: 0.01. Hence, the 2D and 3D measurements of the peak of FPPA° towards adduction post-IC (°) showed a mean difference of 1.30 units. There was a positive correlation ($r = 0.849$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards abduction post-IC (°), 2D mean: 2.13 (SD: 4.93), 3D mean: 1.1 (SD: 5.45), mean difference: 1.03, r: 0.709 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of FPPA° towards abduction post-IC (°) showed a mean difference of 1.03 units. There was a moderate positive correlation ($r = 0.709$)

between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

The validity analysis comparing the measurements between the 2D and 3D methods during LH (º) demonstrated a high level of agreement, as indicated by the Bland–Altman test. In addition, no significant difference was observed between the findings of the 2D and 3D methods, with a very small effect size (–0.156). The interpretations of each variable assessed using both 2D and 3D methods are provided below:

For the peak of ankle° towards dorsiflexion pre-IC (°), 2D mean: –15.16 (SD: 6.00), 3D mean: –19.27 (SD: 6.08), mean difference: 4.11, r: 0.711 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of ankle° towards dorsiflexion pre-IC (°) showed a mean difference of 4.11 units. There was a moderate positive correlation ($r = 0.711$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For peak of ankle° towards plantarflexion pre-IC (°), 2D mean: –13.69 (SD: 6.30), 3D mean: –19.42 (SD: 5.80), mean difference: 5.73, r: 0.910 and p-value: 0.01. Therefore, the 2D and 3D measurements of the peak of ankle° towards plantarflexion pre-IC (°) showed a mean difference of 5.73 units. There was a positive correlation ($r = 0.910$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For ankle° dorsi/plantarflexion at IC (°), 2D mean: –16.05 (SD: 7.09), 3D mean: –16.93 (SD: 7.38), mean difference: 0.88, r: 0.989 and p-value: 0.01. Hence, the 2D and 3D measurements of the ankle° dorsi/plantarflexion at IC (°) showed a mean difference of 0.88 units. There was a strong positive correlation ($r = 0.989$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For peak of ankle° towards dorsiflexion post-IC (°), 2D mean: –2.50 (SD: 6.61), 3D mean: –2.29 (SD: 6.82), mean difference: 0.21, r: 0.979 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of ankle° towards dorsiflexion post-IC (°) showed a mean difference of 0.21 units. There was a strong positive correlation ($r = 0.979$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For peak of ankle° towards plantarflexion post-IC (°), 2D mean: 19.395 (SD: 5.22), 3D mean: 16.725 (SD: 4.38), mean difference: 2.67, r: 0.813 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of ankle° towards plantarflexion post-IC (°) showed a mean difference of 2.67 units. There was a strong positive correlation ($r = 0.813$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For peak of ankle° towards eversion pre-IC (°), 2D mean: –0.185 (SD: 13.52), 3D mean: –2.70 (SD: 5.61), mean difference: 2.52, r: 0.695 and p-value: 0.05. Hence, the 2D and 3D measurements of the peak of ankle° towards eversion pre-IC (°) showed a mean difference of 2.52 units. There was a moderate positive correlation ($r = 0.695$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements approaches statistical significance ($p < 0.10$).

For peak of ankle° towards inversion pre-IC (°), 2D mean: 1.44 (SD: 7.83), 3D mean: –3.085 (SD: 6.41), mean difference: 4.53, r: 0.770 and p-value: 0.05. Thus, the 2D and

3D measurements of the peak of ankle° towards inversion pre-IC (°) showed a mean difference of 11.53 units. There was a positive correlation ($r = 0.770$) between the two measurements, indicating a moderate level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For ankle° eversion/inversion at IC (°), 2D mean: 2.405 (SD: 5.87), 3D mean: 1.58 (SD: 4.84), mean difference: 0.82, r: 0.967 and p-value: 0.01. Hence, the 2D and 3D measurements of the ankle° eversion/inversion at IC (°) showed a mean difference of 0.82 units. There was a strong positive correlation ($r = 0.967$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For peak of ankle° towards eversion post-IC (°), 2D mean: –2.59 (SD: 4.93), 3D mean: –5.15 (SD: 3.36), mean difference: 2.56, r: 0.644 and p-value: 0.05. Thus, the 2D and 3D measurements of the peak of ankle° towards eversion post-IC (°) showed a mean difference of 2.56 units. There was a moderate positive correlation ($r = 0.644$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements approaches statistical significance ($p < 0.10$).

For peak of ankle° towards inversion post-IC (°), 2D mean: 9.19 (SD: 5.06), 3D mean: 8.92 (SD: 4.59), mean difference: 0.27, r: 0.894 and p-value: 0.01. The 2D and 3D measurements of the peak of ankle° towards inversion post-IC (°) showed a mean difference of 0.27 units. There was a positive correlation ($r = 0.894$**) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards extension pre-IC (°), 2D mean: 27.17 (SD: 8.47), 3D mean: 27.01 (SD: 8.08), mean difference: 0.16, r: 0.962 and p-value: 0.01. The 2D and 3D measurements of the peak of knee° towards extension pre-IC (°) showed a mean difference of 0.16 units. There was a strong positive correlation (r = 0.962) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards flexion pre-IC (°), 2D mean: 31.03 (SD: 10.69), 3D mean: 22.13 (SD: 10.36), mean difference: 8.9, r: 0.923 and p-value: 0.01. The 2D and 3D measurements of the peak of knee° towards flexion pre-IC (°) showed a mean difference of 8.9 units. There was a strong positive correlation (r = 0.923) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For IC knee angle at the sagittal plane, 2D mean: 24.80 (SD: 8.55), 3D mean: 22.72 (SD: 7.41), mean difference: 2.08, r: 0.949 and p-value: 0.01. The 2D and 3D measurements of the knee angle at the sagittal plane at IC showed a mean difference of 2.08 units. There was a very strong positive correlation (r = 0.949) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For knee° flexion/extension angle at IC (°), 2D mean: 22.02 (SD: 6.93), 3D mean: 20.95 (SD: 7.37), mean difference: 1.07, r: 0.974 and p-value: 0.01. The 2D and 3D measurements of the knee° flexion/extension angle at IC (°) showed a mean difference of 1.07 units. There was a very strong positive correlation (r = 0.974) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of knee° towards flexion post-IC (°), 2D mean: 45.43 (SD: 6.62), 3D mean: 43.715 (SD: 7.73), mean difference: 1.72, r: 0.949, and p-value: 0.01. The 2D and 3D measurements of the peak of knee° towards flexion post-IC (°) showed a mean difference of 1.72 units. There was a very strong positive correlation ($r = 0.949$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards adduction pre-IC (°), 2D mean: –4.28 (SD: 8.81), 3D mean: –6.14 (SD: 6.31), mean difference: 1.86, r: 0.521 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of FPPA° towards adduction pre-IC (°) showed a mean difference of 1.86 units. There was a weak positive correlation ($r = 0.521$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards abduction pre-IC (°), 2D mean: –2.98 (SD: 7.55), 3D mean: –3.1 (SD: 5.03), mean difference: 0.12, r: 0.585 and p-value: 0.05. Hence, the 2D and 3D measurements of the peak of FPPA° towards abduction pre-IC (°) showed a mean difference of 0.12 units. There was a weak positive correlation ($r = 0.585$) between the two measurements, indicating some agreement. The correlation between the 2D and 3D measurements was marginally significant ($p < 0.05$).

For FPPA° adduction/abduction at IC (°), 2D mean: –6.68 (SD: 5.84), 3D mean: –7.33 (SD: 6.21), mean difference: 0.65, r: 0.912 and p-value: 0.01. Thus, the 2D and 3D measurements of the FPPA° adduction/abduction at IC (°) showed a mean difference of

0.65 units. There was a very strong positive correlation ($r = 0.912$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards adduction post-IC (°), 2D mean: –11.37 (SD: 7.73), 3D mean: –12.21 (SD: 6.17), mean difference: 0.84, r: 0.805 and p-value: 0.01. Hence, the 2D and 3D measurements of the peak of FPPA° towards adduction post-IC (°) showed a mean difference of 0.84 units. There was a strong positive correlation ($r = 0.805$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

For the peak of FPPA° towards abduction post-IC (°), 2D mean: –1.50 (SD: 5.77), 3D mean: –2.43 (SD: 3.77), mean difference: 0.93, r: 0.730 and p-value: 0.01. Thus, the 2D and 3D measurements of the peak of FPPA° towards abduction post-IC (°) showed a mean difference of 0.93 units. There was a positive correlation ($r = 0.730$) between the two measurements, indicating a high level of agreement. The correlation between the 2D and 3D measurements was statistically significant ($p < 0.05$).

In the context of ankle inversion angle analysis, no previous study has been conducted using the 2D methods to directly compare the results. However, in the current study, the ankle inversion angle in SLL exhibited moderate to excellent ICC values, which ranged from 0.64 at the IC phase to 0.91 throughout the entire task. The SEM values for ankle inversion angle ranged from 0.81° to 2.99°.

Similarly, in the LH trials, the ankle inversion ICC scores ranged from moderate to good, with values ranging from 0.75 at the IC phase to 0.96 at the minimum angle pre-IC. The corresponding SEM values for the rearfoot angle in LH trials ranged from 0.91° to 2.7°.

It is important to note that due to the lack of previous 2D studies specifically examining rearfoot analysis, the current findings provide valuable insights into the repeatability and reliability of rearfoot angle measurements during the SLL and LH tasks. These results contribute to the understanding of rearfoot kinematics in dynamic movements, highlighting the need for further research to establish comparative analyses with other measurement techniques and explore the clinical implications of rearfoot angle assessments in various functional activities.

Moreover, the findings of Gwynne et al. (2014), who suggested that lower ICC values could be attributed to human errors in marker positioning, data filtering and potential variations in subject performance between different days, are worth considering. By contrast, the higher ICC values observed in the present study suggest that meticulous marker placement was achieved, data filtering was optimised, and the participants performed consistently across the different days of measurement. These factors contribute to the enhanced reliability and repeatability of the results obtained.

However, it is important to acknowledge that the current study had a relatively smaller sample size compared with previous studies that have examined repeatability and reliability. The decision to opt for a smaller sample size in this study was driven by a multifaceted approach, considering both the historical context of previous research and the unique challenges posed by the COVID-19 pandemic. Previous studies, such as the one conducted by Lachaine et al. (2017), have employed a limited number of participants, around 12 subjects, when assessing repeatability. This study delves into the validation of inertial measurement units (IMUs) for ergonomic applications, aiming to address key gaps left by previous studies concerning joint analysis, movement complexity and trial duration. The primary objectives encompass evaluating the technological error and biomechanical model disparities between IMUs and an optoelectronic system while also investigating the influence of task intricacy and duration on measurement outcomes.

As mentioned for reference, the research involved 12 participants whose whole-body kinematics were captured using an Xsens system paired with Optotrak clusters affixed to IMUs. A comparative assessment of joint angles between the two systems was executed during both short functional movements and extended manual material handling tasks. Notably, discrepancies attributed to biomechanical model differences yielded significantly higher root mean square error (RMSE) ($p \leq .001$) in comparison to technological errors. Specifically, the RMSE was systematically higher ($p \leq .001$) during the long, intricate tasks, with a mean of 2.8° across all joints, in contrast to the 1.2° observed during simpler movements. However, they did not attribute this disparity to sample size; rather, they discussed more on the technology for this dispute in the findings. They mentioned that the decision to employ a smaller sample size (12 participants) was grounded in a judicious balance between ensuring a comprehensive evaluation of technological error and biomechanical discrepancies while also enabling efficient data collection and analysis. Although the study underscores the potential of IMUs for accurate tracking during various tasks, the limited sample size remains a potential limitation that could influence the generalisability of the findings. To augment the study's insights, future research endeavours could involve expanding the participant pool to increase the generalisability and explore additional factors that might impact IMU accuracy. Given its meticulous investigation of validation aspects and utilisation of a sample size of 12, this study could serve as a valuable reference for selecting appropriate sample sizes in repeatability and validity studies.

Thus, the seemingly modest sample size was chosen with a specific intent in mind, that is, to meticulously evaluate outcomes prone to potential sources of error, such as examiner variability. The smaller sample size allowed for a focused examination of these intricate nuances, ensuring the robustness and reliability of the findings in the context of limited subject availability (Lachaine et al., 2017) in the current study.

Adding another layer of complexity, the COVID-19 pandemic has introduced unprecedented constraints on research methodologies and participant engagement. In light of the pandemic's impact, the choice to maintain a smaller sample size takes on additional significance. With COVID-19 restrictions and the logistical challenges of securing willing and available participants, a deliberate decision was made to navigate this intricate landscape while still upholding the scientific integrity of the study. Balancing the need for a comprehensive prospective investigation with the practicalities of data collection within the constraints of the pandemic has led to the present approach.

However, it is important to acknowledge that the constrained sample size, although methodologically justified considering both historical research and the pandemic context, may influence the scope and generalisability of the study's outcomes. The potential limitations introduced by the smaller sample size and the unique circumstances surrounding COVID-19 underscore the need for a cautious interpretation of the findings and highlight the broader contextual factors shaping the study's design and execution.

One possible limitation was the potential for decreased statistical power, which may restrict the ability to detect subtle or small effects. However, in the current study, the coefficient of variation was in excellent to good ranges and the Bland–Altman test demonstrated minimal variation in the validity study, suggesting that the sample size did not interfere with the statistical power. However, it is important to acknowledge that the findings of the study may be more prone to random variations and may not fully represent the population under investigation in the prospective study. Therefore, caution should be exercised when generalising the results to larger and specific populations. Moreover, a small sample size may limit the diversity and representativeness of the study participants. This could affect the external validity and generalisability of the findings to broader populations or specific subgroups. It is crucial to acknowledge and consider these limitations when interpreting and applying the study results.

A smaller sample size can still yield valuable insights and provide meaningful results, as recommended by Lachaine et al. (2017). While a larger sample size may offer increased statistical power and generalisability, it is important to strike a balance between the practical constraints of the study and the desire for comprehensive findings. By carefully designing the study with a smaller sample size, researchers can still obtain reliable data that contributes to the existing knowledge base.

In summary, opting for a small sample size in this study offers advantages in terms of resource and time efficiency while still yielding meaningful insights. However, it is important to acknowledge and address the limitations associated with a small sample size, including limited generalisability. Despite these limitations, the present study provides valuable insights into the repeatability and reliability of the measured variables based on the coefficient of variation and the Bland–Altman test. These findings serve as a foundation for future research endeavours that can build upon these results with larger sample sizes to enhance the validation and generalisability of the findings.

4.7. Conclusion

The present study involved a meticulous review of the existing literature, including systematic reviews and meta-analyses, to identify the intrinsic factors that contribute to lower extremity injuries, particularly LAS. This comprehensive review served as the foundation for selecting the most suitable outcome measures and tools to be employed in the repeatability study. By ensuring the appropriateness of these measures, the study aimed to accurately assess and evaluate the various factors related to LAS.

The results of the repeatability study yielded promising findings, demonstrating that both clinical and biomechanical variables assessed using various tools, such as HHD, YBT, goniometer and 2D motion analysis measurements, are reliable and suitable for use in the main prospective study. Moreover, the comparison between the 2D and 3D motion capture systems indicated that both methods are equally effective in measuring joint kinematics, suggesting that 2D motion analysis can serve as a valid instrument for assessing joint kinematics.

Notably, the main prospective study, which will build upon the findings of the repeatability study, aims to contribute novel insights to the existing scientific literature. Specifically, no previous studies have been reported that specifically investigated the selected outcome measures in relation to LAS among military recruits in Saudi Arabia. Therefore, the utilisation of these outcome measures in the main prospective study will provide valuable information regarding the biomechanical risk factors associated with LAS in this specific population.

By employing rigorous methodologies and utilising reliable outcome measures, this study seeks to enhance the understanding of LAS and contribute to the body of knowledge within the scientific community. The findings will have practical implications for injury prevention strategies and rehabilitation interventions tailored to military personnel in Saudi Arabia, ultimately promoting the overall well-being and performance of this population.

CHAPTER 5

Prospective Investigation of Clinical and Biomechanical Risk Factors of Lateral Ankle Sprain in Basic Military Training

This chapter delineates the main prospective study, including the data collection procedure, methodology and investigation of the intrinsic risk factors associated with lateral ankle sprains (LAS) in military recruits.

5.1. Introduction

Physical activity plays a significant role in musculoskeletal injuries, with the type and intensity of activity influencing the risk. Military personnel are a highly active population, especially during their initial training period. This training, spanning approximately 12 weeks and involving extensive daily sessions lasting 12–15 hours, aims to prepare recruits for the physical challenges they will face in their future roles. The training programme encompasses a wide range of activities, including running, jumping, weightlifting, battle training and mountain climbing, each conducted at varying intensities and speeds to enhance the physical fitness of the recruits.

The heightened level of physical activity in military personnel has consistently been associated with a greater incidence of soft tissue injuries, particularly ligamentous injuries affecting the ankle joint (Havenetidis & Paxinos, 2011). Among these injuries, LAS are the most commonly observed. This prevalence can be attributed to the significant stress and strain exerted on the ankle ligaments during the diverse range of activities involved in military training programmes (Leggat & Smith, 2007; Strowbridge & Burgess, 2002). In fact, ankle sprains have been reported as the most frequent injury among military service recruits, accounting for 10% to 30% of all reported injuries (Milgrom et al., 1991).

Thus, engaging in intense and prolonged physical activity is known to increase the risk of musculoskeletal injuries, and this risk is particularly amplified in military recruits due to the rigorous demands of their training. The repetitive and demanding nature of military training exposes recruits to a higher likelihood of developing musculoskeletal injuries, including ankle sprains. Given the physical demands placed on military personnel and the documented association between high-intensity physical activities and an increased risk of musculoskeletal injuries, it is crucial to examine and address the factors that contribute to ankle ligament injuries, particularly LAS. This is particularly relevant in the context of military training in Saudi Arabia, as indicated by the findings of Al Amer et al. (2020). The study revealed that ankle injuries are not only prevalent but also severe enough to result in soldiers being discharged or hospitalised, leading to loss of training days. Such injuries can have a significant impact on the overall health and operational readiness of military personnel. Overall, the information highlights the importance of addressing ankle injuries among military recruits in Saudi Arabia to ensure their health and readiness for duty (Al Amer et al., 2020).

Ankle sprains in soldiers can have negative effects on physical health and operational capabilities, which can impede military readiness and result in financial losses. Undertreated ankle sprains can lead to chronic pain and physical disabilities, affecting the duties and performance of military personnel. Previous retrospective studies have evaluated the risk factors for LAS; however, prospective research is needed to clarify the understanding of LAS and its intrinsic risk factors, especially in the Saudi military population, to control the risk factors and address the healthcare needs of active-duty military personnel.

The high incidence of ankle injuries among military personnel underscores the importance of implementing effective preventive measures. This includes identifying the clinical and biomechanical risk factors associated with ankle injuries and developing targeted training and rehabilitation programmes. By understanding the underlying causes and implementing appropriate strategies, it is possible to mitigate the occurrence and severity of ankle ligament injuries in the military context. This, in turn, can enhance the overall well-being and performance of military personnel, ensuring their optimal readiness for operational duties. Therefore, the objective of this study was to prospectively evaluate the intrinsic risk factors for LAS and other lower limb injuries in Saudi military recruits using clinical measurements such as muscle strength, range of motion (ROM), dynamic balance and body mass index (BMI), as well as lower limb kinematics measurements. In addition, the military environment provides controlled training conditions, which is important for minimising the influence of extrinsic factors on injury risk. By investigating the intrinsic risk factors for LAS in this population, this study can provide important insights for injury prevention strategies in military settings.

5.2. Aims and Objectives

The aim of this chapter was to prospectively identify the intrinsic risk factors for LAS.

Following this aim, the objectives were as follows:

A. To prospectively compare the 2D kinematics between recruits who sustain LAS and those who do not during subsequent follow-ups.

B. To prospectively compare the isometric strength and ROM (°) of the ankle dorsi/plantarflexion and eversion/inversion muscles and the hip abductors and extensors, dynamic balance and bimalleolar width between recruits with and without ankle injuries during subsequent follow-ups.

Research questions

1. Is there any difference between the clinical variables and kinematics of the lower limb joints in individuals with and without LAS?
2. Which risk factor(s) have an association with LAS incidence as compared with other factors?

5.3. Methods

5.3.1. Ethical approval

Prior to commencing the study, ethical clearance and approval were obtained from the Research, Enterprise and Engagement Ethical Approval Panel of the University of Salford (Ethics No. HSR1920-001, see Appendix D). In addition, approval was obtained from the military to ensure compliance with ethical guidelines and regulations.

5.3.2. Instruments

The following instruments were used for clinical, functional and biomechanical measurements:

1. The ROM of ankle joint movements was measured using a manual goniometer in degrees (°) (Hadzic et al., 2009).
2. Muscle strength of the hip and ankle joint muscles was measured using a MicroFet F2 hand-held dynamometer (HHD) that provides results in newton (N),

normalised to the body weight; thus, strength was assessed using the unit N/kg (Kawaguchi et al., 2021). Ankle movements included inversion, eversion, dorsiflexion and plantarflexion (Alfuth & Hahm, 2016; Spink et al., 2010), while hip movements included hip extension and hip abduction. An HHD was also utilised in studies by Kawaguchi et al. (2010), Buckinx et al. (2017) and Narlawar et al. (2019).

3. Dynamic balance was assessed using the Y-Balance Test (YBT) and measured in percentage (%). The distance measurement was taken in centimetres and normalised with the leg length (distance from the anterior superior iliac spine (ASIS) to the medial malleoli) and multiplied by 100, obtaining the YBT in percentage. The YBT focused on three dimensions: anterior, posteromedial and posterolateral. Hartley et al. (2018) and Plisky et al. (2009) also employed the YBT in their studies.
4. Bimalleolar width was measured using a sliding breadth calliper in millimetres (mm). This measurement tool was previously used by Rice et al. (2017).
5. Biomechanical assessments were conducted using 2D motion analysis with three high-speed cameras, measured in pixels and frames per second (fps). The cameras used in the analysis were (cm) OS, with specifications of 60 to 300 fps, 1280 x 1024 resolution, one megapixel, 1/2” sensor, USB 3.0 and e2v Sensor with a Global Shutter (Quintic Consultancy Ltd., Sutton Coldfield, UK). The sampling rate was set at 100 fps. This method of analysis has been previously employed by Maykut et al. (2015) and Olson et al. (2011) in their studies.

Figure 5.1: Clinical and 2D motion analysis setup in the military clinic

5.3.3. Participants

In this study, recruits who enrolled in a 12-week basic military training programme conducted by the Saudi military were recruited as participants. The study invitation included an informative letter and a screening task. In addition, a verbal announcement was made during the first day of assembly to explain the study requirements and screening tasks. A health screening questionnaire was utilised to obtain the medical and surgical history of the participants, including any prior history of ankle sprain or other diseases (refer to Appendix E). The participants were required to be healthy and free from any lower limb injuries, including LAS or musculoskeletal surgery in the previous year. Moreover, the participants were asked if they had any other physical or neurological impairments that could affect their movement. They were provided with an information sheet and given 24 hours to decide whether they would participate in the study. After agreeing to participate, the individuals signed a consent form.

5.3.3.1 Basic military training

The basic military training in Saudi Arabia lasts for 12 weeks and involves daily training programmes that can last for around 12 to 15 hours. This duration is comparable with the basic military training programmes in the UK and USA. The training includes various activities, such as marching, tactical exercises, physical training, shooting and theoretical classes. The theoretical classes are conducted for around 5 hours daily and begin in the second week of training.

5.3.4. Data Collection Procedure

The data collection process involved the assistance of three military clinicians who aided the author in the following steps:

- Sending the examination sheet to the participants and providing explanations about the examination procedure.
- Gathering the participants as a group and escorting them to the examination location.
- Preparing double-sided stickers with markers for the participants.
- Organising the participants by calling them individually into the examination room.
- Removing the markers after successfully completing the assessments.

Data collection took place over a span of two weeks, from 8:00 am to 8:00 pm (12 hours) every day, except Fridays when data collection occurred from 2:00 pm to 8:00 pm (6 hours). On average, 12 to 17 participants were assessed daily, with 5 to 6 participants in the morning, 5 to 7 in the afternoon and 2 to 4 in the evening. To ensure anonymity, the participants were assigned numbers from 1 to 215. Three stations were set up to collect both clinical and biomechanical data using the tools described earlier, as shown in Figure 5.2.

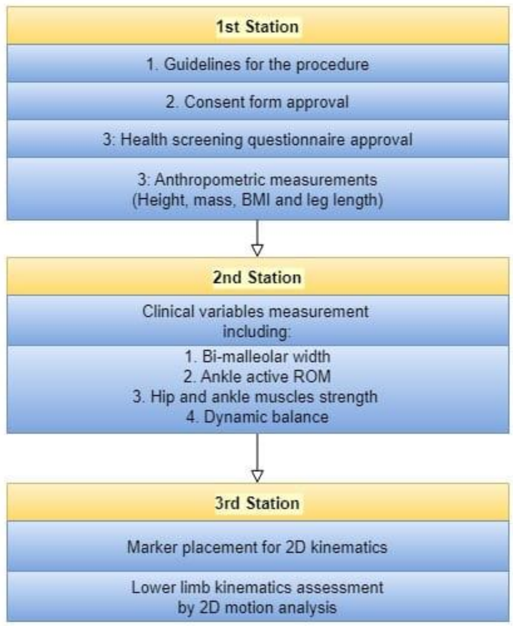


Figure 5.2**:** Schematic representation of the data collection procedure

First station: Consent form and procedure guidelines

At the first station, the participants were given written instructions and guidelines briefing the examination procedure (Appendix F) in Arabic after cross-checking their approved consent form and health questionnaire. They were also verbally briefed about the nature of the clinical and biomechanical examinations, which included muscle strength, ROM (°), bimalleolar width and dynamic balance. The participants who were injury-free signed the consent form before data collection began. The participants' height (cm), leg length (cm), mass (kg) and BMI were then measured and recorded.

Second station: Bimalleolar width and clinical measurement

At the second station, bimalleolar measurement was taken using a sliding breadth calliper and recorded in centimetres. The ROM was then tested using a goniometer, and the results were recorded in degrees. Subsequently, the strength of various muscles was measured using an HHD, specifically the hip abductors, hip extensors, ankle dorsiflexors, ankle plantarflexors, ankle evertors and ankle inverters. The MicroFet F2 HHD provides results in newton (N), which is then normalised by the body weight; thus, strength was assessed with the unit N/kg (Spink et al., 2010). Finally, postural balance was assessed using the YBT in the anterior, posteromedial and posterolateral directions, with the results recorded in percentage (%). The distance measurement was initially taken in cm, normalised with the leg length (distance from the ASIS to the medial malleoli) and then multiplied by 100, thus obtaining the YBT in percentage (%).

After all the measurements were recorded, each participant was instructed to proceed to the next station.

Third station: Kinematic data

At this station, a motion analysis was conducted using 2D motion analysis techniques during single-leg landing (SLL) and lateral hopping (LH) tasks. The specific details of these tasks can be found in Chapter 4, Section 4.1.2.2. To ensure consistency, the same camera settings and floor markers were utilised as described in the repeatability and reliability study outlined in Chapter 4, Section 4.1.2.2. Reflective markers measuring 14.5 mm were placed and securely attached to each participant's body, as previously discussed in Section 4.1.2.2. The participants were given sufficient time to become familiar with the tasks and performed them repeatedly, ranging from three to five times, to minimise any self-conscious movements during the trials. For each participant, three successful trials were recorded for both limbs. For more comprehensive information, please refer to Section 4.1.2.2.

5.3.5. Data Processing

The videos obtained during the kinematic assessment were analysed using the Quintic Biomechanics software package (Version 31) at a frame rate of 100 fps. These videos were securely saved on a personal computer located in a secured room. The analysis process involved several steps.

First, the correct trial was opened in the software, and the marker window was selected. A specific timeframe of 20 milliseconds (ms) prior to initial contact (IC) and 300 ms after IC (post-IC) was set for the trial being analysed.

Second, the data were digitised by selecting the appropriate option and loading the calibration file. The software was then instructed to automatically digitise each new trace based on the timeframe set in the marker window.

In the final step, the data were smoothed using an optimal smoothing technique in the Quintic Biomechanics Version 31 software. This smoothing process aimed to minimise random noise without affecting the overall data. The software utilised an optimal Butterworth filter, which reduces subjective data and helps eliminate errors (Ellis, 2012). Specifically, the rearfoot angles, sagittal and frontal plane projectile angle (FPPA) for the knee and ankle angles were calculated from the three successful trials.

A more detailed explanation of the data processing methodology can be found in Section 4.1.2.2 of Chapter 4. This section provides a comprehensive overview of the data processing procedures employed during the analysis.

5.3.6. Injury Registration and Assessment

During the training process, any individual who sustained injuries underwent assessment and was promptly reported to the military clinic. Once LAS was confirmed, the injury was characterised based on the mechanism of LAS occurrence along with an exam looking for point tenderness over the ATFL ligament, positive anterior drawer and talar tilt tests and factors such as pain, mechanisms of injury, swelling, ROM in degrees, body balance and duration of functional impairment using the Rehabilitation-Oriented Assessment tool (ROAST) (Delahunt et al., 2018). The inclusion criteria for identifying the injured participants included the presence of positive symptoms, such as pain, swelling, decreased ankle ROM, impaired body balance and functional time loss lasting a minimum of 48 hours.

Upon confirmation of injury, the participants' details were added to the list of LAS. To ensure confidentiality, all injury-related data were collected directly by the researcher from the military clinic while maintaining anonymity. An Excel sheet was utilised to record and maintain the collected injury data.

5.3.7. Statistical Analysis

Statistical analysis was conducted using the IBM SPSS statistical software (Version 27). The normality of the data distribution played a crucial role in determining the correlation between risk factors and injury outcomes. To assess the data distribution and reduce the chance of accepting false hypotheses, the Shapiro–Wilk normality test was applied.

For normally distributed variables, an independent t-test was employed to compare the injured and uninjured groups statistically. This approach was suggested by Al Amer et al. (2020) in their study on ankle sprain risk factors in soccer players. The t-test allowed for assessing the statistical difference between the groups and calculating the effect size (Cohen's d). A Cohen's d value of around 0.2 suggests a small effect, which means that there is some difference between the two groups, but it may not be practically significant. A Cohen's d value of around 0.5 indicates a medium effect, which implies that the difference between the groups is noticeable and may have practical significance. A Cohen's d value of around 0.8 or above represents a large effect, which means the difference between the groups is substantial and is likely to have a significant practical impact (Rosenthal & Rosnow, 2008).

To ensure the accuracy of the reported mean differences between the two groups (injured vs. non-injured), the values were compared with the Standard Error of Measurement (SEM) obtained from the reliability study conducted in Chapter 4. This comparison was conducted to confirm that the observed mean difference is not simply attributed to measurement error. The significance of the mean difference being above the SEM and Minimal Detectable Difference (MDD) is that it suggests the observed difference is larger than what can be attributed to measurement error alone. In other words, it indicates that the difference between the two groups is likely to be a true difference and not a result of random variability in the measurements. On the other hand, if the mean difference is below the SEM and MDD, it suggests that the observed difference is within the range of measurement error. This means the difference between the groups may be too small to confidently conclude that it is a genuine difference. In such cases, the measured difference may be attributed to measurement variability rather than a true difference between the groups.

In line with previous studies, including Rice et al. (2017), binary logistic analysis was used to identify the predictive variables for LAS. Binary logistic regression analysis was performed for each variable to identify the predictive variables. The interaction between different variables was assessed using a predictive model obtained through forward stepwise logistic regression. The coefficient (B) represents the estimated regression coefficient for each variable. The p-value indicates the significance of the coefficient, while the Wald statistic measures the significance of the coefficient estimate. The odds ratio (OR) reflects the change in odds for a one-unit change in the corresponding variable. The 95% confidence interval (CI) provides a range within which the true OR is likely to lie. In the logistic regression analysis, the OR was calculated and used as a measure of the association strength between a risk factor (exposure) and the outcome (injury). The OR is obtained by dividing the odds of the outcome in the exposed group by the odds of the outcome in the unexposed group. An OR of 1 indicates no association and that the odds of the event occurring are the same in both groups. In this case, the event is equally likely to happen or not happen in both groups. An OR greater than 1 indicates an increase in risk, suggesting that the event is more likely to occur in one group compared with the other. Specifically, if the OR is, for example, 2, it means the odds of the event happening are two times higher in one group than in the other. Conversely, an OR less than 1 indicates a decrease in risk, suggesting that the event is less likely to occur in one group compared with the other. For instance, if the OR is 0.5, it means the odds of the event happening are half as likely in one group than in the other. It is important to note that the OR provides an estimate of the relative risk but is not the same as the relative risk (Ranganathan et al., 2015).

At the end of the analysis, the discriminatory capability of each variable was assessed using Receiver Operating Characteristic (ROC) curves. Significant variables ($p < 0.05$) from the binary logistic regression were selected for ROC analysis. The ROC curve provides a graphical representation of the diagnostic performance of a test (Tilson et al., 2010). It plots the true positive rate (sensitivity) against the false positive rate (1-specificity) at various cut-off points of the test. The highest sensitivity and specificity values on the ROC curve indicate the optimal trade-off between correctly identifying true positives and minimising false positives for a given test. This point on the curve, known as the optimal cut-off point, represents the threshold at which the test should be considered positive or negative. It strikes a balance between sensitivity and specificity (Mandrekar, 2010). Determining the optimal cut-off point is important as it allows for the differentiation of individuals with and without a specific condition or disease. This cut-off point can be used to classify individuals into two groups based on their test results, such as injured versus non-injured individuals (Rota & Antolini, 2014). For instance, in medical diagnostics, the optimal cut-off point on an ROC curve can help establish a threshold value for a test to identify patients likely to have a certain disease or condition. This information can guide treatment decisions and improve patient outcomes.

The area under the ROC curve (AUC) is a commonly used measure to quantify the diagnostic accuracy of a test. The AUC indicates the discriminatory power of each variable in predicting the outcome. The p-values indicate the statistical significance of the associations, and the CI provides a range of plausible values for the population associations. A higher AUC indicates a greater predictive potential and suggests that the variable is more likely to contribute to the occurrence of the injury. The AUC values range from 0 to 1, with 1 indicating a perfect test and values below 0.5 indicating a test with no discriminatory ability. Typically, an AUC below 0.7 is considered poor, 0.7 to less than 0.8 is considered acceptable, 0.8 to less than 0.9 is considered excellent and 0.9 or greater indicates an outstanding/perfect discrimination ability between the two groups being tested (Peduzzi et al., 1996). Figure 5.3 provides a schematic representation of the statistical analysis process.

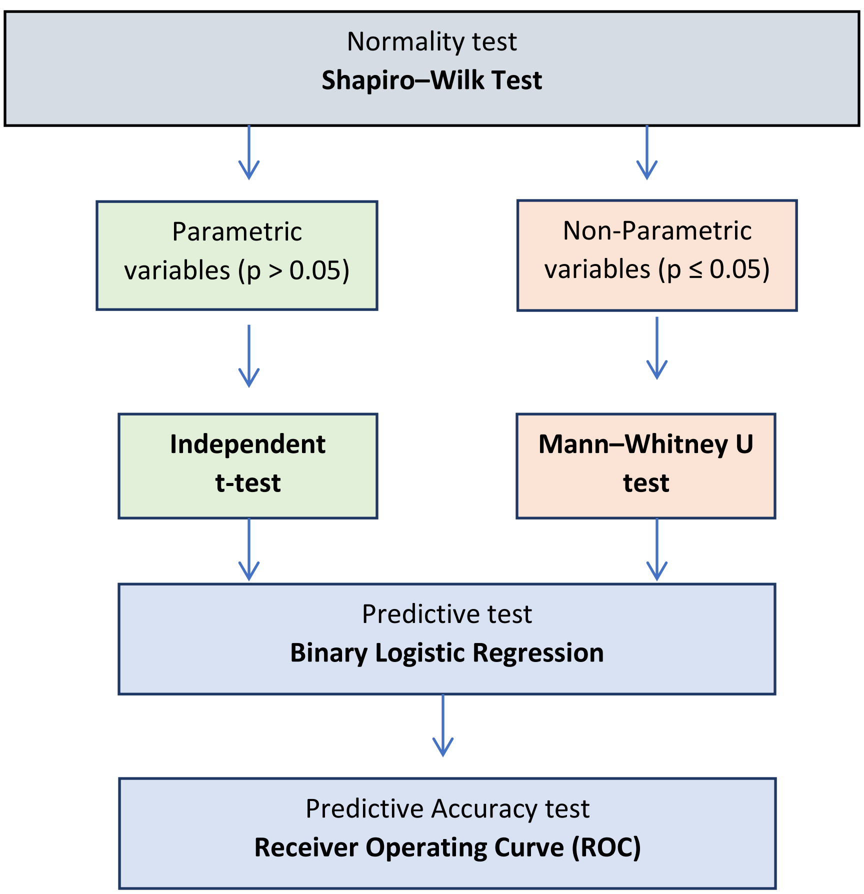


Figure 5.3: Flow chart of the statistical analysis

5.4. Results

5.4.1. Recruitment of Participants

A total of 230 military recruits were initially approached to participate in the study. Among this number, 221 agreed to take part, while nine declined the invitation. Following the health screening process, 217 recruits were deemed eligible for the study. However, during the course of the study, two recruits decided to withdraw for personal reasons, and an additional 11 recruits experienced severe musculoskeletal injuries and had to drop out of the training programme. As a result, only 204 participants remained and were assessed over a period of 12 weeks for the study. Please refer to Figure 5.4 for a visual representation of the participant flow.

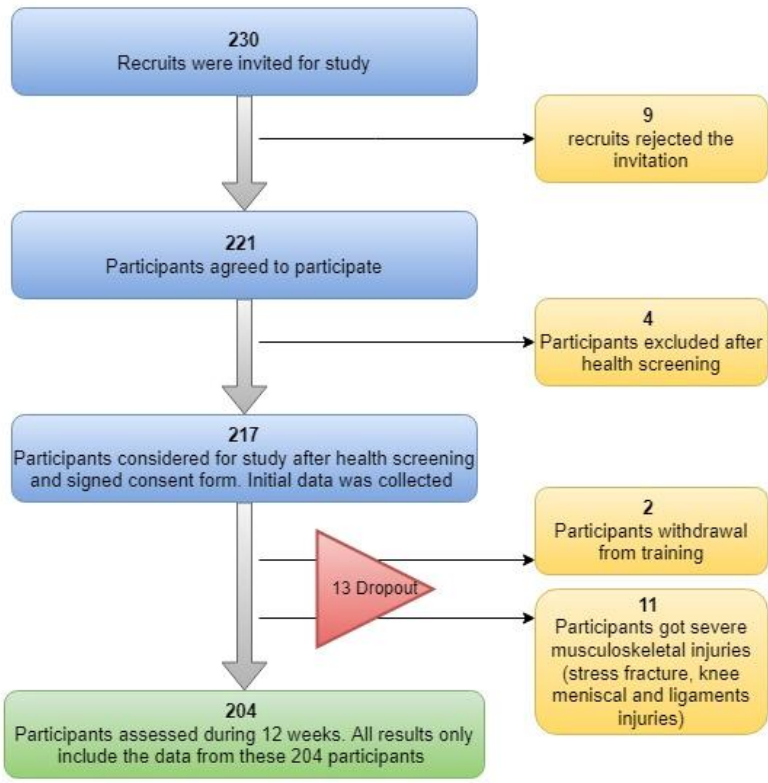


Figure 5.4: Recruitment of participants

5.4.2. Demographic Characteristics

The participants in the study had a mean age of 23.14 ± 2.06 years, with an average weight of 66.47 ± 7.53 kg. The mean BMI was 21.87 ± 2.34 kg/m^2, and the average height was 174.28 ± 4.20 centimetres. Detailed demographic characteristics of the population are presented in Table 5.1.

Table 5.1: Demographic characteristics of the participants

Variable	Age (years)	Mass (kg)	BMI (kg/m^2)	Height (cm)
Mean ± SD	23.14 ± 2.06	66.47 ± 7.53	21.93 ± 2.20	174.28 4.20

5.4.3. Injury Data for Prospective Study

Weekly report and risk of LAS

Among the 204 recruits in the study, the first reported cases of LAS occurred during the second week of training. The highest number of LAS cases, totalling six injuries, was observed in the fourth week, while the third week had five recruits with LAS. Out of the total 163 reported musculoskeletal injuries, LAS accounted for 30 cases, representing approximately 18.4% of all injury cases. It is important to note that each recruit experienced LAS only once during the training period, and no instances of LAS recurrence were found among the recruits. Figure 5.5 provides a visual representation of the number of LAS per week during the initial 12 weeks of training.

Risk of LAS = Number of participants with LAS/Total number of participants

Risk of LAS = 30/204 = 0.1471 or approximately 14.7%

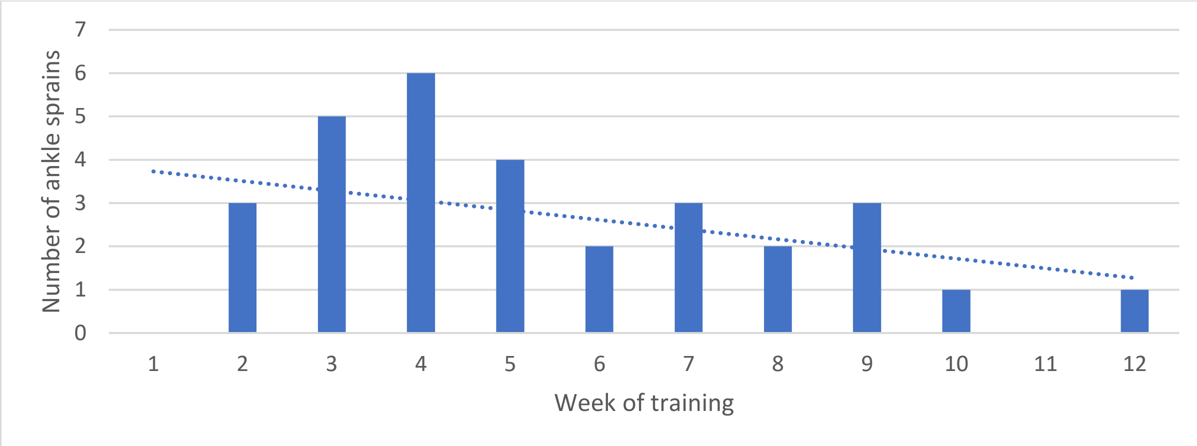


Figure 5.5: Number of LAS per week of training for the first 12 weeks with the same footwear

Total number of musculoskeletal injuries during 12 weeks of training

During the 12-week study duration, it is worth noting that each participant with LAS reported the injury only once. This could be attributed to the relatively short duration of the study, which may have reduced the likelihood of reinjury or the occurrence of multiple injuries in the same individual. It is possible that the participants took necessary rest breaks and followed appropriate rehabilitation protocols after sustaining an injury, thereby minimising the chances of experiencing further injuries or exacerbating the existing ones.

No cases of bilateral lower limb injuries or recurrent injuries were reported by any participant, indicating that the LAS cases observed were isolated to a single limb. In addition to the 30 reported LAS injuries, several other musculoskeletal injuries were recorded during the study period. These injuries included 59 cases of muscle strains and tendinopathies, 43 cases of patellofemoral pain and 31 recruits reporting back pain. Moreover, there were 11 additional injuries reported, which consisted of three cases of stress fractures, three cases of knee meniscal injuries and five cases of knee ligament injuries. Figure 5.6 provides a visual representation of these various injuries' occurrences.

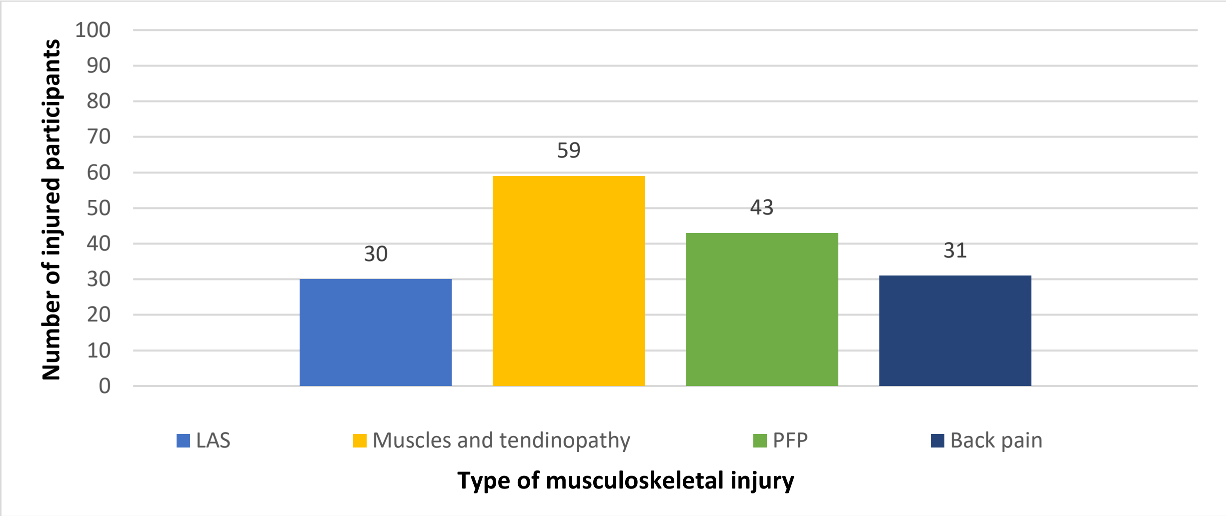


Figure 5.6: Distribution of injuries during the 12 weeks of training

Table 5.2 provides information regarding the side of the injured limb for each specific injury, along with the corresponding number and percentage of participants who experienced the injury. Among all reported injuries, the incidence of injury recurrence in the same participant was higher for conditions such as back pain and muscle strains of the leg. Specifically, there were 3 documented cases of recurrent back pain in the same participant, and 2 documented cases of recurrent muscle strains of the leg in the same participant. The participants took adequate rest periods in an attempt to fully resolve injury symptoms before returning to activity. Of the total injuries reported in the study, the recurrence of back pain and leg muscle strains in individual participants represented the majority of reinjuries. While, no LAS recurrent injury reported.

Table 5.2: Numbers and percentages of injured participants and injured limbs in each injury

Injury	Right limb	Left limb	Both limbs	Number of injuries	Injury %
MAT	26	23	10	59	36.19 %
PFP	13	15	15	43	26.38 %
BP	-	-	-	31	19.01%
LAS	14	16	-	30	18.40 %
Total	53	54	25	163	-

Note: ***MAT:*** *Muscles and tendinopathy injuries,* ***PFP:*** *Patellofemoral pain,* ***BP:*** *Back pain,* ***LAS:*** *Lateral ankle sprain*

Loss of training days due to LAS

During the period from the occurrence of an LAS until the resolution of signs and symptoms, the participants refrained from participating in any activities of the military training programme. This period is referred to as functional time loss. Functional time loss indicates that the participants followed the rest, icing, compression and elevation (RICE) protocol and abstained from engaging in any activities to facilitate a speedy recovery.

Figure 5.7 illustrates the extent of functional time loss experienced by the participants with LAS, as recorded in the military training centre. The duration of time lost varied, with a minimum of 3 days and a maximum of 21 days. On average, the participants experienced a functional time loss of 8.16 days (SD 0.34).

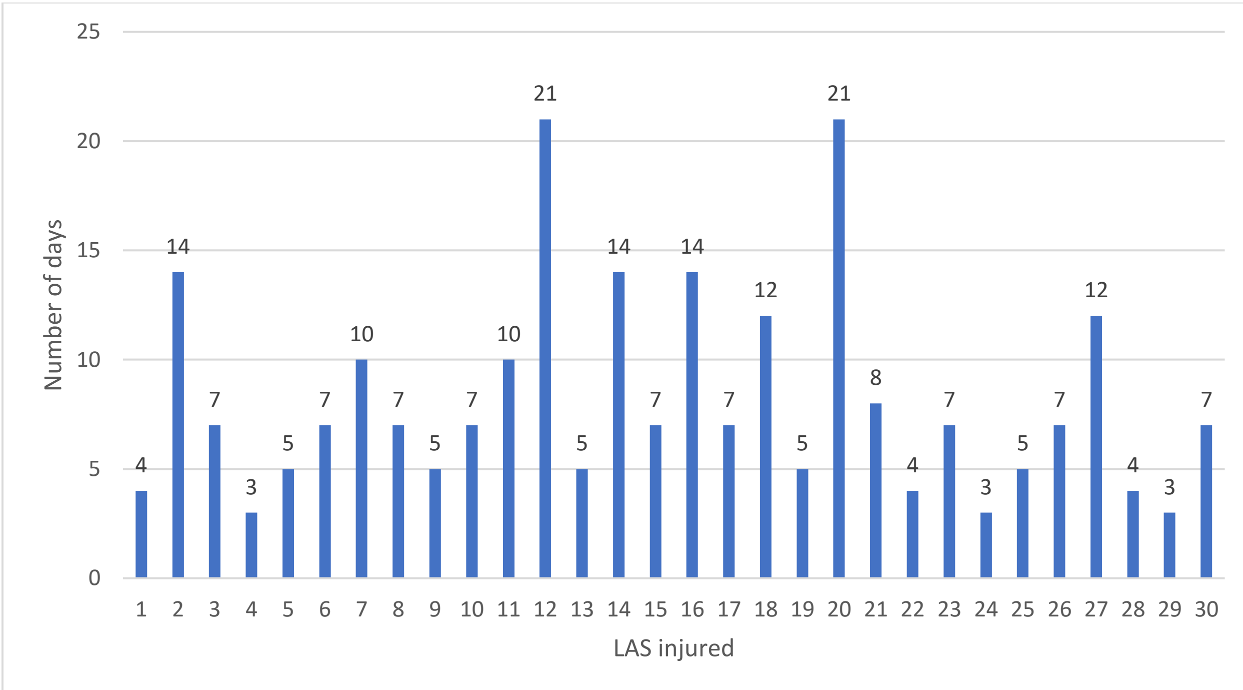


Figure 5.7: Loss of functional training days for LAS-injured individuals

Activity-related mechanism of LAS injury

All instances of LAS in the study occurred while the participants were wearing the same training footwear during their training activities. Figure 5.7 provides insights into specific physical activities that were strongly associated with the occurrence of LAS. These activities included landing, jump landings and hopping, which were a result of various training tasks, such as climbing buildings, ascending or descending stairs, running for a daily distance of 15 km, jumping over obstacles and performing drop landings from helicopters. It is important to note that the participants did not have any additional load or weight-bearing when these injuries occurred. Figure 5.8 also indicates other activities that contributed to LAS, such as descending from buildings and lateral jumping.

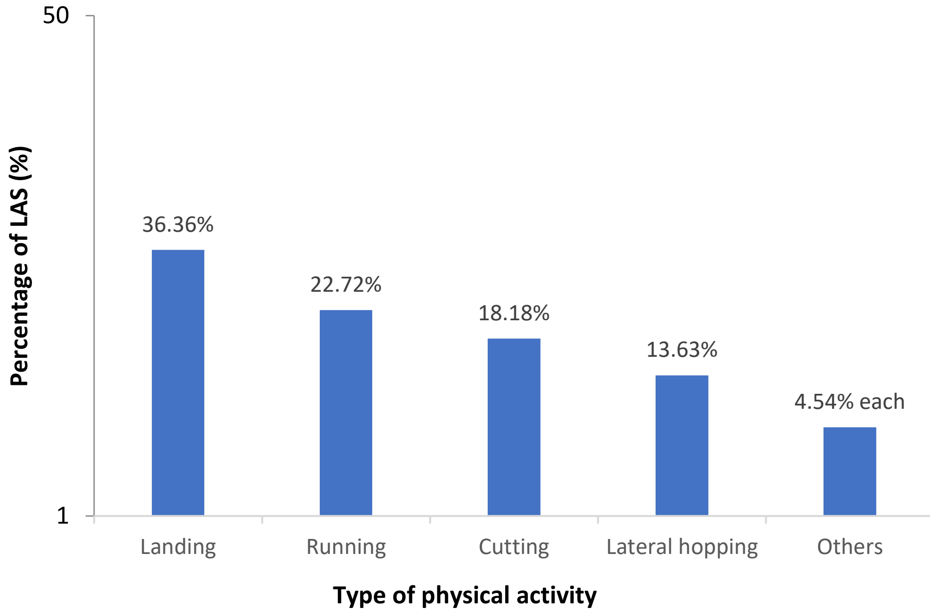


Figure 5.8: LAS according to mechanisms

5.4.4. Comparison of Demographic Variables Between Groups

Out of the 204 participants, 30 individuals (14.7%) developed LAS, indicating a significant difference in mean mass (kg) and BMI compared with the uninjured subjects ($p < 0.05$). The mean mass (kg) and BMI of the injured participants were found to be significantly higher than those of the uninjured subjects, with a p-value of less than 0.01 and a large effect size. These findings are presented in Table 5.3, which provides a comparison of the demographic variables between the two groups.

Table 5.3: Mean, SD, 95% CI, effect size and p-value of demographic variables

Variable	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Age (years)	Uninjured	174	23.10	2.01	0.16	0.57	–0.23	–0.112	–1.04	0.58
	Injured	30	23.33	2.30	0.42					
Mass (kg)	Uninjured	174	65.24	7.24	0.59	**0.00**	–7.04	–0.997	–9.91	–4.26
	Injured	30	72.33	6.57	1.199					
Height (cm)	Uninjured	174	174.12	4.34	0.35	0.24	–0.97	–0.233	–2.63	0.68
	Injured	30	175.10	3.37	0.61					
BMI (kg/m²)	Uninjured	174	21.52	2.31	0.19	**0.00**	–2.02	–0.909	–2.91	–1.148
	Injured	30	23.56	1.78	0.32					
Leg length (cm)	Uninjured	174	97.30	4.12	0.33	0.26	-0.89	–0.224	–2.47	0.68
	Injured	30	98.20	3.23	0.58					
Bimalleolar width (cm)	Uninjured	174	7.07	0.45	0.03	0.50	–0.05	–0.134	–0.23	0.11
	Injured	30	7.13	0.41	0.07					

Note: ***Kg:*** *Kilogramme,* ***Cm:*** *Centimetre,* **kg/m²*:*** *Kilogramme per square metre,* ***IC: (°)****: Degree,* ***N/Kg:*** *Newton per kilogramme.*

5.4.5. Comparison of Clinical Variables Between Groups

Table 5.4 presents the results of the comparison between the injured and uninjured groups for the 14 clinical variables assessed. The following variables showed a significant difference between the groups, and all had mean differences were greater than the SEM and MDD. The injured group had statistically lower ankle dorsiflexion strength (N/kg) (mean difference: 0.18, effect size: 0.55, SEM: 0.04, MDD: 0.11). The injured group also had statistically lower plantarflexor strength (N/kg) (mean difference: 0.34, effect size: 0.541, SEM: 0.06, MDD: 0.16). The invertor strength (N/kg) was lower in the injured group (mean difference: 0.22, effect size: 0.75, SEM: 0.04, MDD: 0.11). The evertor strength (N/kg) was also lower in the injured group, (mean difference: 0.12, effect size: 0.420, SEM: 0.03, MDD: 0.08).

Among all the goniometry measurements, the ankle dorsiflexion ROM was lower in the injured group, (mean difference: 2.81, effect size: 0.83, SEM: 0.34, MDD: 0.94). The injured group also demonstrated a lower anterior YBT (%) (mean difference: 5.37, effect size: 0.940, SEM: 1.36, MDD: 3.76). These differences between groups exceeded the SEM and MDD from the reliability study, suggesting that the mean difference was not due to measurement error and were statistically significant, with a p-value of less than 0.05 and effect sizes ranging from moderate to great. The measures identified as greater than the MDD were clinically and statistically significant and selected for regression analysis.

Table 5.4: Mean, SD, 95% CI, effect size and p-value of the clinical variables

Variable	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Hip extensor strength (N/kg)	Uninjured	174	3.39	0.60	0.04	0.12	0.17	0.311	–0.04	0.40
	Injured	30	3.21	0.37	0.06					
Hip abductor strength (N/kg)	Uninjured	174	3.04	0.55	0.04	0.34	0.10	0.190	–0.11	0.31
	Injured	30	2.93	0.45	0.08					
Ankle dorsiflexor strength (N/kg)	Uninjured	174	2.16	0.34	0.02	**0.00**	0.18	0.550	0.05	0.31
	Injured	30	1.98	0.26	0.04					
Plantarflexor strength (N/kg)	Uninjured	174	4.10	0.66	0.05	**0.00**	0.34	0.541	0.09	0.60
	Injured	30	3.75	0.49	0.09					
Invertor strength (N/kg)	Uninjured	174	1.88	0.29	0.02	**0.00**	0.22	0.747	0.10	0.33
	Injured	30	1.66	0.30	0.05					
Evertor strength (N/kg)	Uninjured	174	1.66	0.31	0.02	**0.03**	0.13	0.420	0.09	0.24
	Injured	30	1.54	0.21	0.03					
Ankle dorsiflexion ROM (°)	Uninjured	174	14.34	3.52	0.29	**0.00**	2.81	0.834	1.48	4.15
	Injured	30	11.52	2.49	0.45					
Ankle plantarflexion ROM (°)	Uninjured	174	35.16	5.72	0.47	0.13	1.67	0.301	–0.52	3.86
	Injured	30	33.49	4.55	0.83					

Variable	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Invertors ROM (°)	Uninjured	174	12.61	1.97	0.16	0.23	–0.46	0.301	–1.24	0.30
	Injured	30	13.08	1.92	0.35					
Evertors ROM (°)	Uninjured	174	2.53	0.50	0.04	0.24	0.11	0.233	–0.08	0.31
	Injured	30	2.41	0.44	0.08					
Anterior YBT (%)	Uninjured	174	70.81	6.05	0.49	**0.00**	5.37	0.940	3.11	7.63
	Injured	30	65.43	3.52	0.64					
Posteromedial YBT (%)	Uninjured	174	74.96	10.95	0.90	0.61	1.09	0.101	–5.35	3.35
	Injured	30	75.97	11.34	2.07					
Posterolateral YBT (%)	Uninjured	174	81.33	9.89	0.81	0.39	1.67	0.170	–3.55	4.30
	Injured	30	80.95	10.24	1.87					

Note: ***YBT:*** *Y-balance test,* ***ROM:*** *Range of motion,* ***IC: (°)****: Degree,* ***N/Kg:*** *Newton per kilogramme,* ***%:*** *percentage*

5.4.6. Comparison of Biomechanical Variables Between Groups

During lateral hopping

Among the 20 biomechanical variables assessed during LH (Table 5.5), none of the variables exhibited a significant difference between the injured and uninjured groups, with a p-value of less than 0.05. In addition, the effect sizes for these variables were low, suggesting minimal or negligible differences between the two groups in terms of biomechanical factors during the LH task.

Table 5.5: Mean, SD, 95% CI, effect size and p-value of significant biomechanical variables during the LH task

Variable during LH	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Peak of ankle° towards dorsiflexion pre-IC (°)	Uninjured	174	16.94	6.14	0.50	0.35	1.18	0.187	–1.31	3.69
	Injured	30	15.75	7.25	1.32					
Peak of ankle° towards plantarflexion pre-IC (°)	Uninjured	174	18.37	6.14	0.50	0.46	0.91	0.187	–1.57	3.39
	Injured	30	17.46	6.91	1.26					
Ankle° dorsi/plantarflexion at IC (°)	Uninjured	174	14.98	6.09	0.50	0.33	1.20	0.194	–1.25	3.66
	Injured	30	13.78	6.81	1.24					
Peak of ankle° towards dorsiflexion post-IC (°)	Uninjured	174	–12.74	3.37	0.61	0.22	0.84	0.242	–0.53	2.21
	Injured	30	–11.89	3.50	0.28					

Variable during LH	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Peak of ankle° towards plantarflexion post-IC (°)	Uninjured	174	11.23	5.85	0.48	0.33	1.15	0.193	–1.20	3.51
	Injured	30	10.08	6.53	1.19					
Peak of knee° towards extension pre-IC (°)	Uninjured	174	35.83	7.41	0.60	0.54	0.91	0.120	–2.08	3.90
	Injured	30	34.92	8.35	1.52					
Peak of knee° towards flexion pre-IC (°)	Uninjured	174	39.30	8.11	0.66	0.41	1.37	0.165	–1.91	4.66
	Injured	30	37.92	9.26	1.69					
Knee° flexion/extension angle at IC (°)	Uninjured	174	33.69	6.92	0.56	0.71	0.50	0.072	–2.27	3.28
	Injured	30	33.18	7.58	1.38					
Peak of knee° towards extension post-IC (°)	Uninjured	174	30.50	7.00	0.57	0.96	–0.06	–0.009	–2.83	2.71
	Injured	30	30.56	7.07	1.29					
Peak of knee° towards flexion post-IC (°)	Uninjured	174	51.15	7.48	0.61	0.92	–0.13	–0.018	–3.05	2.79
	Injured	30	51.28	6.93	1.26					
Peak of ankle° towards eversion pre-IC (°)	Uninjured	174	0.47	4.88	0.40	0.86	–0.16	–0.034	–2.08	1.75
	Injured	30	0.63	4.71	0.86					
Peak of ankle° towards inversion pre-IC (°)	Uninjured	174	3.11	4.48	0.36	0.70	–0.33	–0.076	–2.09	1.41
	Injured	30	3.44	4.19	0.76					

Variable during LH	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Ankle° eversion/inversion at IC (°)	Uninjured	174	4.79	3.63	0.29	0.76	–0.21	–0.059	–1.66	1.23
	Injured	30	5.01	3.83	0.70					
Peak of ankle° towards eversion post-IC (°)	Uninjured	174	–2.59	2.83	0.23	0.91	0.06	0.021	–1.11	1.23
	Injured	30	–2.66	3.56	0.64					
Peak of ankle° towards inversion post-IC (°)	Uninjured	174	8.35	2.73	0.22	0.86	0.09	0.035	–1.03	1.23
	Injured	30	8.25	3.51	0.64					
Peak of FPPA° towards adduction pre-IC (°)	Uninjured	174	2.94	3.25	0.26	0.46	–0.47	–0.146	–1.75	0.80
	Injured	30	3.41	3.16	0.57					
Peak of FPPA° towards abduction pre-IC (°)	Uninjured	174	3.92	2.97	0.24	0.80	–0.14	–0.050	–1.32	1.02
	Injured	30	4.07	2.97	0.54					
FPPA° adduction/abduction at IC (°)	Uninjured	174	4.21	2.76	0.22	0.70	0.21	0.077	–0.87	1.30
	Injured	30	4.00	2.69	0.49					
Peak of FPPA° towards adduction post-IC (°)	Uninjured	174	–3.43	3.96	0.32	0.56	–0.45	–0.117	–2.00	1.09
	Injured	30	–2.97	3.65	0.66					
Peak of FPPA° towards abduction post-IC (°)	Uninjured	174	5.54	3.14	0.25	0.96	–0.03	–0.010	–1.31	1.24
	Injured	30	5.57	3.66	0.66					

Note: ***LH:*** *Lateral hopping,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plan projection angle,* ***IC:*** *Initial contact,* ***(°)****: Degree, (cm)****:*** *Centimetre*

During single-leg landing

Among the biomechanical variables assessed during SLL, the results in Table 5.6 revealed two variables that displayed a significant difference between the injured and uninjured groups. The peak towards dorsiflexion post-IC (°) was significantly lower in the injured group. The ankle dorsiflexion angle exhibited a mean difference of 1.80, SEM of 2.10 and MDD of 5.82. The effect sizes indicated a moderate degree of distinction between the injured and uninjured groups, with effect size = 0.503.

Table 5.6: Mean, SD, 95% CI, effect size and p-value of significant biomechanical variables

Variable during SLL	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Peak of ankle° towards dorsiflexion pre-IC (°)	Uninjured	174	28.78	5.66	0.46	0.39	0.97	0.171	–1.27	3.23
	Injured	30	27.80	5.94	1.08					
Peak of ankle° towards plantarflexion pre-IC (°)	Uninjured	174	31.09	5.72	0.47	0.49	0.77	0.136	–1.48	3.04
	Injured	30	30.31	5.78	1.05					
Ankle° dorsi/plantarflexion at IC (°)	Uninjured	174	24.24	5.42	0.44	0.28	1.19	0.217	–0.98	3.37
	Injured	30	23.04	5.92	1.08					

Variable during SLL	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Peak of ankle° towards dorsiflexion post-IC (°)	Uninjured	174	–16.38	3.71	0.67	**0.01**	1.80	0.503	0.38	3.22
	Injured	30	–14.58	3.56	0.29					
Peak of ankle° towards plantarflexion post-IC (°)	Uninjured	174	18.20	5.22	0.42	0.16	1.48	0.281	–0.60	3.58
	Injured	30	16.71	5.65	1.03					
Peak of knee° towards extension pre-IC (°)	Uninjured	174	16.93	5.55	0.45	0.73	0.39	0.069	–1.84	2.63
	Injured	30	16.54	6.23	1.13					
Peak of knee° towards flexion pre-IC (°)	Uninjured	174	18.03	5.52	0.45	0.78	0.30	0.055	–1.91	2.53
	Injured	30	17.72	6.15	1.12					
Knee° flexion/extension angle at IC (°)	Uninjured	174	19.32	5.43	0.44	0.82	–0.24	–0.044	–2.44	1.94
	Injured	30	19.57	6.13	1.12					
Peak of knee° towards extension post-IC (°)	Uninjured	174	21.31	5.21	0.42	0.45	–0.80	–0.044	–2.93	1.32
	Injured	30	22.12	6.20	1.13					
Peak of knee° towards flexion post-IC (°)	Uninjured	174	56.60	7.11	0.58	0.29	–1.49	–0.209	–4.30	1.32
	Injured	30	58.10	7.14	1.30					

Variable during SLL	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
Peak of ankle° towards eversion pre-IC (°)	Uninjured	174	9.23	5.07	0.41	0.39	–0.88	–0.209	–2.92	1.15
	Injured	30	10.11	5.60	1.02					
Peak of ankle° towards inversion pre-IC (°)	Uninjured	174	11.22	5.29	0.43	0.46	–0.78	–0.147	–2.90	1.32
	Injured	30	12.01	5.68	1.03					
Ankle° eversion/inversion at IC (°)	Uninjured	174	6.73	4.48	0.36	0.61	–0.45	–0.100	–2.25	1.34
	Injured	30	7.18	4.87	0.88					
Peak of ankle° towards eversion post-IC (°)	Uninjured	174	–9.47	2.91	0.24	0.07	1.19	0.384	–0.03	2.42
	Injured	30	–10.66	3.92	0.71					
Peak of ankle° towards inversion post-IC (°)	Uninjured	174	3.83	4.00	0.32	0.96	–0.03	–0.009	–1.64	1.57
	Injured	30	3.87	4.45	0.81					
Peak of FPPA° towards adduction pre-IC (°)	Uninjured	174	1.46	2.76	0.22	0.09	0.91	0.339	–0.15	1.97
	Injured	30	0.55	2.22	0.40					
Peak of FPPA° towards abduction pre-IC (°)	Uninjured	174	1.81	2.77	0.22	0.08	0.94	0.352	–0.11	2.01
	Injured	30	0.86	2.23	0.40					

Variable during SLL	Groups	N	Mean	SD	Std. Error Mean	p value	Mean Diff.	Effect size	95% CI	
									Lower	Upper
FPPA° adduction/abduction at IC (°)	Uninjured	174	1.65	2.77	0.22	0.09	0.90	0.334	–0.16	1.97
	Injured	30	0.75	2.34	0.42					
Peak of FPPA° towards adduction post-IC (°)	Uninjured	174	–1.27	3.91	0.32	0.66	0.35	0.088	–1.22	1.93
	Injured	30	–1.62	4.43	0.80					
Peak of FPPA° towards abduction post-IC (°)	Uninjured	174	8.60	4.98	0.40	0.79	0.27	0.053	–1.75	2.30
	Injured	30	8.32	5.8	1.07					

Note: ***SLL:*** *Single-leg landing,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***FPPA:*** *Frontal plan projection angle,* ***IC:*** *Initial contact,* ***(°)****: Degree*

5.4.7. Logistic Regression Analysis

The results of the binary logistic regression analysis for each variable are presented in Table 5.7.

The OR of the mass was 1.14, indicating an increase in risk with increasing weight. In addition, for ankle dorsiflexion ROM (°), the OR was 0.80, indicating a decrease in risk with the increase in ankle dorsiflexion angle. For anterior YBT (%), the OR was 0.84, indicating a decrease in risk with increasing anterior YBT score. Moreover, for the peak ankle dorsiflexion (º) during SLL post-IC, the OR was 0.80, indicating that LAS risk increases with a decrease in the peak ankle dorsiflexion (º) during SLL post-IC.

Table 5.7: Binary logistic regression: Significance value, OR and 95% CI of OR for each variable

Variable	B	p value	Wald	OR	95% CI for EXP(B)	
					Lower	Upper
Mass (kg)	0.13	0.00	11.34	1.14	1.06	1.24
Ankle dorsiflexion ROM (°)	–0.26	0.00	9.40	0.80	0.65	0.91
Anterior YBT (%)	–0.17	0.00	10.71	0.84	0.75	0.93
Peak of ankle towards dorsiflexion at post-IC (°)	–0.22	0.00	8.32	0.80	0.68	0.93
Constant	0.72	0.87	0.02	2.05		

Note: ***YBT:*** *Y-balance test,* ***ROM:*** *Range of motion,* ***SLL:*** *Single-leg landing,* ***Ankle and knee:*** *Angle in the sagittal plane,* ***IC:*** *Initial contact,* ***(°)****: Degree,* ***Kg:*** *Kilogramme,* ***B:*** *Estimated regression coefficient,* ***p-value:*** *Significance of the coefficient,* ***Wald:*** *Significance of the coefficient estimate,* ***OR:*** *Odds ratio,* ***CI:*** *Confidence interval 95%*

Please note that the constant term (intercept) does not have an OR or CI as it represents the baseline odds when all other variables are held constant.

5.4.8. Receiver Operating Curve

Figure 5.9 presents the ROC curve analysis for the significant variables identified in the regression model. In Table 5.8, various metrics and measures are presented for each variable.

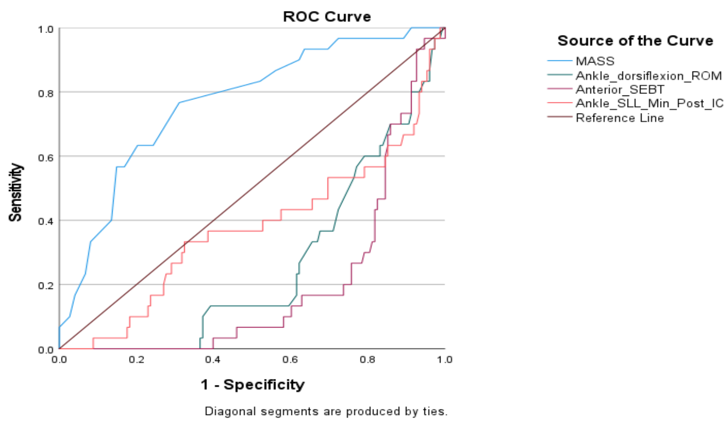


Figure 5.9: ROC curve

Table 5. 8: Area under ROC curve, significance level and 95% CI of the predictive factors of LAS

Variable	Cut-Off Point	AUC	P	95% CI	
				Lower	Upper
MASS (kg)	67.50	0.766	0.000	0.674	0.858
Ankle dorsiflexion ROM (°)	6.83	0.262	0.000	0.179	0.344
Anterior YBT (%)	62.9	0.198	0.000	0.129	0.267
Peak of ankle towards dorsiflexion post-IC (°)	–13.85	0.374	0.030	0.256	0.429

Note: ***YBT:*** *Y-balance test,* ***ROM:*** *Range of motion,* ***(°)****: Degree,* ***Kg:*** *Kilogramme,* ***(%):*** *Percentage*

The variable mass (kg) has a cut-off point of 67.5. The AUC value of 0.766 suggests that this variable has acceptable discriminatory power in predicting the outcome. Meanwhile, the AUC of the other included variables showed no discriminatory power, as ankle dorsiflexion ROM (°) has an AUC value of 0.262, anterior YBT (%) has an AUC value of 0.198 and the peak of ankle towards dorsiflexion (º) during SLL post-IC has an AUC of 0.374.

5.5. Discussion

In this prospective study, a total of 204 military recruits were included. These recruits underwent a 12-week military training programme. The primary objective of the study was to investigate the clinical and biomechanical factors that contribute to LAS among military recruits. The authors chose to focus on the military population because they share similar characteristics, such as age group, demographics and the absence of previous injury history, making them an ideal group for this study.

In essence, this research corroborates the presence of multiple inherent factors contributing to LAS through regression analysis. However, it underscores the significance of mass (kg) as a screening parameter after ROC analysis. The investigation highlights the specific risk indicators that might lead to LAS: a mass exceeding 67.5 kg, ankle dorsiflexion ROM below 6.83°, anterior reach less than 62.9% in the YBT and a peak of ankle towards dorsiflexion at post-IC (°) during SLL that is below –13.85°. It is important to note the study's limitation of a 12-week data collection period. While no re-injuries occurred during this timeframe, the brief follow-up duration obstructs the attainment of a comprehensive understanding of the enduring outcomes and recurrence rates linked to LAS.

One advantage of studying the military population is that the external environmental conditions can be controlled for each participant, which helps minimise the impact of environmental factors as potential confounders in the study. The authors cited previous studies to support the rationale for selecting the military population and highlighted the relevance of their findings within this specific context (Blacker et al., 2008; Campos et al., 2016; Davey et al., 2011; Jordaan & Schwellnus, 1994; Rice et al., 2017; Schwartz et al., 2018; Wilkinson et al., 2008).

By conducting a prospective study and focusing on a well-defined population, this study aimed to gain insights into the risk factors associated with LAS among military recruits. This approach allows for the examination of both clinical and biomechanical factors, providing a comprehensive understanding of the factors contributing to LAS in this specific population.

Study sample

The current study included a population size of 204 military recruits, which is relatively small compared with the previous studies conducted by Rice et al. (2017), which had 419 military recruits, and Milgrom et al. (1991), which had 390 military recruits. The smaller sample size in this study was a result of the COVID-19 circumstances, which limited the ability to include additional samples or cohorts for examination. However, nine out of 14 studies included in the meta-analysis (Chapter 3) had a lower sample size than this study. Notably, one of these studies was conducted among the female military, with a sample size of 83 (Mei-Dan et al., 2005).

The duration of injury reporting in this study was 12 weeks, which aligns with the studies conducted by Blacker et al. (2008), Campos et al. (2016) and Greeves (2001), given that they utilised a similar timeframe during the basic military training in their investigations of military recruits. This duration is consistent with the typical timeframe required to complete military training, including the allocated training time for recruits in the Saudi military. By contrast, Rice et al. (2017) had a longer duration of 32 weeks to assess various risk factors for musculoskeletal injuries among military recruits. This longer timeframe was primarily due to the extended duration of the Royal Marine training programme. However, according to a former military in the United States, basic military training lasts for 12 weeks (Hughes et al., 2018; Knapik et al., 2010). This indicates that Rice et al. (2017) might have included a different military programme.

Although the sample size in this study is smaller and the duration of injury reporting is shorter compared with some previous studies, it is important to consider the specific context and constraints, such as the COVID-19 situation, that influenced these factors. Despite these differences, this study contributes valuable insights into the risk factors and injury occurrence within the given population of military recruits in Saudi Arabia.

Injury incidence and loss of training days

During the 12-week military training programme, a total of 163 musculoskeletal injuries were reported and recorded at the military clinic. For clarity, some injuries were reported for the same recruit, particularly muscle injuries and patellofemoral pain, during the training, and these types of injuries require more time for recovery and rehabilitation. These injuries encompassed a range of conditions, including LAS, patellofemoral pain, muscle strains, tendinopathy and back pain. In addition, there were three cases of stress fractures, three knee meniscal injuries and five knee ligament injuries, which resulted in the affected participants discontinuing their participation in the training programme.

Table 5.2 provides a breakdown of the specific injuries, the limbs involved and the overall incidence rates, which help establish an understanding of the distribution and prevalence of each injury among the participants. The highest percentage of reported musculoskeletal injuries in this study were muscle strains and tendinopathies (36.19%

of total injuries), followed by patellofemoral pain (26.38%), back pain (19.02%) and LAS (18.4%).

Among the 204 recruits, 30 sustained LAS, which accounted for 14.7% during the 12-week training programme. This incidence value is similar to previous prospective studies that showed a range of 6% to 32% of LAS occurrence during military training programmes (Mei-Dan et al., 2005; Milgrom et al., 1991; Rice et al., 2017). Thus, the wide range of LAS incidence rates (6%–32%) reported in previous military studies was a clear indicator that point cannot generalise a single injury rate across all populations and training contexts. Beyond differences in age, gender balance and injury definitions, there are likely important nuances in training progression, load management and recovery protocols that contribute substantially to injury risk. For instance, none of the cited studies provided detailed quantification of load volumes, rest days, activity type distribution or individualised programming based on fitness levels.

This variability in LAS incidence could be attributed to differences in sample demographics, training exposures, training time, type of gender, recruits affected by extrinsic factors, such as backpack and military shoes, and injury definitions between studies. This could explain the sample affected by factors like age or gender and military shoes. By contrast, Mei-Dan et al. (2005) used stricter diagnostic criteria for LAS, requiring evidence of ligament tear, possibly explaining their higher than 32% incidence. It is clear that this high incidence of LAS was due to gender, as the sample only comprised females. In addition, laxity and fat mass could play a role in this LAS occurrence. Therefore, standardising injury definitions and tracking training volumes better could help identify factors influencing LAS incidence within military populations (Rice et al. 2017; Milgrom et al. 1991).

Moreover, the association between physical activity and injury risk is complex, nonlinear and dependent on the interactions of multiple individual, training and environmental factors. The current study took an overly simplistic view by not characterising the specific training programme variables and individual factors involved. Rather than general and superficial recommendations to avoid activity, future research should use more rigorous designs and precise variable tracking to identify safe training practices and modifications that can minimise injury risk even with high activity levels. This nuanced understanding will provide practical guidance beyond reactionary warnings against all physical activity that lack proper context and critical analysis.

Moreover, in Chapter 3 of this thesis, the systematic review found that people who engage in high-intensity activities are more likely to experience LAS than the general inactive population on the first occasion (Beynon et al., 2005). Comparing the general non-athletic population to military personnel and athletes, recurrent sprains are two to three times more common (Mei-Dan et al., 2005). Future prospective research should aim to recruit more representative samples that include both genders and mixed training intensity exposure. This could elucidate potential gender and exposure differences in LAS incidence and help foster generalisability.

As an analogy, a recent study by Thompson et al. (2019) found that novice runners randomised to a 10% weekly mileage increase had significantly lower injury rates than those with a 30% weekly increase. This exemplifies how precise quantification of training load progressions can reveal nuanced dose-response patterns—an approach lacking in the military LAS literature that simply dichotomises groups as trained or untrained. Similarly, difficulty in equate risk factors between training programmes without considering differential exposures to running, marching, load carriage, drill manoeuvres or other activities. The failure to account for this level of detail is a major limitation.

Furthermore, the exclusive focus on only LAS or general overuse injuries ignores the potential for differential effects across various injury types (Mei-Dan et al., 2005; Milgrom et al., 1991; Rice et al., 2017; Schwartz et al., 2018). In the current study, the results contradicted the military studies by finding higher rates of strains and tendinopathies versus LAS. This underscores the need to report comprehensive injury distributions rather than isolated injury variables when comparing across training contexts.

Moreover, the tissue fatigue theory ignores crucial connections between training loads, motor adaptation and injury risk. The temporal association between rapidly increased external demands and heightened injury rates in the first 2–4 weeks of training strongly implicates a dose-dependent relationship rather than simple tissue tolerance being exceeded. As noted by Mueller and Maluf (2002), physiological and neuromuscular adaptations likely play a greater role than hypothetical ligament remodelling. Supporting this notion, military studies implementing gradual progressions in volume and intensity show attenuated spikes in early-phase injuries (Kaufman et al., 2000).

Thus, the uncritical attribution of LAS rates to tissue fatigue disregards substantial evidence on dose-response patterns and the interconnected nature of external loads and internal adaptations. Rather than focusing solely on ligamentous stress thresholds, a holistic approach accounting for the interplay between training volumes, movement repetitiveness, rest, coordination, strength gains and tissue mechanics is needed. While gradual tissue adaptation likely occurs, it is not the primary driver of temporal injury patterns. The rapid onset suggests acute excessive demands surpassing readiness. These interconnected factors will provide clearer guidance on military training design, injury screening and prevention strategies (Leggat & Smith, 2007; Kaufman et al., 2000).

Rather than tissue adaptation, the gradual decline in LAS rates over the 12-week training period can likely be attributed to neuromuscular and physiological adaptations over time. As recruits gained strength and coordination through consistent training, they developed abilities to better stabilise the ankle joint and withstand the demands of high-load activities (Mueller & Maluf, 2002). Military studies have shown that progressive conditioning focused on ankle strength, balance and movement quality helps protect against initial spikes in ligamentous injury rates seen during early training phases (Kaufman et al., 2000).

Moreover, in contrast to the theory of tissue adaptation presented earlier, ligaments may not significantly alter their ultimate stress thresholds, as they are largely collagenous structures without robust remodelling capacity (Higgins & Wendland, 2015). The notion of microtrauma accumulation exceeding tissue thresholds is also questionable since the spikes in injury rates occur long before maximal tissue fatigue is reached. Rather than simplistic tissue fatigue models, the aetiology of LAS during military training is multifactorial, related to rapid increases in external demands outstripping physiological and motor readiness.

For instance, ankle evertor strength gains allow greater resistance against excessive inversion during landing. Enhanced motor unit synchronisation and firing patterns refine movement quality and coordination. In addition, gradual exposure enables the refinements in muscular endurance, power generation and postural control needed to withstand intense training volumes. In this manner, the temporal decline in LAS rates stems from improved dynamic stabilisation, movement mechanics and physical durability.

The medical records from the military training centre indicated that the functional activity time lost due to LAS ranged from 3 to 21 days, with an average of 8.16 days. This finding is consistent with the study conducted by Schwartz et al. (2018), which reported an average of 8 days of training loss due to LAS. It takes approximately 8 days for the pain and inflammation to subside after LAS. This was also supported by Waterman et al. (2010), who reported a similar average functional time loss of 7.9 days among military recruits, as it takes an average of 7.9 days for the signs and symptoms, including pain, inflammation and regaining normal ROM in the ankle joint, to get resolved (Waterman et al., 2010).

Zambraski & Yancosek, (2012) and other studies suggested that manpower or training days were lost because the injured participants were advised to rest, use bracing and undergo a rehabilitation programme (Halabchi et al., 2016; Shahi et al., 2021). The rehabilitation programme typically includes specific physical therapy exercises, such as neuromuscular, ROM, strengthening, stretching and proprioceptive exercises (Halabchi et al., 2016; Pourgharib Shahi et al., 2021). The RICE protocol, as recommended by Wayne et al. (2011), was followed within the first 24 to 48 hours after LAS. The decision to allow participants to return to the military training programme was based on the resolution of the signs and symptoms (pain, swelling, ROM) and functional performance and stability tests (Shahi et al., 2021).

Univariate analysis: Comparison between injured and uninjured groups

Demographic differences between groups

In this study, no differences in age, height or leg length were observed between the injured and uninjured groups. This is unsurprising given the homogeneous recruitment and screening protocols, which align with other military studies (Baumhauer et al., 1995; Rice et al., 2017). However, the systematic review found statistically increased LAS risk with greater height in male recruits (Figure 3.4), suggesting that military exclusion criteria may obscure this association.

The injured group showed greater body mass and higher BMI than the uninjured group, concurring with Milgrom et al. (1991). By contrast, Rice et al. (2017) reported lower mass and BMI in the injured recruits. This discrepancy may stem from differing fitness levels, given that Rice measured BMI after training adaptations occurred in the second week, potentially reflecting increased muscle and decreased fat mass. The higher pre-training BMI in the injured group of this study could indicate poor conditioning in maintaining dynamic balance, which contributes to landing mechanics that increase LAS risk (Hughes & Rochester, 2008).

The greater body mass and BMI in the injured cohort of this study may have contributed to foot imbalance and unsafe landing biomechanics (Hughes & Rochester, 2008). The additional load could hinder proper positioning during a foot strike, creating medial collapse or uncontrolled lateral motion. This highlights the importance of physical preparation and controlled landing progressions to safely manage higher loads during military training. BMI alone appears to be an insufficient predictor, given that muscular recruits can have elevated BMIs. More direct body composition assessments like skinfolds or bioimpedance analysis may provide clearer insights into the injury risk factors (Mei et al., 2002).

In summary, the injured group showed higher pre-training mass and BMI, potentially indicating poorer initial conditioning that impacted their landing techniques. However, BMI has limitations as a stand-alone risk factor. Critically examining different training exposures, detailed body composition and landing mechanics will provide a greater understanding of the nuanced association between physique, fitness and dynamic ankle stability.

In contrast to Rice et al. (2017), the current study found no differences in bimalleolar width between the injured and uninjured groups. The discrepancy with Rice's findings may stem from the differences in training regimens and participant fitness levels.

In addition, Rice's intensive 32-week infantry programme likely imposed much higher physical demands than the current study's general military training, amplifying the importance of ankle joint stability. The extreme loads in Rice's cohort could have heightened the influence of bimalleolar width on dynamic ankle neuromuscular control compared with the current study in which there was no load. Bimalleolar width may only emerge as a key risk factor under higher training intensities with greater dependence on evertor strength and control.

Hence, the discrepant findings are likely attributable to differences in training exposures, participant fitness and measurement timepoints rather than simply sample size limitations. The studies highlight that the bimalleolar width's role in ankle sprain risk may be highly context-specific and dependent on the demands placed on evertor function. Future recruits with bimalleolar widths of less than 7 cm may be recognised at the beginning of training as having a high risk of suffering this injury. Other athletic populations, especially those who carry extra load, may be able to use these values. The best intervention to lower the risk of ankle inversion injuries will need to be determined by future research (Rice et al., 2017).

Comparison of clinical variables between groups

Recruits who sustained an LAS during the 12-week training programme had lower ankle dorsiflexor, plantarflexor, invertor and evertor strength at the time of assessment compared with the uninjured group. The mean difference between groups exceeded the SEM and MDD from the reliability study, indicating that these differences were beyond measurement error, which was clinically and statistically significant. The finding that injured recruits had lower plantarflexor strength contrasts with Baumhauer et al. (1995) and Hadzic et al. (2009), who reported greater plantarflexor strength in injured athletes. Excessive plantarflexion upon landing likely elevates LAS risk in sports by overloading the ankle ligaments (Hughes & Rochester, 2008). However, military training emphasises load carriage marching, which depends heavily on plantarflexor endurance for propulsion. The reduced plantarflexor fitness in injured recruits may have hindered their ability to tolerate these high-volume marching tasks (Knapik et al., 1992).

Additionally, the multidirectional agility demands of sports like volleyball differ substantially from the linear tactical manoeuvres predominating military training (Knapik et al., 2010). Furthermore, the uniform court surfaces provide consistent traction for volleyball players, as opposed to the unpredictable terrain that military personnel must traverse while carrying heavy loads (Knapik et al., 1992).

This disparity highlights how injury risk factors can vary based on the distinct biomechanical and physiological demands of military versus athletic training regimens (Bullock et al., 2010; Knapik et al., 1992). While excessive plantarflexion may elevate LAS risk in athletes (Hughes & Rochester, 2008), inadequate plantarflexor endurance appears more salient in military populations subjected to high marching volumes with load carriage (Knapik et al., 1992). Thorough tracking of training exposures, load quantification and analysis of muscle function during specific military tasks will provide greater clarity on the nuanced association between strength capacities and injury susceptibility.

This study reported the differences in evertor and invertor strength between the injured and uninjured groups, unlike previous studies (Baumhauer et al., 1995; Willems et al., 2005a). Baumhauer et al. (1995) reported no statistical significance in ankle joint muscle strength between the injured and uninjured groups of college-aged athletes. Their study focused on college-aged athletes with a mean age of 18 years, whereas the present study concentrated on a military population with a mean age of 23 years. In addition, the work demand and muscle conditioning of military recruits differ from those of college-level athletes. This discrepancy indicates that the factors contributing to LAS may vary between different age groups and populations.

Furthermore, the evertor strength (N/kg) was lower in the injured participants of this study ($p < 0.05$), with a mean difference of 0.12, effect size of 0.420, SEM of 0.03 and MDD of 0.08. The disparity may be attributed to the calculation of eccentric and concentric muscle strength of the other studies, whereas this study used the isometric measure (Willems et al., 2005b). Moreover, the study of Baumhauer et al. (1995) calculated muscle strength in pounds and without normalisation. The instruments used in calculating muscle strength in the mentioned studies (Baumhauer used Cybex 6000 Dynamometer Lumex Inc., Ronkonkoma, New York) also differ from those used in this study. Furthermore, the discrepancy may be due to the differences in methods and the population and the comparatively longer study duration of the contrasting studies, given that the present study duration was 12 weeks, which is fairly lower than other studies.

In the comparison of hip muscle strength variables between the injured and uninjured groups, neither hip extensor strength nor hip abductor strength demonstrated a statistically significant difference ($p > 0.05$). Thus, hip strength parameters did not come out of the analysis as risk factors for LAS. This may be because the participants were only assessed for 12 weeks, and there was no case of a previous history of ankle sprain.

The findings regarding hip muscle strength variables In this study differed from those reported by De Ridder et al. (2017), who associated decreased hip extension strength with LAS in 133 youth soccer players (HR: 0.1, 95% CI: 0.02–0.71, $p = 0.019$). The hazard ratio (HR) is a measure in statistics that compares the likelihood of an event or outcome happening in one group compared with another. It is commonly used in survival analysis to understand how different factors influence the timing of an event, such as disease occurrence or death. An HR of 1 means both groups have the same likelihood, while an HR greater than 1 indicates a higher likelihood in the first group and an HR less than 1 suggests a lower likelihood in the first group. In their study, hip muscle groups did not show a significant association with the risk of LAS, except for hip extension strength, although they used the same dynamometer (Microfet ® HHD).

This disparity may be partly attributed to the large age difference between the samples. Ridder et al. (2017) examined youth soccer players aged 10–16 years, whereas the current military sample's age average was 23.1 years. Younger populations likely use different movement strategies, with greater dependence on hip and trunk control for multidirectional agility in soccer (Read et al., 2018; Wilczyński et al., 2020).

Furthermore, Ridder et al. (2017) had a relatively small injury subgroup (n = 10) versus the current study (n = 30), reducing statistical power to detect subgroup differences. Overall, the distinct movement patterns and injury susceptibility between growing youth and skeletally mature adults likely contributed to the contrasting findings. While hip strength appears salient in adolescent soccer players, ankle strength emerges as more relevant to adult military personnel due to differing physical and neural maturity levels.

While Kawaguchi et al. (2021) identified hip abductor weakness as a risk factor in soccer players, the small age difference of 3.4 years between their sample (mean of 19.8 years) and the current military group (mean of 23.2 years) is unlikely to fully explain the discrepancy. However, there are likely differences in hip strength assessment methods that may have contributed to the contrasting findings.

The injured group showed reduced ankle dorsiflexion ROM compared with the uninjured group, with a mean difference of 2.81°, a large effect size of –0.09 and SEM of 0.34°, in line with Hadzic et al. (2009), who also reported less dorsiflexion ROM in injured volleyball players. Insufficient dorsiflexion ROM may increase LAS risk by limiting shock absorption upon ground contact, causing excessive plantarflexion motion and stress on the lateral ankle ligaments (Denegar et al., 2002; Tajima, 2012).

Furthermore, reduced dorsiflexion ROM can restrict the ankle's ability to achieve a properly aligned foot position during activities like SLL, which often precedes LAS. Therefore, enhancing dorsiflexion flexibility allows greater accommodation of landing forces and minimising positional faults (Hoch et al., 2015), likely contributing to the lower injury rates observed in those with greater dorsiflexion range.

However, ROM alone provides limited insight without simultaneously assessing ankle motor control throughout that range. Future studies should aim to quantify ankle neuromuscular function and inverted/everted resistance across the full sagittal plane ROM. This would provide greater clarity on the combined influence of flexibility and dynamic stability on injury risk rather than flexibility as an isolated factor.

Therefore, reduced ankle dorsiflexion ROM appears to be a risk factor for LAS; however, future research is needed on its interaction with muscular strength and activation patterns in military populations to elucidate the precise mechanisms linking flexibility and joint control to injury susceptibility.

Lastly, the anterior YBT reach distance was found to be lower in the injured group, with a mean difference of 5.37 (%), a large effect size of 0.94 and SEM of 1.36 (%). The mean difference exceeds the MDD of 3.76 (%), which was indicated to be statistically and clinically significant with minimal measurement error. The YBT assesses dynamic balance in three directions: anterior, posteromedial and posterolateral. The injured group specifically had reduced anterior reach distance, with no differences in the other directions. This selective dysfunction in anterior reach aligns with previous research, which found that impaired ankle dorsiflexion ROM (DF ROM) correlates with diminished anterior YBT performance (Hartley et al., 2018). Restricted DF ROM has also been associated with increased LAS injury risk, likely due to the reduced ability to safely progress anteriorly balanced over the ankle and compensate for perturbations (Noronha et al., 2013). The current study's findings suggest that anterior reach deficits could indicate impaired ankle mobility that may predispose recruits to LAS. Further research is warranted to determine whether poor anterior YBT performance predicts future LAS and whether targeted training to improve sagittal plane ankle DF ROM and anterior balance reduces injury risk. The difference in the dynamic balance in different directions in the current study was also assessed by Noronha et al. (2013). They found that decreased performance in the posterolateral direction < 80 increases the risk of LAS by 48%. They also normalised the distance of the reach with leg length measured from the ASIS to the medial malleoli, similar to the current study. However, they did not report any difference in the anterior reach leg balance best (SEBT) between the injured and injured groups. The contrasting findings may be attributed to the differences in population, as they selected students (mean age of 20.9 ±2.7) participating in any sports activity at least twice a week. Moreover, they followed the participants for a period of 52 weeks, which is much more than the current study's period of 12 weeks, which could have led to the aforementioned results. One important contrasting point from their study is that they also selected 43% of individuals with a previous history of ankle sprain (52 out of 121 total). According to Noronha et al. (2013), previous ankle injury changes the pattern of muscle activation, which causes recurrent ankle sprain.

This significant difference observed in the anterior YBT scores between the uninjured and injured groups can also be attributed to the role of balance in ankle stability. The anterior YBT specifically measures the ability to maintain balance while reaching forward. According to Vaes et al. (2002), this requires the coordinated activation of various muscles around the ankle. A higher score in the uninjured group suggests better balance control and stability in that direction, reducing the risk of ankle sprains. An individual's ability to maintain balance while reaching forward reflects their proprioception, neuromuscular control and coordination. A higher anterior YBT score in the uninjured group indicates better balance control and proprioceptive awareness, which are crucial for avoiding ankle sprains during activities that involve forward movements (Noronha et al., 2013).

On the other hand, the lack of significant differences in the posteromedial and posterolateral YBT scores may indicate that balance control in these directions may not play a significant role in ankle stability or the occurrence of LAS in this particular population. It is possible that other factors, such as muscle strength, joint mobility or external forces during physical activities, have a more prominent influence on ankle stability in these directions. There are also many studies suggesting the lack of association of balance with LAS, such as Beynnon et al. (2002) and Willems et al. (2005 a, b), who found no association of dynamic balance with LAS. Both studies did not use SEBT to assess dynamic balance, which can predispose to the conflict between these studies and the current study. Thus, further research is needed on various populations to confirm the association of balance with LAS, as the related literature is scarce, and there is no consensus on the results.

Comparison of biomechanical variables

During SLL, the peak of ankle towards dorsiflexion at post-IC (°) ($p < 0.05$) exhibited a significant difference between the injured and uninjured groups. The peak of ankle towards dorsiflexion exhibited a mean difference of 1.80, an effect size of 0.50, SEM of 2.10, and an MDD of 5.82. The effect sizes indicated a moderate degree of distinction between the injured and uninjured groups concerning peak ankle dorsiflexion angle during SLL at post-IC (°). However, the mean difference is lower than SEM and MDD, which indicates that this difference is not clinically significant and could be due to tool insufficiency. This may also be the reason why other variables included for the SLL and LH tasks did not demonstrate any significant difference ($p > 0.05$), as shown in Table 5.6.

Rice et al. (2017) examined running biomechanics, while the current study analysed landing tasks. Therefore, directly comparing the results is limited due to differences in the activities assessed. Rice et al. found that rearfoot angle during running was not associated with LAS risk in military recruits, similar to the current study's finding that rearfoot angle was not a significant risk factor. However, the different tasks studied may elicit distinct biomechanical strategies, as running is a continuous activity relying on ankle plantarflexors. On the contrary, tasks such as landing, jumping and hopping involve discrete challenges to the joint of the lower limb, particularly the ankle joint, such as maintaining body balance, absorption of impact forces, eccentric control by muscles around the ankle along with other related mechanisms of injury cause sudden change in the ankle towards inversion (Fong et al., 2009).

Thus, the lack of association between rearfoot kinematics and LAS injury risk cannot be generalised across tasks. The current evidence suggests that rearfoot motion during isolated tasks, such as running or landing, may not be predictive. However, tasks that combine both running and landing, such as agility manoeuvres, may still reveal an association worthy of further study. In addition, the reliance on 2D motion capture in both studies may obscure subtle alterations in multiplanar ankle biomechanics. Further research using 3D analysis during military-specific tasks could provide more definitive evidence regarding rearfoot kinematics and LAS injury risk. The similar lack of association between isolated tasks provides preliminary evidence that rearfoot motion may have limited predictive value. However, given the differences between studies, the variation underscores the need for task-specific biomechanical analysis and the importance of multi-plane 3D motion capture to thoroughly characterise ankle kinematics related to LAS injury.

Furthermore, along with SLL, a comprehensive investigation targeting the enhancement of injury risk assessment for LAS among military recruits was conducted in this study, specifically focusing on a lateral hop task, as it involves movements highly relevant to the types of dynamic activities performed during military training that have been linked to LAS injuries. Specifically, a lateral hop requires lateral and multidirectional jumping and landing, which mimic common manoeuvres that recruits must perform during training (Johnson & Stoneman, 2007). Previous research has identified these types of dynamic weight-bearing activities that involve cutting and pivoting as risks for LAS in military populations (Kovaleski et al., 2002). Therefore, the lateral hop task was selected for analysis in this study due to its biomechanical similarity to military-specific activities and previous evidence linking it to LAS rather than due to the specific age or training duration of the sample. Focusing on tasks that closely match the real-world demands placed on recruits was intended to enhance the applicability and specificity of the injury risk assessment.

The current study's central motive was to scrutinise potential injury risk factors associated with LAS and ascertain whether the lateral hop task could serve as a more perceptive functional evaluation tool over time when juxtaposed with a forward hop test. However, none of the kinematic variables during the lateral hop task proved to be a risk factor for LAS ($p < 0.05$). The mean difference of the respective variables was less than the MDD, which proved that they are neither clinically nor statistically significant. This study selected this task based on previous studies, including Ridder et al., (2015); Johnson & Stoneman (2007), on the military population. Johnson & Stoneman (2007) found both lateral and forward hop for distance tests to correlate with the Sports Ankle Rating System (SAR), a validated tool to assess ankle function (Williams et al., 2003).

However, in the current study, the lateral hop did not seem to be a kinematic variable as a risk factor for LAS. One extremely important limiting factor is the involvement of parallax error during the lateral hop. The 2D kinematics was used to explore this task. While one camera covered the front aspect and the other covered the back aspect, the change in position during the movement of a lateral hop caused the interference of this error, resulting in the lack of significant findings in this task. Therefore, more extensive studies are needed to explore 2D kinematics during a lateral hop, with a larger sample size and minimised parallax error. Further prospective studies also need to investigate whether the lateral hop task is a risk factor for LAS or not, as it is one of the challenging tasks reported by the recruits in this thesis.

Logistic regression and ROC analysis

The logistic regression analysis revealed significant associations between the variables greater body mass, lower ankle dorsiflexion ROM, reduced anterior YBT reach distance and lower peak of ankle towards dorsiflexion angle during SLL post-IC as predictors of ankle LAS. These findings suggest potential targets for injury screening and prevention efforts. For example, interventions aimed at improving DF ROM and anterior reach balance could help reduce LAS injury risk. Additionally, these variables could be tracked over time as measures of injury risk and progress in injury prevention programmes. Therefore, further research is needed to determine the efficacy of interventions targeting these factors to reduce LAS incidence.

Furthermore, based on the ROC findings, only the variable mass (kg) appears to have a moderate predictive value for LAS, as indicated by its AUC value. The other variables, ankle dorsiflexion ROM (°), anterior YBT (%) and peak of ankle dorsiflexion at post-IC (°), have low to poor discriminatory power, suggesting that they may not be strong predictors of LAS in the context of this study. While the ROC analysis indicates that these variables have limited predictive ability on their own, previous studies have based their findings on logistic regression analysis without assessing predictive power. Therefore, the significant associations found between these variables and LAS in the logistic regression analysis will still be discussed, but the limitations of their predictive ability should be noted. Further research is needed to better understand why the ROC analysis did not find significant predictive ability for some variables that have been found to be significantly associated with LAS in the logistic regression.

Mass (kg) showed a significant association with the outcome, as indicated by a p-value of 0.00. The 1.148 OR suggests that for every one-unit increase in mass (kg), the odds of the outcome increase by a factor of 1.148. (CI: 1.060–1.245). The AUC for mass is 0.766, the cut-off point is 67.5 (kg), MD is –7.04, SEM is 0.01 and MDD is 0.024. In the current study, a total of number of LAS were reported was 30 injured recruits, 22 recruits were with mass > 67.5 (kg). While eight were with mass < 67.5 (kg). The average mass of the injured participants was 72.33 kg, SD ± 7.2. The mass bracket of the injured participants was from 65.76 to 78.9 (kg), while for the uninjured, it was 58.33 to 72.81 (kg). This suggested that there was no injured participant with mass below 65.76 (kg).

The rationale behind this is that a higher body mass could potentially lead to increased forces acting on the ankle joint during dynamic activities, making it more susceptible to injury. However, it is essential to note that research in this area is complex, and the association between body mass and ankle sprains is not entirely straightforward as the previous studies combined weight with height in different parameters, such as BMI and mass. Milgrom et al. (1991) and Kobayashi et al. (2016) reported in their studies that greater body mass and body mass index, respectively, were associated with LAS based on regression analysis results. They did not use ROC analysis. A greater mass component has been found to be associated with increased LAS occurrence as more mass causes more stress on the joints and ligaments, ultimately weakening the ligaments that result in LAS (De Noronha et al., 2013; Kobayashi et al., 2016; Milgrom et al., 1991). They also suggested that an increase in body mass causes a higher body centre point, resulting in body imbalance during foot strike on the ground, shifting all the stress to the lateral ligaments that tend to cause LAS (Milgrom et al., 1991).

Furthermore, ankle dorsiflexion ROM (°) demonstrated a significant association with the outcome, as shown by a p-value of 0.00. The 0.80 OR implies that for every one-unit increase in ankle dorsiflexion ROM, the odds of the outcome decrease by a factor of 0.80 (CI: 0.652–0.910). Hadzic et al. (2009) also used logistic regression analysis to finalise their results and demonstrated that decreased ankle dorsiflexion ROM (º) is a predictive factor for LAS (OR: 0.63, 95% CI: 0.41–0.97) in volleyball players, suggesting that decreased dorsiflexion ROM (º) causes the foot to attain a more pronated position during foot contact on the ground, which tends to increase the chance of LAS. Meanwhile, Noronha et al. (2013) did not report any association between dorsiflexion ROM and LAS using logistic regression analysis. The disparity is due to the fact that Noronha et al. (2013) used the weight-bearing lunge method to assess dorsiflexion ROM, as presented in the methodology of testing, whereas the current study assessed ROM in a non-weight-bearing position. This disparity in methods can cause the associated muscle involvement during the ROM testing due to the difference in positions of testing. Noronha also selected students participating in physical activities at least twice a week, whereas Hadzic and the current study selected physically active individuals participating regularly in physical activities.

Similarly, the variable anterior YBT (%) showed a significant association with the outcome, as indicated by a p-value of 0.00. The 0.84 OR suggests that for every one-unit increase in anterior YBT (%), the odds of the outcome decrease by a factor of 0.84.

The 95% CI of 0.753–0.931 indicates that the true population OR is likely to decline. Gribble et al. (2016) conducted a study on 539 high school and collegiate football players and screened them for LAS risk factors prior to the season with SEBT. They also used logistic regression analysis and concluded that poor performance in anterior SEBT is a risk factor for LAS. They found that BMI is associated with LAS. However, the increase in BMI was due to the increase in mass in the injured group because the injured and uninjured groups presented no significant difference in height ($p > 0.05$). Thus, mass should also be studied in terms of muscle mass and fat mass, which influence the occurrence of LAS, as suggested by (Rice et al. 2017; Milgrom et al. 1991).

Contrastingly, De Noronha et al. (2013) discovered that a decrease in posterolateral (PL) SEBT is a predictive factor for LAS (HR: 0.96, 95% CI: 0.92–0.99) in the three different directions. While they followed the same protocol of assessing dynamic balance using the three directions of SEBT (Ant, PL, PM), they did not normalise the reach with leg length and multiplied it by 100. The contradiction can be attributed to the study population of students participating in physical activity at least twice a week and the study duration of 52 weeks.

Similar findings were provided by Attenborough et al. (2016), who indicated that a low PL SEBT (%) is a risk factor for LAS. They proposed that weak lateral ligament strength is associated with poor balance. Therefore, individuals should undergo training to improve dynamic balance to enhance the strength of lateral ligaments and reduce the risk of LAS. Supporting the suggestion, Wang et al. (2021) conducted a study to investigate the effects of resistance training and balance training over a period of six weeks, with five days a week and two sets per day for 20 minutes. The results of their study demonstrated that both resistance training and balance training significantly improved strength and dynamic balance ($p < 0.05$), thereby contributing to the prevention of LAS.

Lastly, the decreased peak of ankle towards dorsiflexion at post-IC (°) demonstrated a significant association, with $p < 0.00$ (95% CI: 0.68–0.93) and OR of 0.80, suggesting that for every one-unit increase in the peak of ankle dorsiflexion post-IC (°), the odds of the outcome decreases by a factor of 0.80. Although previous studies aimed to determine the biomechanical predictive factors for LAS, none of them expressed ankle dorsiflexion in the sagittal plane during SLL min post-IC (º) in their findings. However, the findings of this study on the ankle dorsiflexion ROM (º) using the goniometer suggest that a decrease in ankle dorsiflexion ROM (º) is associated with the risk of LAS. Thus, it is suggested that a decrease in the latter may also affect the foot angle during ground contact and may predispose to the delayed action of dorsiflexors that, in turn, cause more pressure on the lateral side of the foot and increase the chance of LAS. Rice et al. (2017) suggested that the pressure on the lateral foot upon initial contact with the ground increases the risk of LAS. Thus, whenever a military recruit is found with such suspected findings, management should start with a proper foot landing by balancing the action of the agonist and antagonist so injuries can be prevented.

The current study supports the existence of multiple intrinsic factors contributing to LAS by regression analysis but also emphasises the importance of mass (kg) after ROC analysis as a screening variable. This study showed that a higher mass of over 67.5 kg, lower than 5.33° ankle dorsiflexion ROM and lower than 59.40% anterior reach for YBT could be risk factors for LAS with reference to the limitation of the duration of data collection, which was limited to 12 weeks in this study. While no re-injuries were reported during this period, the short follow-up duration hinders an understanding of the long-term outcomes and recurrence rates of LAS. The impact of COVID-19 and the subsequent lockdowns also limited the re-testing of the injured participants at the end of the training baseline and conducting a survey using the Cumberland tool, which could help understand the intrinsic risk of LAS in more detail as well as recurrent injuries, if any. Thus, extended follow-up periods are needed to assess the potential for re-injury and evaluate the long-term implications of LAS more effectively. Certainly, this study identified lower ankle dorsiflexion ROM, reduced anterior YBT reach distance and lower peak of ankle towards the dorsiflexion angle during SLL post-IC as risk factors. However, there is a correlation between the different methods of predicting the limitation of dorsiflexion. This outcome has been identified in previous literature to be correlated with ankle instability (Hoch et al., 2015). This may explain why the difference in method cause the variance in findings as compared to the previous studies. Another reason might be that, despite the military being strict on previous injuries, some of the recruits may have concealed their history of injuries, including LAS.

Considering the current literature, it is suggested that a comprehensive screening session must be conducted prior to basic military training to assess the potential risk factors for LAS. However, based on the findings of this study, the screening should focus on body mass as the strongest predictor of LAS risk. While ankle dorsiflexion ROM, anterior YBT and the peak towards ankle dorsiflexion during SLL post-IC were significantly associated with LAS in the regression analysis, the ROC analysis indicates that they may have limited utility as stand-alone screening tests.

Certainly, there are a few potential reasons for this discrepancy. The logistic regression assesses the association between the risk factors and LAS but does not directly evaluate how well they predict LAS. The ROC analysis specifically looks at predictive performance. Therefore, a variable can be significantly associated but not have a high predictive validity on its own. Many of the risk factors are likely correlated to some degree, so their predictive ability overlaps. The regression models their joint associations, but the ROC assesses them individually.

Moreover, given these factors, the current study agrees that it is important to focus any screening programme on the strongest predictors, such as body mass. However, there may still be value in including the associated factors, such as ankle dorsiflexion ROM and anterior YBT, to provide a more comprehensive assessment. Even if their individual predictive ability is low, they may enhance the sensitivity when combined with the stronger predictors. Thus, the ideal screening programme likely warrants further research to optimise the balance of predictive power, simplicity and comprehensiveness. Continued analysis of which factors add incremental predictive validity over the strongest individual factors would help refine the screening approach. A screening programme focused on the most predictive risk factors would help identify high-risk individuals and allow tailored training interventions to reduce their risk. However, this prospective study found that not all of these factors are statistically significant in predicting LAS. This finding suggests that, while these factors may contribute to an overall risk profile, they do not individually present a consistent or significant risk for LAS. On the other hand, the 2D camera utilised to collect lateral hop task data in the present study may have been insufficient to capture the nuanced biomechanics of this movement due to parallax error. Another reason may be that the highly trained nature of the recruits in this military population likely impacted the results, given their advanced fitness and specialised training for military service. This study could fill the gap in the literature; however, it is not entirely surprising that only a few significant risk factors were identified. Rather than a flaw in the study design itself, this null finding points to the need for alternative methods and assessments to elucidate LAS risk factors in this population. Moreover, the relatively small sample size of recruits included in the study may have impacted the ability to detect significant effects.

This study, which suggests screening individuals for risk factors of LAS, can be related to the findings and concerns raised by Bahr et al. (2016). They discussed the potential benefits of identifying the risk factors for injuries and designing screening tools to prevent such injuries. They emphasised the need for targeted measurements and intervention programmes to decrease injury incidence in physically active individuals. This study aligns with this perspective by proposing the screening of individuals for risk factors of LAS. By identifying specific risk factors through screening, this study aims to implement preventive measures and reduce the occurrence of these ankle sprains. This objective is in line with Bahr et al.'s goal of implementing targeted interventions and measurements based on known risk factors.

Bahr et al. (2016) also raised concerns about the feasibility and effectiveness of using periodic health examinations for screening purposes. They emphasised the need to establish the validity of screening tests for sports injuries through three important steps.

First, demonstrating a strong correlation between markers from the screening test and the risk of injury in prospective studies is essential. This step reinforces the importance of this study's findings, as it contributes to the understanding of the association between identified risk factors and the occurrence of LAS. Second, evaluating the properties of the screening test in relevant population samples using appropriate statistical methods is crucial. Although Bahr et al. mentioned the lack of examples of screening tests for sports injuries with adequate test properties, this study takes a step forward in exploring the potential of screening for LAS risk factors.

Lastly, Bahr et al. highlighted the need to demonstrate that a measurement and intervention programme targeting athletes identified as high-risk through the screening programme is more effective than a general intervention programme applied to all athletes. While this study focused on identifying risk factors through screening, the effectiveness of specific preventive measures based on the screening results would need to be evaluated in future intervention studies. It is important to note that Bahr et al. mentioned the current lack of evidence supporting the use of screening for injury risk and the challenge of predicting injuries accurately due to the substantial overlap between individuals with high and low risk. However, this study contributes to the body of knowledge by exploring the screening approach for LAS risk factors. Further research could build upon the findings.

In summary, testing the individuals over multiple sessions test will give more accuracy of predicting injury. This study aligns with the goals of Bahr et al. in terms of identifying risk factors through screening to implement targeted measurements and interventions for injury prevention. While acknowledging the challenges and gaps highlighted by Bahr et al., this study takes a step towards understanding the association between LAS risk factors and the potential for implementing preventive measures. Further research and intervention studies are needed to validate and refine the screening approach for LAS risk factors.

To provide adequate healing time after an acute LAS is also considered as a prevention strategy to minimise relapse. Thus, regarding the decision to return to sports activities, the international inter-professional Delphi survey may be recommended for use in the military context. This survey recommends that clinicians assess athletes after acute LAS and consider various factors, such as pain severity, ankle impairments, athlete perception, sensorimotor control and sports performance (PAASS), before making a decision to return to sports (Smith et al., 2021). Implementing these recommendations could provide valuable guidance to healthcare providers and clinicians in evaluating readiness to return to military training activities.

This prospective study found high rates of musculoskeletal injuries, with the highest being muscle strains (36.19%), patellofemoral pain (26.38%), back pain (19.02%) and LAS (18.40%). This distribution contrasts with systematic review findings that focused solely on LAS as the injury outcome. The high rate of other injury types highlights the need for multivariate injury analysis beyond isolated variables.

The 18.4% LAS rate in this study falls within the wide range of 6%–32% from previous military research. However, this variability likely stems from differences in demographics, training exposures and injury definitions between studies that were not critically appraised in the current study's initial results. For instance, the younger population (mean age 19 years) of this study may have experienced lower training volumes than the older recruits (mean age 26 years) in Rice et al. (2017), which could contribute to their higher (32%) ankle sprain rate. A clearer quantification of load, activity type and recovery periods could help explain these discrepancies.

The current study claimed similarities in injury risk factors, such as body mass and muscle strength, with prior studies. However, differences in population, methods and isolated injury reporting make these comparisons dubious. The simplistic correlational approach of this study provides weaker evidence than studies that manipulate training doses or analyse multivariate risks. For example, the systematic review included a randomised controlled trial (RCT) showing that reduced running volumes decreased injury rates—a direct experimental test lacking in this study's observational data.

Caution is needed when generalising the extreme regimens of military personnel to safe public health guidelines. For instance, this study did not track precise training volumes, which limits insights into dose-response patterns and safe upper thresholds. While descriptive data from military samples have value for hypothesis generation, civilian application warrants the meticulous quantification of volumes, equipment, biomechanics and recovery periodisation based on experimental methods.

Further studies are needed to investigate clinical and biomechanical variables to gain a more comprehensive understanding of these factors. The current study's limitations related to 2D motion capture and sample size precluded definitive evaluation of lateral hop kinematics as prospective risk factors for LAS. Further research with 3D analysis and greater statistical power is warranted to better understand its potential as part of a comprehensive screening battery. In addition, there is currently a lack of evidence regarding criteria for returning to military training activities following LAS. Therefore, it is important for researchers and rehabilitation consultants to address this gap and develop guidelines that can assist healthcare providers and clinicians in making informed decisions regarding return to military training.

The robustness of undertaking a study to determine risk factors for injury based on a sample size of approximately 200 individuals may be questioned, considering the various factors that influenced the sample throughout the study. Thus, it is important to elaborate on these factors to provide a strong explanation. First, it was mentioned that all recruits were invited to participate in the study, and an acceptance rate of around 98% was achieved. This high acceptance rate suggests a strong initial engagement and interest from the participants, which can be advantageous for the study's validity and reliability.

However, during the data collection phase, there were instances wherein recruits had to withdraw from the study due to reasons such as sustaining injuries. These withdrawals impacted the final sample size. Furthermore, the COVID-19 pandemic played a significant role in the sample size of the study. The mention of a lockdown suggests that the study was conducted during a period of restrictions and social distancing measures, which limited follow-up of the injured recruits. Surprisingly, despite these challenging circumstances, the sample size increased. It can be hypothesised that the lockdown measures might have created an environment where individuals had more time and willingness to participate in the study, leading to a larger sample size.

This prospective study had several limitations that should be considered when interpreting the findings. First, the diagnosis of LAS was made by the physician at the military clinic, suggesting a certain level of confidence in the accuracy of the diagnoses.

However, it is important to acknowledge the potential limitations and uncertainties associated with the diagnostic process. Factors such as variability in clinical judgment, the possibility of misdiagnosis or overlap with other ankle pathologies should be taken into account.

The most significant limitation of this study is its lack of generalisability. Since it focused on a specific military population, the findings may not be applicable to the general population or individuals in different age groups. Previous literature has suggested that there may be differences in results due to variations in population. Therefore, it is crucial to explore the risk factors in the general population, as well as in different age groups.

In addition, it should be noted that while the study participants were diagnosed with LAS, this does not guarantee that every individual had only this specific injury and not any other underlying issues. Some military recruits may not report their injuries to avoid potential career implications, while others may provide fake medical histories or fail to disclose previous injuries. This possibility of concurrent or comorbid injuries should be acknowledged as a potential limitation in the interpretation of the study findings.

Regarding the mechanism of injury, it is important to provide clarity on the level of confidence in identifying and understanding the specific mechanisms that lead to LAS in the study population. If the study was able to accurately assess and document the mechanisms of injury, it should be explicitly stated to demonstrate the robustness of the research methodology. However, if there are uncertainties or limitations in determining the exact mechanisms, these should be acknowledged and discussed as potential areas for further investigation or improvement in future studies.

Furthermore, although extrinsic risk factors are controlled in the military population, ensuring equal experimental conditions for all participants, it is important to recognise that some factors may have a greater impact on the occurrence of injury than others. For example, the nature of training activities that involve jumping, landing, ascending and descending rather than solely running or carrying a backpack may influence the risk of injury. The influence of factors, such as ground surface and specific training activities, should be considered in future studies to gain a more comprehensive understanding of their role in the occurrence of LAS.

5.6. Conclusion

LAS is the result of multiple contributing risk factors, and as the number of these factors increases, so does the risk of injury. However, many of these factors are modifiable, as discussed earlier, which means that the injury can be prevented by modifying these risk factors.

The results of the current study highlighted several risk factors for LAS. The most significant risk factor identified was higher body mass, which was found to have a moderate level of predictive value. On the other hand, decreased ankle DF ROM in degrees and anterior YBT were found to have low to poor discriminatory power. These risk factors are modifiable and can be controlled through various means. For instance, weight reduction programmes can be implemented to reduce body mass. Physical training programmes can be designed to improve landing techniques, while physical therapy can be used to enhance anterior YBT, ankle dorsiflexion ROM and peak ankle dorsiflexion angle during SLL.

The findings of this prospective study provide guidance for further research on the demographic, clinical and biomechanical risk factors for LAS on a larger scale and in different populations, extending for a longer period of time. Screening individuals based on the identified risk factors can help identify those at risk of LAS. These individuals can then participate in a primary risk mitigation training programme before military training, which focuses on reducing weight and improving anterior YBT and ankle dorsiflexion ROM. By modifying these risk factors, the incidence of LAS can be reduced. Weight reduction can be achieved through a balanced diet and exercise, while stretching exercises and resistance training can improve ankle dorsiflexion ROM. Dynamic balance exercises can help enhance the anterior YBT, and proper landing techniques can improve one’s landing techniques to prevent LAS. Moreover, this study sets the groundwork for future prospective studies aiming to identify the risk factors for LAS, enabling a more detailed exploration of these factors in the general population for better applicability.

In conclusion, it is crucial to address concerns regarding the confidence in diagnosis, mechanisms and implications of this confidence level throughout the thesis. By acknowledging potential limitations, discussing uncertainties and providing contextual information, the research findings can be presented in a more comprehensive and nuanced manner. This approach enhances the credibility and transparency of the study while also highlighting areas for further investigation and improvement in future research endeavours.

CHAPTER 6

Overall discussion, conclusion and suggestions

Lateral ankle sprains (LAS) are common injuries associated with physical activity, particularly in physically active individuals (Doherty et al., 2014; Gribble et al., 2016). The high prevalence of LAS in sports-related activities has prompted extensive research on potential risk factors. However, conflicting findings among studies and a lack of reliability assessments for key variables have hindered the establishment of clear risk factors for LAS. This PhD thesis aims to address these gaps in knowledge by conducting a comprehensive investigation of the intrinsic risk factors for LAS.

The thesis consists of three main parts, each contributing to the body of knowledge on LAS. The first part involves a literature review, systematic review and meta-analysis of previous studies focusing on LAS risk factors (Chapters 2 and 3). By synthesising the existing evidence, this thesis aims to provide a comprehensive overview of the known risk factors for LAS, identify the gaps in the literature and contribute to a better understanding of this injury.

Building upon the information gathered from the systematic review, the second part of the thesis focuses on assessing the repeatability, reliability and validity of the tools used to measure the identified risk factors. Specifically, this chapter examines the validity of 2D motion analysis as an alternative to 3D kinematics, which is considered the gold standard for kinematic assessment but may be impractical for larger populations due to time and budget constraints (Chapter 4) (Maykut et al., 2015; Olson et al., 2011). By establishing the reliability and validity of these measurement tools, this research enhances the feasibility of studying the risk factors for LAS in larger populations.

The third and final part of the thesis involves a prospective study conducted during a military training programme to investigate the potential risk factors for LAS (Chapter 5). By observing a specific group of individuals in a controlled setting, this study aims to uncover the intrinsic risk factors that may contribute to LAS in military recruits. The findings from this prospective study, combined with the results of the systematic review and reliability assessments, will provide valuable insights into the risk factors for LAS and their implications in the military context.

In conclusion, this PhD thesis seeks to address the need for a comprehensive understanding of the intrinsic risk factors for LAS. By conducting a systematic review and meta-analysis, assessing measurement tools and conducting a prospective study, this research contributes to the body of knowledge on LAS and provides valuable insights for injury prevention and management. The limitations, contributions and future recommendations stemming from this research will be discussed in the subsequent chapters, offering a comprehensive overview of the findings and their implications.

6.1. Discussion

The present study conducted a comprehensive review of the existing literature to identify the intrinsic factors contributing to lower extremity injuries, specifically focusing on LAS. This systematic review involved the examination of systematic reviews and meta-analyses, ensuring a thorough evaluation of the available evidence.

The systematic review of 14 prospective studies conducted as part of this research aimed to identify the risk factors associated with LAS. The review revealed several potential outcomes that were consistently associated with an increased risk of LAS. These included body mass and height in males, muscle weakness and limited ranges of motion (ROM) in specific joints. These findings align with previous research that has identified these factors as potential contributors to LAS.

This systematic review provides the most comprehensive and up-to-date analysis of the intrinsic risk factors for LAS. The review includes studies that have investigated a wide range of factors, such as body mass, body mass index (BMI), height, muscle strength, ROM, muscle reaction time, rearfoot angle, joint laxity, proprioception, dynamic control, plantar pressure, calf circumference, foot width and the presence of peroneus tertius.

The findings of the systematic review and meta-analysis revealed significant associations between certain risk factors and LAS. In the injured group, males demonstrated higher body mass, BMI and greater height compared with the uninjured group (De Noronha et al., 2013; Fousekis et al., 2012; Rice et al., 2017; Willems et al., 2005b). Demographic variables, such as mass, BMI, age, height, limb length and bi-malleolar width, have been prospectively studied to identify their association with LAS risk.

Regarding muscle strength, the results showed weaker concentric dorsiflexion at 30° in the injured group than the uninjured group. However, no significant differences were observed at 120° and neutral angles. In terms of concentric plantarflexion, both males and females in the injured group exhibited significantly weaker muscles at 120°. No association was found between eversion and inversion strength at various angles between the injured and uninjured groups (Willems et al., 2005a, 2005b). These muscle strength variables were further investigated in the prospective study to assess their predictive potential for LAS.

Dynamic balance, as assessed by the Y-Balance Test (YBT), was studied by Noronha et al. (2013) and Attenborough et al. (2016). They found that a decrease in reach in the posterolateral (PL) direction was associated with an increased risk of LAS. On the other hand, Rice et al. (2017) investigated various biomechanical variables but did not find any significant predictors of LAS.

Overall, this systematic review highlights the intrinsic risk factors for LAS identified in previous studies. The findings emphasise the importance of factors such as body mass, BMI, height, muscle strength, dynamic balance and biomechanical variables in understanding and predicting the occurrence of LAS. However, it is important to note the conflicts between the results of some studies included in the systematic review. These conflicts indicate a lack of consensus regarding the specific risk factors for LAS. Such inconsistencies may arise due to variations in study design, sample characteristics and measurement techniques across different studies. Moreover, the limitations of the existing literature pose challenges in drawing definitive conclusions.

One of the limitations observed in the literature is the relatively small sample sizes of many studies. Small sample sizes can limit the generalisability of the findings and may not accurately represent the broader population at risk for LAS. Additionally, there was considerable heterogeneity in terms of the age groups and physical activity levels of the participants included in the studies. These variations introduce additional complexities when interpreting the results and make it challenging to establish definitive risk factors applicable across different populations.

Furthermore, the different methods employed to measure dynamic balance, muscle strength and ROM across studies contribute to the conflicting results. These measurement variations can introduce inconsistencies in identifying and quantifying risk factors. For instance, different assessment tools or protocols may yield different outcomes, making it difficult to compare the results directly.

Considering these limitations, it is clear that further high-quality prospective research is needed to better understand the intrinsic risk factors associated with LAS. Future studies should aim to address these limitations by utilising larger sample sizes that represent diverse populations. Consistency in participant characteristics and standardised measurement protocols would enhance the comparability and reliability of the findings across studies.

The findings from the literature review also provided the groundwork for selecting appropriate outcome measures and tools to be used in the subsequent repeatability study. The repeatability study aimed to assess the reliability and suitability of various clinical and biomechanical variables as risk factors for LAS. Measurements, such as muscle strength, ROM and dynamic balance, were employed to evaluate the clinical variables. Hand-held dynamometry was used to assess muscle strength, while goniometry was utilised for ROM assessment. Dynamic balance was evaluated using three directions of the YBT. For biomechanical variable assessment, 2D motion analysis was employed after confirming its validity through comparison with 3D kinematics. This process ensured that the selected tools were reliable and appropriate for use in the main prospective study.

In the repeatability and reliability study, several statistical measures were utilised to assess the consistency and accuracy of the outcome measures. Coefficient of variation, interclass class coefficient (ICC), standard error of measurement (SEM) and minimal detectable difference (MDD) were employed to evaluate the repeatability and reliability of the measurements.

The results of the repeatability study demonstrated excellent repeatability for the hand-held dynamometer (HHD) and goniometer, indicating consistent measurements of muscle strength and ROM, respectively. The YBT showed excellent repeatability for the anterior direction and moderate repeatability for the posteromedial and PL directions. The sliding-breadth calliper, used to measure bi-malleolar width, exhibited excellent repeatability. Moderate repeatability was observed for the foot plantar pressure assessment (FPPA) during single-leg landing (SLL) and lateral hopping (LH).

Furthermore, good to excellent ICC scores were obtained for the SLL in the sagittal plane with knee flexion, indicating strong agreement between repeated measurements. The LH outcomes also demonstrated moderate to excellent ICC scores, indicating good reliability. The rearfoot angle during SLL showed moderate to excellent repeatability, further supporting the reliability of this measurement. These findings provide confidence in the use of these tools for the prospective study, as the high repeatability ensures that the results will be free from intra-rater errors.

Moving on to the validity study, the comparison between the 2D and 3D motion analyses demonstrated a strong correlation between the two methods. Pearson correlation coefficients (r) were calculated to assess the magnitude of the correlation, and the results ranged from small to very large correlation values ($r = 0.58$ to 0.998). These results indicate a significant association between the measurements obtained from both methods during SLL and LH. The use of the Bland–Altman test further supported the validity of the 2D motion analysis by evaluating the agreement between the two methods.

By employing these statistical measures, the study ensured the reliability and validity of the outcome measures used in both the repeatability and validity studies. The high repeatability of the measurements guarantees consistency and precision, while the strong correlation and agreement between the 2D and 3D motion analyses validate the use of the 2D method in assessing joint kinematics.

By employing rigorous statistical analysis and validation techniques, this study ensures the reliability and validity of the outcome measures, enhancing the overall quality and credibility of the research. These findings contribute to the body of knowledge on the intrinsic risk factors for LAS and provide a foundation for accurate assessment and further investigation in this field.

The prospective study included a total of 204 military recruits over a 12-week training period. Of the initial 217 participants, 13 dropped out due to severe injuries. The injury data collected from the military clinic revealed a total of 163 injuries in various musculoskeletal areas, including LAS, patellofemoral pain, muscle strain, tendinopathy and back pain. LAS accounted for 18.4% of the total reported injuries, while muscle strain and tendinopathy were the most commonly reported injuries (36.19%). These findings align with previous studies highlighting the prevalence of LAS in physically active individuals (Gribble et al., 2016).

Interestingly, the injury pattern observed in the current study differed from that reported in the general population and sports-related studies. This discrepancy suggests that the unique characteristics of the military population, including their specific physical activities and demands, may contribute to the differences in injury trends. Notably, the number of LAS cases increased over the first few weeks of training, with the highest number reported in the fourth week. However, as the training session progressed, the number of LAS cases decreased. In the 11th week, no injuries were reported, and only one LAS case was reported in the 12th week. This injury trend can be explained by two theories. The first is the cumulative micro-trauma theory, suggesting that ligaments weaken over time due to repeated stress (Kaufman et al., 2000b; Smith, 2007). In the early weeks of intensive training, the repetitive stresses on the ankle may have cumulative effects, reducing the ligament strength and predisposing the trainees to LAS. The second is the tissue adaptation theory, which proposes that tissues gradually adapt to higher loads, reducing the incidence of injuries (Higgins et al., 2015; Mueller et al., 2002). Although the initial training weeks placed high stresses on the ankle and caused microtrauma, the subsequent training likely stimulated beneficial tissue adaptations. This included increased ligament strength and neuromuscular control, enhancing the ankle's resilience against LAS.

Together, these theories explain the rise in LAS in the early high-stress training period due to ligament microtrauma accumulation. As the training continued, tissue adaptations developed, allowing the ankles to withstand the demands on them and reducing LAS incidence. This trend highlights the balance between repetitive microtrauma that increases injury risk and the longer-term tissue adaptations that decrease injury susceptibility. Monitoring this timeline of risk versus adaptation can inform training design and LAS prevention strategies.

In summary, the prospective study revealed injury patterns and risk factors specific to the military population. The findings suggest that the intensity and duration of training sessions impact injury incidence, with initial increases followed by a decrease over time. Comparisons were made between injured and uninjured participants regarding clinical and biomechanical variables using the t-test. Significant differences were observed between the groups in several clinical and biomechanical variables, including mass, ankle dorsiflexion strength, plantarflexor strength, invertor strength, evertor strength, ankle dorsiflexion ROM and anterior single-leg stance reach distance (YBT). These differences exceeded the SEM and were statistically significant ($p < 0.05$), with effect sizes ranging from moderate to large. However, the mean difference of the biomechanical variables minimum ankle dorsiflexion angle post initial contact (SLL min angle post-IC) and rearfoot SLL min angle post-IC was lesser than the SEM and MDD, predisposing these factors to be due to measurement error.

Furthermore, the binary logistic regression analysis identified four variables associated with LAS: higher mass, decreased dorsiflexion ROM, lower anterior YBT and ankle minimum angle on SLL post-IC, indicating their influence on the likelihood of the outcome. The odds ratios provided estimates of the effect magnitude and direction, while the confidence intervals gave the expected range for the true population odds ratios.

Higher mass was found to be a significant predictor of LAS, consistent with previous studies by Milgrom et al. (1991), De Noronha et al. (2013) and Kobayashi et al. (2016). Increased mass leads to added stress on the joints and ligaments, weakening them over time and increasing the risk of LAS. Additionally, higher body mass is associated with poor balance during foot strikes, shifting stress to the lateral ligaments and increasing the likelihood of an LAS.

Lower anterior YBT (cm) was identified as a predictive factor for LAS, in contrast to studies by Noronha et al. (2013) and Attenborough et al. (2016), which found lower PL SEBT (cm) to be a predictive factor. This suggests that maintaining postural balance is crucial for preventing LAS in both anterior and posterior directions. Weakening of the ankle lateral ligament reduces dynamic balance, thereby increasing the risk of LAS. Therefore, training programmes should focus on improving balance in all directions on the SEBT to reduce the risk of LAS among military recruits, the general population and athletes.

Decreased ankle dorsiflexion ROM (°) was identified as a predictive factor for LAS, consistent with findings from Hadzic et al. (2009). A decrease in ankle dorsiflexion ROM causes the foot to adopt a more pronated position during ground contact, thereby increasing the risk of LAS. Prior to training sessions, it would be beneficial to implement muscle training programmes that aim to improve ankle dorsiflexion ROM. Physical therapy exercises that target strengthening of the ankle muscles should also be considered to prevent LAS.

The decrease in ankle dorsiflexion angle during SLL post-IC (°) in the sagittal plane was identified as a predictive factor for LAS. However, there is currently insufficient evidence to support this finding, indicating a need for further exploration of the biomechanical risk factors. Training programmes should emphasise proper landing techniques and strategies to improve dorsiflexion angle during SLL in the sagittal plane, thereby reducing the risk of LAS. Similar to how peak hip and knee flexion during SLL can help prevent ACL injuries (Li et al., 2021), identifying landing strategies that increase ankle dorsiflexion just before ground contact may help prevent LAS.

Moreover, ROC curve analysis was performed to identify the predictive potential and strength of association between the risk factors and the outcomes. The area under the curve (AUC) was used to assess the predictive potential of each variable. The optimal cut point was determined by maximising sensitivity and 1-specificity or visually identifying the point closest to the upper left-hand corner of the ROC curve. The AUC and significance (p-value < 0.05) were reported, along with 95% confidence intervals, in Table 5.8. A higher AUC indicates greater predictive potential.

The ROC curve analysis and metrics in Table 5.8 and Figure 5.9 help evaluate the significance and predictive potential of the selected variables, providing valuable insights into their association with the outcome of interest. The ROC analysis indicates that body mass (MASS) has a moderate predictive ability for LAS in this study, with an AUC of 0.766 and a cut-off of 67.5 kg. Participants with a mass over 67.5 kg accounted for 22 of the 30 total LAS cases. However, despite the high number of 22 injured participants out of 30 this may mean as a risk factor in reality. Furthermore, this should be calculated in muscle mass or fat mass in future research and the mass variable may lead to LAS with combination of other risk factor such as reduce in dorsiflexion ROM or dynamic balance. By contrast, the other variables, namely, ankle dorsiflexion ROM, anterior reach YBT and peak ankle dorsiflexion, showed low to poor discriminatory power in the ROC analysis (Rice et al. 2017; Milgrom et al. 1991).

Although logistic regression found significant associations between these variables and LAS, lower ankle dorsiflexion ROM (< 5.33°) and anterior reach on YBT (< 59.40%)

were also associated with LAS risk according to the logistic regression but with poorer predictive performance on the ROC analysis. Therefore, ROC analysis reveals limited individual predictive ability. Further research should explore why the predictive performance was poorer than expected based on the logistic regression results.

The association between higher mass and LAS is likely due to increased forces acting on the ankle joint during activities in those with greater mass. A higher body mass could lead to greater ground reaction forces and joint loads, placing greater strain on the lateral ankle ligaments and predisposing them to injury. However, the association between mass and ankle sprain risk is complex, as other anthropometric factors like BMI and mass moment are also implicated. As noted in previous studies, greater overall mass and BMI are associated with increased LAS rates, which is attributed to reduced balance possibly by contributing larger ground reaction forces and torque on the ankle joint (Kobayashi et al., 2016; Milgrom et al., 1991). A higher mass may shift the body's centre of gravity outwards, challenging lateral postural stability during foot strikes and increasing ligament strains (Milgrom et al., 1991).

In summary, higher body mass appears to be a predictive risk factor for LAS in this military population based on the ROC analysis. However, more research is needed to elucidate the injury mechanisms linking greater mass to LAS susceptibility. The injured Individuals above cut off point 67.5 kg were 22 versus 8. While, uninjured above at the same cut off point were 134 and 40 individuals below cut off value. As a researcher may could not do anything for mass, the finding suggest that could reduce fatty mass to reduce risk of LAS prior physical training. A comprehensive approach accounting for body composition, biomechanics and neuromuscular factors may provide further insights.

The findings suggest that multiple intrinsic factors may contribute to LAS susceptibility, with higher mass holding particular predictive value in this population. However, the short 12-week follow-up meant that re-injury rates and long-term outcomes could not be evaluated. Therefore, extended monitoring is needed to better understand LAS recurrence and its implications.

The correlations between reduced dorsiflexion ROM, anterior reach and lower dorsiflexion angle at initial contact hint at limitations in flexibility and fitness in this military cohort. Some recruits may have also concealed prior LAS history despite the screening. Overall, a comprehensive approach accounting for multiple intrinsic and extrinsic factors is likely needed for effective LAS prevention and management in military trainees.

Therefore, the current thesis findings support previous theories that highlight the presence of multiple intrinsic factors for LAS. It is recommended to control these risk factors through appropriate means. Coaches and trainers can use these factors as important screening variables for LAS, particularly in military recruits where the risk may be higher. High-risk individuals should undergo pre-training programmes that specifically target these factors to minimise the likelihood of LAS.

To address these risk factors effectively, it is essential to incorporate a dedicated training session before basic military training. This session should thoroughly evaluate and address all potential risk factors, providing preventive training interventions accordingly. Specifically, training programmes should focus on improving ankle dorsiflexion ROM (°), anterior YBT (cm) and ankle dorsiflexion SLL min post-IC (°) to prevent LAS.

Further research should delve into the detailed examination of ankle dorsiflexion ROM (°), anterior YBT (cm) and ankle dorsiflexion SLL min post-IC (°) in the sagittal plane, along with other biomechanical variables. This exploration will enhance the understanding of these factors and their association with LAS. It is important to examine these variables in correlation with relevant clinical factors that could potentially influence biomechanics. By conducting comprehensive studies that encompass both biomechanical and clinical variables, this study could gained a deeper insight into the association between altered ankle biomechanics, decreased dorsiflexion ROM and LAS. This knowledge will contribute to the development of more effective preventive measures and intervention strategies.

6.2. Conclusion

LAS injuries are a common musculoskeletal condition primarily affecting physically active individuals. The systematic review conducted in this study revealed the potential risk factors for LAS, including body mass, height, muscle weakness and limited ROM. However, conflicting findings in the literature and limitations in the reviewed studies, such as small sample sizes and measurement variations, emphasise the need for further research. To gain a clearer understanding of the intrinsic risks associated with LAS, future studies should employ robust methodologies and address these limitations. Such research efforts will contribute to the development of effective injury prevention strategies and enhance the overall knowledge in this field.

In addition, a repeatability and reliability study demonstrated excellent repeatability for the HHD, goniometer and sliding breadth calliper, while the YBT and FPPA showed moderate to excellent repeatability. The ICC scores indicated good to excellent agreement for measurements such as SLL, LH and rearfoot angle. These findings support the utilisation of these assessment tools in prospective studies, ensuring accurate and consistent evaluation of the intrinsic risk factors for LAS.

Furthermore, a validity study confirmed a strong correlation between 2D and 3D motion analyses, with Pearson correlation coefficients ranging from small to very large. This indicates a significant association between the measurements obtained from both methods during activities like SLL and LH. The Bland–Altman test further validated the accuracy of the 2D motion analysis by assessing the agreement between the two methods.

LAS can lead to functional impairment and increase the likelihood of recurrence. Therefore, it is essential to prospectively assess the factors that contribute to LAS to identify individuals at high risk. By doing so, predictive risk factors can be controlled, and preventive treatment plans can be implemented before an injury occurs. In the current prospective study, clinical and biomechanical factors were evaluated as predictive risk factors for LAS. The study found that greater body mass (kg) is a significant and associated predictive factor for LAS. Higher mass over 67.5 kg is a significant and cloud be consider as risk factor for LAS in military recruits based on the ROC analysis. Lower ankle dorsiflexion ROM (< 5.33°) and anterior reach on YBT (< 59.40%) were also associated with LAS risk factors according to logistic regression, although with poorer predictive performance on ROC analysis. These findings contribute to the identification of individuals at high risk of LAS and can help mitigate such a condition.

6.3. Contribution to the Literature

This study makes significant contributions to the existing literature in several ways. First, the systematic review conducted in this research represents an up-to-date and comprehensive assessment of the intrinsic factors that contribute to LAS. This review synthesises the existing literature and provides a comprehensive understanding of the current evidence base. By consolidating and analysing the available research, this study contributes to the body of knowledge on LAS and provides a valuable resource for future studies and clinical practice.

Furthermore, this study validates the use of 2D motion analysis as a reliable alternative to 3D kinematics. The confirmation of the validity of 2D motion analysis provides evidence supporting its use as a cost-effective, simple and time-saving method in assessing and analysing motion patterns. This finding has practical implications, as it can encourage the adoption of 2D motion analysis in clinical and research settings where 3D motion analysis may be resource-intensive or impractical.

Finally, it is the first prospective research to investigate LAS among the Saudi military population during their basic military training. In addition, it is the first epidemiological study to focus specifically on LAS among the Saudi military population during basic military training. These findings provide valuable insights into the occurrence and prevalence of LAS within the Saudi military, serving as a reference for future injury prevention and treatment plans.

The results of this study have important implications for the identification and management of recruits at high risk of LAS. By identifying those individuals who are more susceptible to these injuries, preventive strategies can be developed and implemented to mitigate the risks. This proactive approach to injury prevention will not only benefit the individuals but also contribute to the overall well-being of the Saudi military population.

Coaches and practitioners can utilise the information from this prospective study to develop screening protocols that accurately identify individuals at high risk of LAS. Early identification of these risk factors enables the implementation of preventive measures, potentially reducing the incidence of LAS among military personnel.

Overall, this study significantly contributes to the literature by providing novel insights into LAS among the Saudi military population, validating the use of 2D motion analysis, identifying predictive factors and conducting an up-to-date systematic review. These contributions enhance the understanding of LAS, inform injury prevention strategies and guide future research in this field.

6.3. Limitations and Future Recommendations

The following are some limitations of the current study with reference to the chapters. In the systematic review chapter, the inclusion and exclusion criteria used to select studies for the systematic review should be carefully defined to minimise bias and ensure the generalisability of the findings. Objective criteria based on study design, population and outcome measures should be considered. Furthermore, future systematic reviews should include both published and unpublished studies, such as grey literature or conference proceedings, to obtain a more comprehensive overview of the available evidence and minimise publication bias.

In the reliability study of the instruments, a lesser sample size was considered to be a possible limitation. Thus, future reliability studies should aim for larger and more representative sample sizes to enhance the generalisability of the results to the broader population. This will provide more robust evidence regarding the reliability of the instruments under investigation.

In the prospective study, although the focus was on a specific military population, it is important to acknowledge that the findings may not directly apply to other populations or contexts. Future studies should consider including diverse populations with varying demographic characteristics and physical demands to improve external validity.

Moreover, extending the duration of the prospective study beyond the 12-week training period would provide a more comprehensive understanding of the long-term effects and factors influencing the outcomes. Longer follow-up periods, such as up to three years, would allow for a more comprehensive analysis of injury occurrence and re-occurrence.

Additionally, this study only focused on the intrinsic factors; however, considering both intrinsic and extrinsic factors for LAS would provide a more comprehensive understanding of the multifactorial nature of these injuries. Future studies should consider incorporating extrinsic factors, such as footwear, training surfaces and environmental conditions, to enhance the overall understanding of the risk factors influencing LAS.

It is essential to acknowledge and consider these limitations when interpreting the outcomes of each chapter. These limitations may impact the generalisability, reliability and validity of the findings.

The following are some ways these findings could inform future research and risk mitigation strategies. The identification of higher mass as a predictive risk factor indicates that future studies should further investigate the mechanisms linking greater mass to LAS susceptibility, for example, analysing forces during activities, joint kinematics and neuromuscular control in those with higher vs. lower mass. Moreover, the findings suggest that flexibility, stability and strength deficits may contribute to risk. Future work could explore targeted training programmes to address these areas and track the effects on LAS rates.

Furthermore, screening protocols incorporating mass cut-offs, flexibility tests and movement assessments could help identify high-risk recruits for focused prevention efforts. Additionally, education on proper landing mechanics, ankle stability exercises and avoiding overloading the ankle during training may help mitigate the risk associated with higher mass.

Prospective studies with extended follow-up should evaluate long-term outcomes, recurrence rates and implications of LAS. This can identify the need for improved rehabilitation and secondary prevention. Research on whether prior injury increases LAS risk is also needed, as some recruits may conceal their history. More rigorous screening and tracking of prior injury may be warranted. A multifactorial model examining the interactions of various intrinsic and extrinsic variables should be tested to determine the combination of factors most predictive of LAS in this population.

Guidelines for assessing individuals after injury should be developed to guide fitness trainers and healthcare providers in making informed decisions regarding return to training activities. Coaches and trainers could modify strengthening, ROM and balance technique programmes to address the identified risk factors and prevent LAS. Future research should assess military and general populations from different countries to establish generalised protocols for the prevention and management of LAS.

In summary, these findings provide directions for future research on the risk factors and preventive interventions, with the goal of reducing the burden of LAS on military members through evidence-based training and rehabilitative practices. By addressing these limitations and implementing the recommended strategies, future research can enhance the understanding of LAS, improve injury prevention strategies and guide effective treatment and rehabilitation approaches.

References

Abdel-aziem, A. A., & Draz, A. H. (2014). Chronic ankle instability alters eccentric eversion/inversion and dorsiflexion/plantarflexion ratio. *Journal of Back and Musculoskeletal Rehabilitation*, *27*, 47–53. https://doi.org/10.3233/BMR-130418

Al-Mohrej, O. A., & Al-Kenani, N. S. (2016). Acute ankle sprain: conservative or surgical approach? *EFORT Open Reviews*, *1*(2), 34–44. https://doi.org/10.1302/2058-5241.1.000004

Al Amer, H. S., & Mohamed, S. H. P. (2020). Prevalence and Risk Factors of Ankle Sprain Among Male Soccer Players in Tabuk, Saudi Arabia: A Cross-Sectional Study. *The Open Sports Sciences Journal*, *13*(1), 27–33. https://doi.org/10.2174/1875399x02013010027

Al Bimani, S. A., Gates, L. S., Warner, M., Ewings, S., Crouch, R., & Bowen, C. (2018). Characteristics of patients with ankle sprain presenting to an emergency department in the south of England (UK): A seven-month review. *International Emergency Nursing*, *41*, 38–44. https://doi.org/10.1016/j.ienj.2018.05.008

Anandacoomarasamy, A., & Barnsley, L. (2005). Long term outcomes of inversion ankle injuries. *British Journal of Sports Medicine*, *39*(3), e14–e14. https://doi.org/10.1136/bjsm.2004.011676

Andersen, T. E., Floerenes, T. W., Arnason, A., & Bahr, R. (2004). Video Analysis of the Mechanisms for Ankle Injuries in Football. *American Journal of Sports Medicine*, *32*(SUPPL. 1), 69–79. https://doi.org/10.1177/0363546503262023

Arnold, E. M., Hamner, S. R., Seth, A., Millard, M., & Delp, S. L. (2013). How muscle fiber lengths and velocities affect muscle force generation as humans walk and run at different speeds. *Journal of Experimental Biology*, *216*(11), 2150–2160. https://doi.org/10.1242/jeb.075697

Ashton-Miller, J. A., Ottaviani, R. A., Hutchinson, C., & Wojtys, E. M. (1996). What best protects the inverted weightbearing ankle against further inversion?: Evertor muscle strength compares favorably with shoe height, athletic tape, and three orthoses. *American Journal of Sports Medicine*, *24*(6), 800–809. https://doi.org/10.1177/036354659602400616

Attenborough, A. S., Sinclair, P. J., Sharp, T., Greene, A., Stuelcken, M., Smith, R. M., & Hiller, C. E. (2017). The identification of risk factors for ankle sprains sustained during netball participation. *Physical Therapy in Sport*, *23*, 31–36. https://doi.org/10.1016/j.ptsp.2016.06.009

Bahr, R., & Bahr, I. A. (1997). Incidence of acute volleyball injuries: A prospective cohort study of injury mechanisms and risk factors. *Scandinavian Journal of Medicine and Science in Sports*, *7*(3), 166–171. https://doi.org/10.1111/j.1600-

0838.1997.tb00134.x

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: A key component of preventing injuries in sport. *British Journal of Sports Medicine*, *39*(6), 324–329. https://doi.org/10.1136/bjsm.2005.018341

Bahr, Roald. (2016). Why screening tests to predict injury do not work-and probably never will.: A critical review. *British Journal of Sports Medicine*, *50*(13), 776–780. https://doi.org/10.1136/bjsports-2016-096256

Bahr, Roald, Pena, F., Shine, J., Lew, W. D., & Engebretsen, L. (1998). Ligament force and joint motion in the intact ankle: A cadaveric study. *Knee Surgery, Sports Traumatology, Arthroscopy*, *6*(2), 115–121. https://doi.org/10.1007/s001670050083

Bansbach, H. M., Lovalekar, M. T., Abt, J. P., Rafferty, D., Yount, D., & Sell, T. C. (2017). Military personnel with self-reported ankle injuries do not demonstrate deficits in dynamic postural stability or landing kinematics. *Clinical Biomechanics*, *47*(June 2016), 27–32. https://doi.org/10.1016/j.clinbiomech.2017.05.008

Baumbach, S. F., Brumann, M., Binder, J., Mutschler, W., Regauer, M., & Polzer, H. (2014). The influence of knee position on ankle dorsiflexion - A biometric study. *BMC Musculoskeletal Disorders*, *15*(1), 1–7. https://doi.org/10.1186/1471-2474-15-246

Baumhauer, J. F., Alosa, D. M., Renström, P. A. F. H., Trevino, S., & Beynnon, B. (1995). A Prospective Study of Ankle Injury Risk Factors. *The American Journal of Sports Medicine*, *23*(5), 564–570. https://doi.org/10.1177/036354659502300508

Ben-noun, L. (2021). *the Validity of Ankle for*. *October*.

Beninato, M., Fernandes, A., & Plummer, L. S. (2014). Minimal clinically important difference of the Functional Gait Assessment in older adults. *Physical Therapy*, *94*(11), 1594–1603. https://doi.org/10.2522/ptj.20130596

Beninato, M., & Portney, L. G. (2011). Applying concepts of responsiveness to patient management in neurologic physical therapy. *Journal of Neurologic Physical Therapy*, *35*(2), 75–81. https://doi.org/10.1097/NPT.0b013e318219308c

Beynnon, B. D., Renström, P. A., Alosa, D. M., Baumhauer, J. F., & Vacek, P. M. (2001a). Ankle ligament injury risk factors: A prospective study of college athletes. *Journal of Orthopaedic Research*, *19*(2), 213–220. https://doi.org/10.1016/S0736-0266(00)90004-4

Beynnon, B. D., Renström, P. A., Alosa, D. M., Baumhauer, J. F., & Vacek, P. M. (2001b). Ankle ligament injury risk factors: A prospective study of college athletes. *Journal of Orthopaedic Research*, *19*(2), 213–220. https://doi.org/10.1016/S0736-0266(00)90004-4

Bittencourt, N. F. N., Meeuwisse, W. H., Mendonça, L. D., Nettel-Aguirre, A., Ocarino, J. M., & Fonseca, S. T. (2016). Complex systems approach for sports injuries: Moving from risk factor identification to injury pattern recognition - Narrative review and new concept. *British Journal of Sports Medicine*, *50*(21), 1309–1314. https://doi.org/10.1136/bjsports-2015-095850

Blacker, S. D., Wilkinson, D. M., Bilzon, J. L. J., & Rayson, M. P. (2008). Risk factors for training injuries among British army recruits. *Military Medicine*, *173*(3), 278–286. https://doi.org/10.7205/MILMED.173.3.278

Bobak, C. A., Barr, P. J., & O'Malley, A. J. (2018). Estimation of an inter-rater intra-class correlation coefficient that overcomes common assumption violations in the assessment of health measurement scales. *BMC Medical Research Methodology*, *18*(1), 1–11. https://doi.org/10.1186/s12874-018-0550-6

Bohannon, R. W. (1988). Make tests and break tests of elbow flexor muscle strength. *Physical Therapy*, *68*(2), 193–194. https://doi.org/10.1093/ptj/68.2.193

Boonthathip, M., Chen, L., Trudell, D., & Resnick, D. (2011). Lateral ankle ligaments: MR arthrography with anatomic correlation in cadavers. *Clinical Imaging*, *35*(1), 42–48. https://doi.org/10.1016/j.clinimag.2009.12.022

Bridgman, S. A., Clement, D., Downing, A., Walley, G., Phair, I., & 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. *Emergency Medicine Journal*, *20*(6), 508–510. https://doi.org/10.1136/emj.20.6.508

Brockett, C. L., & Chapman, G. J. (2016). Biomechanics of the ankle. *Orthopaedics and Trauma*, *30*(3), 232–238. https://doi.org/10.1016/j.mporth.2016.04.015

Buckinx, F., Croisier, J. L., Reginster, J. Y., Dardenne, N., Beaudart, C., Slomian, J., Leonard, S., & Bruyère, O. (2017). Reliability of muscle strength measures obtained with a hand-held dynamometer in an elderly population. *Clinical Physiology and Functional Imaging*, *37*(3), 332–340. https://doi.org/10.1111/cpf.12300

Bulathsinhala, L., Hill, O. T., Scofield, D. E., Haley, T. F., & Kardouni, J. R. (2015). Epidemiology of ankle sprains and the risk of separation from service in US Army soldiers. *Journal of Orthopaedic and Sports Physical Therapy*, *45*(6), 477–484. https://doi.org/10.2519/jospt.2015.5733

Burr, N., Pratt, A. L., & Stott, D. (2003). Inter-rater and Intra-rater Reliability when Measuring Interphalangeal Joints. *Physiotherapy*, *89*(11), 641–652. https://doi.org/10.1016/s0031-9406(05)60097-1

Campos, L. C. B., Campos, F. A. D., Bezerra, T. A. R., & Pellegrinotti, I. L. (2016). Evaluation of recruits morphofunctional profile from a military unit of Brazilian Air Force. *Cinergis*, *17*(2), 91–95.

Caulfield, B. M., & Garrett, M. (2002). Functional instability of the ankle: Differences in patterns of ankle and knee movement prior to and post landing in a single leg jump. *International Journal of Sports Medicine*, *23*(1), 64–68. https://doi.org/10.1055/s-

2002-19272

Chamorro, C., Armijo-Olivo, S., De La Fuente, C., Fuentes, J., & Javier Chirosa, L. (2017). Absolute reliability and concurrent validity of hand held dynamometry and isokinetic dynamometry in the hip, knee and ankle joint: Systematic review and meta-analysis. *Open Medicine (Poland)*, *12*(1), 359–375. https://doi.org/10.1515/med-2017-0052

Chandran, A., Morris, S. N., Wasserman, E. B., Boltz, A. J., & Collins, C. L. (2021). Methods of the National Collegiate Athletic Association Injury Surveillance Program, 2014–2015 through 2018–2019. *Journal of Athletic Training*, *56*(7), 616–621. https://doi.org/10.4085/1062-6050-406-20

Chen, E. T., McInnis, K. C., & Borg-Stein, J. (2019). Ankle Sprains: Evaluation, Rehabilitation, and Prevention. *Current Sports Medicine Reports*, *18*(6), 217–223. https://doi.org/10.1249/JSR.0000000000000603

Choi, J. H., Choi, K. J., Chung, C. Y., Park, M. S., Sung, K. H., & Lee, K. M. (2021). Consistency and Reliability of Ankle Stress Radiography in Patients With Chronic Lateral Ankle Instability. *Orthopaedic Journal of Sports Medicine*, *9*(5), 23259671211004100. https://doi.org/10.1177/23259671211004099

Chu, V. W. S., Fong, D. T. P., Chan, Y. Y., Yung, P. S. H., Fung, K. Y., & Chan, K. M. (2010). Differentiation of ankle sprain motion and common sporting motion by ankle inversion velocity. *Journal of Biomechanics*, *43*(10), 2035–2038. https://doi.org/10.1016/j.jbiomech.2010.03.029

Clapper, M. P., & Wolf, S. L. (1988). Comparison of the reliability of the Orthoranger and the standard goniometer for assessing active lower extremity range of motion. *Physical Therapy*, *68*(2), 214–218. https://doi.org/10.1093/ptj/68.2.214

Cooke, R., Rushton, A., Martin, J., Herrington, L., & Heneghan, N. R. (2020). Practicability of lower extremity functional performance tests and their measurement properties in elite athletes: Protocol for a systematic review. *BMJ Open*, *10*(12), e042975. https://doi.org/10.1136/bmjopen-2020-042975

Copay, A. G., Subach, B. R., Glassman, S. D., Polly, D. W., & Schuler, T. C. (2007). Understanding the minimum clinically important difference: a review of concepts and methods. *Spine Journal*, *7*(5), 541–546. https://doi.org/10.1016/j.spinee.2007.01.008

Dalmau-Pastor, M., Malagelada, F., Calder, J., Manzanares, M. C., & Vega, J. (2020). The lateral ankle ligaments are interconnected: the medial connecting fibres between the anterior talofibular, calcaneofibular and posterior talofibular ligaments. *Knee Surgery, Sports Traumatology, Arthroscopy*, *28*(1), 34–39. https://doi.org/10.1007/s00167-019-05794-8

Davey, T., Delves, S. K., Lanham-New, S. A., Allsopp, A. J., & Fallowfield, J. L. (2011). Body composition of Royal Marine recruits during 32 weeks of military training. *Proceedings of the Nutrition Society*, *70*(OCE4), 2021.

https://doi.org/10.1017/s0029665111002011

Davis, P. R., McKay, M. J., Baldwin, J. N., Burns, J., Pareyson, D., & Rose, K. J. (2017). Repeatability, consistency, and accuracy of hand-held dynamometry with and without fixation for measuring ankle plantarflexion strength in healthy adolescents and adults. *Muscle and Nerve*, *56*(5), 896–900. https://doi.org/10.1002/mus.25576

Dawe, E. J. C., & Davis, J. (2011). (vi) Anatomy and biomechanics of the foot and ankle. *Orthopaedics and Trauma*, *25*(4), 279–286. https://doi.org/10.1016/j.mporth.2011.02.004

De Noronha, M., França, L. C., Haupenthal, A., & Nunes, G. S. (2013). Intrinsic predictive factors for ankle sprain in active university students: A prospective study. *Scandinavian Journal of Medicine and Science in Sports*, *23*(5), 541–547. https://doi.org/10.1111/j.1600-0838.2011.01434.x

De Noronha, M., Refshauge, K. M., Herbert, R. D., & Kilbreath, S. L. (2006). Do voluntary strength, proprioception, range of motion, or postural sway predict occurrence of lateral ankle sprain? *British Journal of Sports Medicine*, *40*(10), 824–828. https://doi.org/10.1136/bjsm.2006.029645

De Ridder, R., Willems, T., Vanrenterghem, J., Robinson, M. A., & Roosen, P. (2015). Lower limb landing biomechanics in subjects with chronic ankle instability. *Medicine and Science in Sports and Exercise*, *47*(6), 1225–1231. https://doi.org/10.1249/MSS.0000000000000525

De Ridder, R., Witvrouw, E., Dolphens, M., Roosen, P., & Van Ginckel, A. (2017). Hip Strength as an Intrinsic Risk Factor for Lateral Ankle Sprains in Youth Soccer Players. *American Journal of Sports Medicine*, *45*(2), 410–416. https://doi.org/10.1177/0363546516672650

de Vries, N. M., Staal, J. B., van der Wees, P. J., Adang, E. M. M., Akkermans, R., Olde Rikkert, M. G. M., & Nijhuis-van der Sanden, M. W. G. (2016). Patient-centred physical therapy is (cost-) effective in increasing physical activity and reducing frailty in older adults with mobility problems: a randomized controlled trial with 6 months follow-up. *Journal of Cachexia, Sarcopenia and Muscle*, *7*(4), 422–435. https://doi.org/10.1002/jcsm.12091

Delahunt, E., Monaghan, K., & Caulfield, B. (2007). Ankle function during hopping in subjects with functional instability of the ankle joint. *Scandinavian Journal of Medicine and Science in Sports*, *17*(6), 641–648. https://doi.org/10.1111/j.1600-0838.2006.00612.x

Delahunt, Eamonn, Bleakley, C. M., Bossard, D. S., Caulfield, B. M., Docherty, C. L., Doherty, C., Fourchet, F., Fong, D. T., Hertel, J., Hiller, C. E., Kaminski, T. W., McKeon, P. O., Refshauge, K. M., Remus, A., Verhagen, E., Vicenzino, B. T., Wikstrom, E. A., & Gribble, P. A. (2018). Clinical assessment of acute lateral ankle sprain injuries (ROAST): 2019 consensus statement and recommendations of the International Ankle Consortium. *British Journal of Sports Medicine*, *52*(20), 1304–

1310. https://doi.org/10.1136/bjsports-2017-098885

Delahunt, Eamonn, & Remus, A. (2019). Risk factors for lateral ankle sprains and chronic ankle instability. *Journal of Athletic Training*, *54*(6), 611–616. https://doi.org/10.4085/1062-6050-44-18

Denegar, C. R., Hertel, J., & Fonseca, J. (2002). The effect of lateral ankle sprain on dorsiflexion range of motion, posterior talar glide, and joint laxity. *Journal of Orthopaedic and Sports Physical Therapy*, *32*(4), 166–173. https://doi.org/10.2519/jospt.2002.32.4.166

DiGiovanni, C. W., Kuo, R., Tejwani, N., Price, R., Hansen, S. T. J., Cziernecki, J., & Sangeorzan, B. J. (2002). Isolated Gastrocnemius Tightness. *JBJS*, *84*(6). https://journals.lww.com/jbjsjournal/fulltext/2002/06000/isolated_gastrocnemius_tightness.10.aspx

Dingenen, B., Barton, C., Janssen, T., Benoit, A., & Malliaras, P. (2018). Test-retest reliability of two-dimensional video analysis during running. *Physical Therapy in Sport*, *33*(July), 40–47. https://doi.org/10.1016/j.ptsp.2018.06.009

Docherty, C. L., Arnold, B. L., Gansneder, B. M., Hurwitz, S., & Gieck, J. (2005). Functional-performance deficits in volunteers with functional ankle instability. *Journal of Athletic Training*, *40*(1), 30–34. http://www.ncbi.nlm.nih.gov/pubmed/15902321%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1088342

Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., & Delahunt, E. (2015). Single-leg drop landing motor control strategies following acute ankle sprain injury. *Scandinavian Journal of Medicine and Science in Sports*, *25*(4), 525–533. https://doi.org/10.1111/sms.12282

Doherty, C., Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., & Delahunt, E. (2015). Single-leg drop landing movement strategies 6 months following first-time acute lateral ankle sprain injury. *Scandinavian Journal of Medicine and Science in Sports*, *25*(6), 806–817. https://doi.org/10.1111/sms.12390

Doherty, Cailbhe, Bleakley, C., Delahunt, E., & Holden, S. (2017). Treatment and prevention of acute and recurrent ankle sprain: An overview of systematic reviews with meta-analysis. *British Journal of Sports Medicine*, *51*(2), 113–125. https://doi.org/10.1136/bjsports-2016-096178

Doherty, Cailbhe, Bleakley, C., Hertel, J., Caulfield, B., Ryan, J., & Delahunt, E. (2016). Recovery from a First-Time Lateral Ankle Sprain and the Predictors of Chronic Ankle Instability. *American Journal of Sports Medicine*, *44*(4), 995–1003. https://doi.org/10.1177/0363546516628870

Doherty, Cailbhe, Delahunt, E., Caulfield, B., Hertel, J., Ryan, J., & Bleakley, C. (2014). The incidence and prevalence of ankle sprain injury: A systematic review and meta-analysis of prospective epidemiological studies. *Sports Medicine*, *44*(1), 123–140. https://doi.org/10.1007/s40279-013-0102-5

Downing, J. W., Klein, S. J., & D'Amico, J. C. (1978). The axis of motion of the rearfoot complex. *Journal of the American Podiatry Association*, *68*(7), 484–499. https://doi.org/10.7547/87507315-68-7-484

Dubin, J. C., Comeau, D., McClelland, R. I., Dubin, R. A., & Ferrel, E. (2011). Lateral and syndesmotic ankle sprain injuries: A narrative literature review. *Journal of Chiropractic Medicine*, *10*(3), 204–219. https://doi.org/10.1016/j.jcm.2011.02.001

Ekeland, A. (1997). Injuries in military parachuting : study of 4499 jumps. *Differences*, *28*(3), 219–222.

Elizabeth, C. D., Pfile, K. R., Weniger, G. R., Ingersoll, C. D., Herman, D., & Hart, J. M. (2011). Neuromuscular changes after aerobic exercise in people with anterior cruciate ligament-reconstructed knees. In *Journal of Athletic Training* (Vol. 46, Issue 5, pp. 476–483). National Athletic Trainers' Association, Inc. https://doi.org/10.4085/1062-6050-46.5.476

Ellis, G. (2012). Control System Design Guide: Using Your Computer to Understand and Diagnose Feedback Controllers, Fourth Edition. In *Control System Design Guide: Using Your Computer to Understand and Diagnose Feedback Controllers, Fourth Edition*. Butterworth-Heinemann. https://doi.org/10.1016/C2010-0-65994-3

ERKUT, O., RAMAZANOGLU, N., UZUN, S., CAMLIGUNEY, A. F., BOZKURT, S., TIRYAKI, C., KUCUK, V., SIRMEN, B., & KARADENIZLI, Z. I. (2014). Comparision of dynamic and static balance in adolescents handball and soccer players. *Turkish Journal of Sport and Exercise*, *16*(1), 47–47. https://doi.org/10.15314/tjse.201416111

Fenn, B. P., Song, J., Casey, J., Waryasz, G. R., Digiovanni, C. W., Lubberts, B., & Guss, D. (2021). Worldwide epidemiology of foot and ankle injuries during military training: A systematic review. *BMJ Military Health*, *167*(2), 131–136. https://doi.org/10.1136/bmjmilitary-2020-001591

Ferran, N. A., & Maffulli, N. (2006). Epidemiology of Sprains of the Lateral Ankle Ligament Complex. *Foot and Ankle Clinics*, *11*(3), 659–662. https://doi.org/10.1016/j.fcl.2006.07.002

Fong, C. M., Blackburn, J. T., Norcross, M. F., McGrath, M., & Padua, D. A. (2011). Ankle-dorsiflexion range of motion and landing biomechanics. *Journal of Athletic Training*, *46*(1), 5–10. https://doi.org/10.4085/1062-6050-46.1.5

Fong, D. T., Chan, Y.-Y., Mok, K.-M., Yung, P. S., & Chan, K.-M. (2009). Understanding acute ankle ligamentous sprain injury in sports. *BMC Sports Science, Medicine and Rehabilitation*, *1*(1), 1–14. https://doi.org/10.1186/1758-2555-1-14

Fong, D. T. P., Chu, V. W. S., & Chan, K. M. (2012). Myoelectric stimulation on peroneal muscles resists simulated ankle sprain motion. *Journal of Biomechanics*, *45*(11), 2055–2057. https://doi.org/10.1016/j.jbiomech.2012.04.025

Fousekis, K., Tsepis, E., & Vagenas, G. (2012). Intrinsic risk factors of noncontact ankle sprains in soccer: A prospective study on 100 professional players. In *American Journal of Sports Medicine* (Vol. 40, Issue 8, pp. 1842–1850). https://doi.org/10.1177/0363546512449602

Fox, A., Bonacci, J., Hoffmann, S., Nimphius, S., & Saunders, N. (2020). Anterior cruciate ligament injuries in Australian football: Should women and girls be playing? You're asking the wrong question. BMJ Open Sport and Exercise Medicine, 6(1), 2018–2020. https://doi.org/10.1136/bmjsem-2020-000778

Fuerst, P., Gollhofer, A., & Gehring, D. (2017). Preparation time influences ankle and knee joint control during dynamic change of direction movements. Journal of Sports Sciences, 35(8), 762–768. https://doi.org/10.1080/02640414.2016.1189084

Gehring, D., Wissler, S., Mornieux, G., & Gollhofer, A. (2013b). How to sprain your ankle - a biomechanical case report of an inversion trauma. *Journal of Biomechanics*, *46*(1), 175–178. https://doi.org/10.1016/j.jbiomech.2012.09.016

Goodrich, E., Morris, B., Hermanns, C., Herda, A., Tarakemeh, A., & Vopat, B. (2022). Epidemiology of Ankle Sprain in the Active-Duty Military Population. *JBJS Reviews*, *10*(6), e21. https://doi.org/10.2106/JBJS.RVW.21.00232

Greeves, J. (2001). Physical training of women in the military. *J Defence Science*, *6*, 228–238.

Gribble, P. A., Bleakley, C. M., Caulfield, B. M., Docherty, C. L., Fourchet, F., Fong, D. T. P., Hertel, J., Hiller, C. E., Kaminski, T. W., McKeon, P. O., Refshauge, K. M., Verhagen, E. A., Vicenzino, B. T., Wikstrom, E. A., & Delahunt, E. (2016). Evidence review for the 2016 International Ankle Consortium consensus statement on the prevalence, impact and long-term consequences of lateral ankle sprains. *British Journal of Sports Medicine*, *50*(24), 1496–1505. https://doi.org/10.1136/bjsports-2016-096189

Gribble, P. A., & Hertel, J. (2003). Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in Physical Education and Exercise Science*, *7*(2), 89–100. https://doi.org/10.1207/S15327841MPEE0702_3

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the star excursion balance test to assess dynamic postural-control deficits and outcomes in lower extremity injury: A literature and systematic review. *Journal of Athletic Training*, *47*(3), 339–357. https://doi.org/10.4085/1062-6050-47.3.08

Gribble, P., & Robinson, R. (2010). Differences in spatiotemporal landing variables during a dynamic stability task in subjects with CAI. *Scandinavian Journal of Medicine and Science in Sports*, *20*(1), 63–71. https://doi.org/10.1111/j.1600-0838.2009.00899.x

Gwynne, C. R., & Curran, S. A. (2014). Quantifying frontal plane knee motion during single limb squats: reliability and validity of 2-dimensional measures. *International Journal of Sports Physical Therapy*, *9*(7), 898–906. http://www.ncbi.nlm.nih.gov/pubmed/25540705%0Ahttp://www.pubmedcentral.nih.g ov/articlerender.fcgi?artid=PMC4275194

Hadzic, V., Sattler, T., Topole, E., Jarnovic, Z., Burger, H., & Dervisevic, E. (2009). Risk factors for ankle sprain in volleyball players: A preliminary analysis. *Isokinetics and Exercise Science*, *17*(3), 155–160. https://doi.org/10.3233/IES-2009-0347

Halabchi, F., Angoorani, H., Mirshahi, M., Shahi, M. H. P., & Mansournia, M. A. (2016a). The prevalence of selected intrinsic risk factors for ankle sprain among elite football and basketball players. *Asian Journal of Sports Medicine*, *7*(3). https://doi.org/10.5812/asjsm.35287

Halabchi, F., Angoorani, H., Mirshahi, M., Shahi, M. H. P., & Mansournia, M. A. (2016b). The prevalence of selected intrinsic risk factors for ankle sprain among elite football and basketball players. *Asian Journal of Sports Medicine*, *7*(3), 306–313. https://doi.org/10.5812/asjsm.35287

Hartley, E. M., Hoch, M. C., & Boling, M. C. (2018a). Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. *Journal of Science and Medicine in Sport*, *21*(7), 676–680. https://doi.org/10.1016/j.jsams.2017.10.014

Hartley, E. M., Hoch, M. C., & Boling, M. C. (2018b). Y-balance test performance and BMI are associated with ankle sprain injury in collegiate male athletes. *Journal of Science and Medicine in Sport*, *21*(7), 676–680. https://doi.org/10.1016/j.jsams.2017.10.014

Hauser, R. a., & Dolan, E. E. (2011). Ligament Injury and Healing : An Overview. *Journal of Prolotherapy*, *3*(4), 836–846.

Havenetidis, K., & Paxinos, T. (2011). Risk factors for musculoskeletal injuries among Greek army officer cadets undergoing basic combat training. *Military Medicine*, *176*(10), 1111–1116. https://doi.org/10.7205/MILMED-D-10-00448

Hegedus, E. J., McDonough, S., Bleakley, C., Cook, C. E., & Baxter, G. D. (2015). Clinician-friendly lower extremity physical performance measures in athletes: A systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *British Journal of Sports Medicine*, *49*(10), 642–648. https://doi.org/10.1136/bjsports-2014-094094

Henry, T., Evans, K., Snodgrass, S. J., Miller, A., & Callister, R. (2016). Risk Factors for Noncontact Ankle Injuries in Amateur Male Soccer Players: A Prospective Cohort Study. *Clinical Journal of Sport Medicine*, *26*(3), 251–258. https://doi.org/10.1097/JSM.0000000000000240

Hermanns, C., Coda, R., Messamore, W. G., Vopat, M., Morris, B. L., Cheema, S., Tarakemeh, A., Schroeppel, P., Mullen, S., & Vopat, B. G. (2020). Epidemiology of Lateral Ankle Ligament Injury: Trends in Clinical Management and Likelihood of Progression to Surgical Intervention. *Foot & Ankle Orthopaedics*, *5*(4), 2473011420S0024. https://doi.org/10.1177/2473011420s00245

Herrington, L., Alenezi, F., Alzhrani, M., Alrayani, H., & Jones, R. (2017a). The reliability and criterion validity of 2D video assessment of single leg squat and hop landing. *Journal of Electromyography and Kinesiology*, *34*, 80–85. https://doi.org/10.1016/j.jelekin.2017.04.004

Herrington, L., Alenezi, F., Alzhrani, M., Alrayani, H., & Jones, R. (2017b). The reliability and criterion validity of 2D video assessment of single leg squat and hop landing. *Journal of Electromyography and Kinesiology*, *34*, 80–85. https://doi.org/10.1016/j.jelekin.2017.04.004

Hertel, J., Miller, S. J., & Denegar, C. R. (2000). Intratester and intertester reliability during the star excursion balance tests. *Journal of Sport Rehabilitation*, *9*(2), 104–116. https://doi.org/10.1123/jsr.9.2.104

Hertel, Jay. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *Journal of Athletic Training*, *37*(4), 364–375.

Herzog, M. M., Kerr, Z. Y., Marshall, S. W., & Wikstrom, E. A. (2019a). Epidemiology of ankle sprains and chronic ankle instability. *Journal of Athletic Training*, *54*(6), 603–610. https://doi.org/10.4085/1062-6050-447-17

Herzog, M. M., Kerr, Z. Y., Marshall, S. W., & Wikstrom, E. A. (2019b). Epidemiology of ankle sprains and chronic ankle instability. *Journal of Athletic Training*, *54*(6), 603–610. https://doi.org/10.4085/1062-6050-447-17

Higgins, J. D., & Wendland, D. M. (2015). The Use of the Physical Stress Theory to Guide the Rehabilitation of a Patient With Bilateral Suspected Deep Tissue Injuries and Hip Repair. *Journal of Acute Care Physical Therapy*, *6*(3), 87–92. https://doi.org/10.1097/jat.0000000000000018

Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539–1558. https://doi.org/10.1002/sim.1186

Hiller, C. E., Refshauge, K. M., Bundy, A. C., Herbert, R. D., & Kilbreath, S. L. (2006). The Cumberland Ankle Instability Tool: A Report of Validity and Reliability Testing. *Archives of Physical Medicine and Rehabilitation*, *87*(9), 1235–1241. https://doi.org/10.1016/j.apmr.2006.05.022

Hing, Wayne; Lopes, Justin, Hume, P. A. . R. D. A. (2011). Comparison of multimodal physiotherapy and " R . I . C . E ." self-treatment for early management of ankle sprains. *New Zealand Journal of Physiotherapy*, *39*(January), 10–16.

Hoch, M. C., Farwell, K. E., Gaven, S. L., & 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), 833–839. https://doi.org/10.4085/1062-6050-50.5.07

Hoch, M. C., & McKeon, P. O. (2011). Normative range of weight-bearing lunge test performance asymmetry in healthy adults. *Manual Therapy*, *16*(5), 516–519.

https://doi.org/10.1016/j.math.2011.02.012

Hollman, J. H., Ginos, B. E., Kozuchowski, J., Vaughn, A. S., Krause, D. A., & Youdas, J. W. (2009). Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. *Journal of Sport Rehabilitation*, *18*(1), 104–117. https://doi.org/10.1123/jsr.18.1.104

Hollman, J. H., Kolbeck, K. E., Hitchcock, J. L., Koverman, J. W., & Krause, D. A. (2006). Correlations between Hip Strength and Static Foot and Knee Posture. *Journal of Sport Rehabilitation*, *15*(1), 12–23. https://doi.org/10.1123/jsr.15.1.12

Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. *Journal of Athletic Training*, *42*(2), 311–319.

Howe, L. P., Bampouras, T. M., North, J., & Waldron, M. (2019). Ankle dorsiflexion range of motion is associated with kinematic but not kinetic variables related to bilateral drop-landing performance at various drop heights. *Human Movement Science*, *64*, 320–328. https://doi.org/10.1016/j.humov.2019.02.016

Hughes, J. M., Gaffney-Stomberg, E., Guerriere, K. I., Taylor, K. M., Popp, K. L., Xu, C., Unnikrishnan, G., Staab, J. S., Matheny, R. W., McClung, J. P., Reifman, J., & Bouxsein, M. L. (2018). Changes in tibial bone microarchitecture in female recruits in response to 8 weeks of U.S. Army Basic Combat Training. *Bone*, *113*(December 2017), 9–16. https://doi.org/10.1016/j.bone.2018.04.021

Hughes, T., & Rochester, P. (2008). The effects of proprioceptive exercise and taping on proprioception in subjects with functional ankle instability: A review of the literature. *Physical Therapy in Sport*, *9*(3), 136–147. https://doi.org/10.1016/j.ptsp.2008.06.003

Hupperets, M. D. W., Verhagen, E. A. L. M., Heymans, M. W., Bosmans, J. E., Van Tulder, M. W., & Van Mechelen, W. (2010). Potential savings of a program to prevent ankle sprain recurrence: Economic evaluation of a randomized controlled trial. *American Journal of Sports Medicine*, *38*(11), 2194–2200. https://doi.org/10.1177/0363546510373470

Hyong, Hyouk; Kim, J. H. (2014). Test of Intrarater and Interrater Reliability for the SEBT. *The Society of Physical Therapy Science*, *26*(8), 1139–1141.

Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, I. M. C. (2003). Hip Strength in Females with and without Patellofemoral Pain. *Journal of Orthopaedic and Sports Physical Therapy*, *33*(11), 671–676. https://doi.org/10.2519/jospt.2003.33.11.671

Johnson, M. R., & Stoneman, P. D. (2007). Comparison of a Lateral Hop Test Versus a Forward Hop Test for Functional Evaluation of Lateral Ankle Sprains. *Journal of Foot and Ankle Surgery*, *46*(3), 162–174. https://doi.org/10.1053/j.jfas.2006.12.007

Jordaan, G., & Schwellnus, M. P. (1994). The incidence of overuse injuries in military recruits during basic military training. *Military Medicine*, *159*(6), 421–426.

https://doi.org/10.1093/milmed/159.6.421

Kalkhoven, J. T., Watsford, M. L., & Impellizzeri, F. M. (2020). A conceptual model and detailed framework for stress-related, strain-related, and overuse athletic injury. *Journal of Science and Medicine in Sport*, *23*(8), 726–734. https://doi.org/10.1016/j.jsams.2020.02.002

Kaminski, T. W., & Hartsell, H. D. (2002). Factors Contributing to Chronic Ankle. *Journal of Athletic Training*, *37*(4), 394–405.

Kaufman, K. R., Brodine, S., & Shaffer, R. (2000). Military training-related injuries: Surveillance, research, and prevention. *American Journal of Preventive Medicine*, *18*(3 SUPPL.), 54–63. https://doi.org/10.1016/S0749-3797(00)00114-8

Kawaguchi, J. K., & Babcock, G. (2010). Validity and Reliability of Handheld Dynametric Strength Assessment of Hip Extensor and Abductor Muscles. *Athletic Training & Sports Health Care*, *2*(1), 11–17. https://doi.org/10.3928/19425864-20101221-04

Kawaguchi, K., Taketomi, S., Mizutani, Y., Inui, H., Yamagami, R., Kono, K., Takagi, K., Kage, T., Sameshima, S., Tanaka, S., & Haga, N. (2021). Hip Abductor Muscle Strength Deficit as a Risk Factor for Inversion Ankle Sprain in Male College Soccer Players: A Prospective Cohort Study. *Orthopaedic Journal of Sports Medicine*, *9*(7), 1–8. https://doi.org/10.1177/23259671211020287

Keep, H., Luu, L., Berson, A., & Garland, S. J. (2016). Validity of the handheld dynamometer compared with an isokinetic dynamometer in measuring peak hip extension strength. *Physiotherapy Canada*, *68*(1), 15–22. https://doi.org/10.3138/ptc.2014-62

Kelln, B. M., McKeon, P. O., Gontkof, L. M., & Hertel, J. (2008). Hand-held dynamometry: Reliability of lower extremity muscle testing in healthy, physically active, young adults. *Journal of Sport Rehabilitation*, *17*(2), 160–170. https://doi.org/10.1123/jsr.17.2.160

Kemler, E., van de Port, I., Valkenberg, H., Hoes, A. W., & Backx, F. J. G. (2015). Ankle injuries in the Netherlands: Trends over 10-25 years. *Scandinavian Journal of Medicine and Science in Sports*, *25*(3), 331–337. https://doi.org/10.1111/sms.12248

Kernozek, T., Durall, C. J., Friske, A., & Mussallem, M. (2008). Ankle bracing, plantar-flexion angle, and ankle muscle latencies during inversion stress in healthy participants. *Journal of Athletic Training*, *43*(1), 37–43. https://doi.org/10.4085/1062-6050-43.1.37

Knapik, J. J., Trone, D. W., Swedler, D. I., Villasenor, A., Bullock, S. H., Schmied, E., Bockelman, T., Han, P., & Jones, B. H. (2010). Injury reduction effectiveness of assigning running shoes based on plantar shape in marine corps basic training. *American Journal of Sports Medicine*, *38*(9), 1759–1767. https://doi.org/10.1177/0363546510369548

Knapik, J., Reynolds, K., Staab, J., Vogel, J. A., & Jones, B. (1992). Injuries Associated with Strenuous Road Marching. *Military Medicine*, *157*(2), 64–67. https://doi.org/10.1093/milmed/157.2.64

Kobayashi, T., Tanaka, M., & Shida, M. (2016). Intrinsic Risk Factors of Lateral Ankle Sprain: A Systematic Review and Meta-analysis. *Sports Health*, *8*(2), 190–193. https://doi.org/10.1177/1941738115623775

Konor, M. M., Morton, S., Eckerson, J. M., & Grindstaff, T. L. (2012). Reliability of three measures of ankle dorsiflexion range of motion. *International Journal of Sports Physical Therapy*, *7*(3), 279–287. http://www.ncbi.nlm.nih.gov/pubmed/22666642%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC3362988

Konradsen, L. (2002). Factors contributing to chronic ankle instability: Kinesthesia and joint position sense. *Journal of Athletic Training*, *37*(4), 381–385.

Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Koshino, Y., Ishida, T., Yamanaka, M., Ezawa, Y., Okunuki, T., Kobayashi, T., Samukawa, M., Saito, H., & Tohyama, H. (2016). Kinematics and muscle activities of the lower limb during a side-cutting task in subjects with chronic ankle instability. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(4), 1071–1080. https://doi.org/10.1007/s00167-015-3745-y

Kottner, J., Audige, L., Brorson, S., Donner, A., Gajewski, B. J., Hróbjartsson, A., Roberts, C., Shoukri, M., & Streiner, D. L. (2011). Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were proposed. *International Journal of Nursing Studies*, *48*(6), 661–671. https://doi.org/10.1016/j.ijnurstu.2011.01.016

Kovaleski, J. E., Hollis, J. M., Heitman, R. J., Gurchiek, L. R., & Pearsall IV, A. W. (2002). Assessment of ankle-subtalar-joint-complex laxity using an instrumented ankle arthrometer: An experimental cadaveric investigation. *Journal of Athletic Training*, *37*(4), 467–474.

Lam, K. C., Marshall, A. N., Bay, R. C., & Wikstrom, E. A. (2022). Assessment of Patient-Reported Outcomes at Return-to-Sport Following Lateral Ankle Sprain Injuries: A Report from the Athletic Training Practice-Based Research Network. Journal of Athletic Training. https://doi.org/10.4085/1062-6050-0111.22

Leggat, P. A., & Smith, D. R. (2007a). Military training and musculoskeletal disorders. *Journal of Musculoskeletal Pain*, *15*(2), 25–32. https://doi.org/10.1300/J094v15n02_06

Leggat, P. A., & Smith, D. R. (2007b). Military training and musculoskeletal disorders. *Journal of Musculoskeletal Pain*, *15*(2), 25–32. https://doi.org/10.1300/J094v15n02_06

Li, L., Baur, M., Baldwin, K., Kuehn, T., Zhu, Q., & Herman, D. (2021). *implications for ACL injury prevention*. 1–17. https://doi.org/10.1016/j.jbiomech.2020.109906.Falling

Lysdal, F. G., Wang, Y., Delahunt, E., Gehring, D., Kosik, K. B., Krosshaug, T., Li, Y., Mok, K. M., Pasanen, K., Remus, A., Terada, M., & Fong, D. T. P. (2022). What have we learnt from quantitative case reports of acute lateral ankle sprains injuries and episodes of 'giving-way' of the ankle joint, and what shall we further investigate? *Sports Biomechanics*, *21*(4), 359–379. https://doi.org/10.1080/14763141.2022.2035801

Maciel, A. (2002). Biomechanics of Hip Joint Capsule I . Introduction II . Mechanical Properties of Biomaterials. *Biomaterials*.

Mandrekar, J. N. (2010). Receiver operating characteristic curve in diagnostic test assessment. *Journal of Thoracic Oncology*, *5*(9), 1315–1316. https://doi.org/10.1097/JTO.0b013e3181ec173d

Maykut, J. N., Taylor-Haas, J. A., Paterno, M. V, DiCesare, C. A., & Ford, K. R. (2015). Concurrent validity and reliability of 2d kinematic analysis of frontal plane motion during running. *International Journal of Sports Physical Therapy*, *10*(2), 136–146. http://www.ncbi.nlm.nih.gov/pubmed/25883862%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4387721

McCann, R. S., Crossett, I. D., Terada, M., Kosik, K. B., Bolding, B. A., & Gribble, P. A. (2017). Hip strength and star excursion balance test deficits of patients with chronic ankle instability. *Journal of Science and Medicine in Sport*, *20*(11), 992–996. https://doi.org/10.1016/j.jsams.2017.05.005

McGuine, T. A., Hetzel, S., Wilson, J., & Brooks, A. (2012). The effect of lace-up ankle braces on injury rates in high school football players. *American Journal of Sports Medicine*, *40*(1), 49–57. https://doi.org/10.1177/0363546511422332

McKay, G. D., Goldie, P. A., Payne, W. R., & Oakes, B. W. (2001). Ankle injuries in basketball: Injury rate and risk factors. *British Journal of Sports Medicine*, *35*(2), 103–108. https://doi.org/10.1136/bjsm.35.2.103

McLean, S. G., Walker, K., Ford, K. R., Myer, G. D., Hewett, T. E., & Van Den Bogert, A. J. (2005). Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *British Journal of Sports Medicine*, *39*(6), 355–362. https://doi.org/10.1136/bjsm.2005.018598

Meeuwisse, W. H. (1994). Assessing Causation in Sport Injury: A Multifactorial Model. *Clinical Journal of Sport Medicine*, *4*(3). https://journals.lww.com/cjsportsmed/fulltext/1994/07000/assessing_causation_in_sport_injury__a.4.aspx

Mei-Dan, O., Kahn, G., Zeev, A., Rubin, A., Constantini, N., Even, A., Nyska, M., & Mann, G. (2005). The medial longitudinal arch as a possible risk factor for ankle sprains: A prospective study in 83 female infantry recruits. *Foot and Ankle International*, *26*(2), 180–183. https://doi.org/10.1177/107110070502600211

Mei, Z., Grummer-Strawn, L. M., Pietrobelli, A., Goulding, A., Goran, M. I., & Dietz, W. H. (2002). Validity of body mass index compared with other body-composition screening indexes for the assessment of body fatness in children and adolescents. *American Journal of Clinical Nutrition*, *75*(6), 978–985. https://doi.org/10.1093/ajcn/75.6.978

Meyer, C., Corten, K., Wesseling, M., Peers, K., Simon, J. P., Jonkers, I., & Desloovere, K. (2013). Test-retest reliability of innovated strength tests for hip muscles. *PLoS ONE*, *8*(11), 1–8. https://doi.org/10.1371/journal.pone.0081149

Michels, F., Wastyn, H., Pottel, H., Stockmans, F., Vereecke, E., & Matricali, G. (2022). The presence of persistent symptoms 12 months following a first lateral ankle sprain: A systematic review and meta-analysis. In Foot and Ankle Surgery (Vol. 28, Issue 7, pp. 817–826). Elsevier Ltd. https://doi.org/10.1016/j.fas.2021.12.002

Miguel Ângelo de Castro, C., & João, T. (2019). Intrinsic and Extrinsic Risk Factors for Lateral Ankle Sprain: A Literature Review. *Archives of Sports Medicine*, *3*(2), 172–177. https://doi.org/10.36959/987/247

Milgrom, C., Lavie, O., Shlamkovitch, N., Finestone, A., Eldad, A., Laor, A., Danon, Y. L., Wosk, J., & Simkin, A. (1991). Risk Factors for Lateral Ankle Sprain: A Prospective Study Among Military Recruits. *Foot & Ankle International*, *12*(1), 26–30. https://doi.org/10.1177/107110079101200105

Mineta, S., Inami, T., Hoshiba, T., Higashihara, A., Kumai, T., Torii, S., & Hirose, N. (2021). Greater knee varus angle and pelvic internal rotation after landing are predictive factors of a non-contact lateral ankle sprain. *Physical Therapy in Sport*, *50*, 59–64. https://doi.org/10.1016/j.ptsp.2021.04.001

Mitchell, A., Dyson, R., Hale, T., & Abraham, C. (2008). Biomechanics of ankle instability. Part 1: Reaction time to simulated ankle sprain. *Medicine and Science in Sports and Exercise*, *40*(8), 1515–1521. https://doi.org/10.1249/MSS.0b013e31817356b6

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, *6*(7), 873–880. https://doi.org/10.1371/journal.pmed.1000097

Mueller, M. J., & Maluf, K. S. (2002). Tissue adaptation to physical stress: A proposed "Physical Stress Theory" to guide physical therapist practice, education, and research. *Physical Therapy*, *82*(4), 383–403. https://doi.org/10.1093/ptj/82.4.383

Munro, A., Herrington, L., & Carolan, M. (2012). Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. *Journal of Sport Rehabilitation*, *21*(1), 7–11. https://doi.org/10.1123/jsr.21.1.7

Murphy, D. F., Connolly, D. A. J., & Beynnon, B. D. (2003). Risk factors for lower extremity injury: A review of the literature. *British Journal of Sports Medicine*, *37*(1), 13–29. https://doi.org/10.1136/bjsm.37.1.13

Narlawar, S. G., Varadharajulu, G., & Kanase, S. (2019). Effect of closed kinematic chain exercises on distal muscle weakness in post guillain barre syndrome. *Indian Journal of Public Health Research and Development*, *10*(7), 111–116. https://doi.org/10.5958/0976-5506.2019.01546.8

Neelapala, Y. V. R., Reddy, Y. R. S., & Danait, R. (2016). EFFECT OF MULLIGAN'S POSTEROLATERAL GLIDE ON SHOULDER ROTATOR STRENGTH, SCAPULAR UPWARD ROTATION IN SHOULDER PAIN SUBJECTS – A RANDOMIZED CONTROLLED TRIAL. *Journal of Musculoskeletal Research*, *19*(03), 1650014. https://doi.org/10.1142/S0218957716500147

Netter, F. H., & SCOTT, J. (2019). *Atlas d'anatomie humaine*. Elsevier Health Sciences.

Niethard, F. U., Pfeil, J., & Biberthaler, P. (2014). *Orthopädie und Unfallchirurgie.[inklusive Filme online]*. Stuttgart: Thieme (Duale Reihe).

Norkin, C. C., & White, D. J. (2016). *Measurement of joint motion: a guide to goniometry*. FA Davis.

Olson, T. J., Chebny, C., Willson, J. D., Kernozek, T. W., & Straker, J. S. (2011). Comparison of 2D and 3D kinematic changes during a single leg step down following neuromuscular training. *Physical Therapy in Sport*, *12*(2), 93–99. https://doi.org/10.1016/j.ptsp.2010.10.002

Orr, R. M., Johnston, V., Coyle, J., & Pope, R. (2015). Reported Load Carriage Injuries of the Australian Army Soldier. *Journal of Occupational Rehabilitation*, *25*(2), 316–322. https://doi.org/10.1007/s10926-014-9540-7

Ozeki, S., Kitaoka, H., Uchiyama, E., Luo, Z. P., Kaufman, K., & An, K. N. (2006). Ankle ligament tensile forces at the end points of passive circumferential rotating motion of the ankle and subtalar joint complex. *Foot and Ankle International*, *27*(11), 965–969. https://doi.org/10.1177/107110070602701117

Park, H. J., Cha, S. D., Kim, S. S., Rho, M. H., Kwag, H. J., Park, N. H., & Lee, S. Y. (2012). Accuracy of MRI findings in chronic lateral ankle ligament injury: Comparison with surgical findings. *Clinical Radiology*, *67*(4), 313–318. https://doi.org/10.1016/j.crad.2011.08.025

Parsons, J. L., Coen, S. E., & Bekker, S. (2021). Anterior cruciate ligament injury: Towards a gendered environmental approach. British Journal of Sports Medicine, 55(17), 984–990. https://doi.org/10.1136/bjsports-2020-103173

Patel, D. R., & Nelson, T. L. (2000). SPORTS INJURIES IN ADOLESCENTS. *Medical Clinics of North America*, *84*(4), 983–1007. https://doi.org/https://doi.org/10.1016/S0025-7125(05)70270-4

Payne, K. A., Berg, K., & Latin, R. W. (1997). Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *Journal of Athletic Training*, *32*(3), 221–225.

Payton, C. J., & Bartlett, R. M. (2007). Biomechanical evaluation of movement in sport and exercise: The British association of sport and exercise sciences guidelines. In *Biomechanical Evaluation of Movement in Sport and Exercise: The British Association of Sport and Exercise Sciences Guidelines*. Routledge. https://doi.org/10.4324/9780203935750

Peel, S. A., Thorsen, T. A., Schneider, L. G., & Weinhandl, J. T. (2020). Effects of Foot Rotation on ACL Injury Risk Variables During Drop Landing. *Journal of Science in Sport and Exercise*, *2*(1), 59–68. https://doi.org/10.1007/s42978-019-00051-3

Peter Peduz$,‘~4~* John Concato, 2’3 Elizabeth Kemper,‘z4 Theodore R. Holford, 4 and Alvan R. Feinstein2~3. (1996). A Simulation Study of the Number of Events per Variable in Logistic Regression Analysis. *American Journal of Preventive Medicine*, *26*(3), 252–253. https://doi.org/10.1016/j.amepre.2003.12.002

Petersen, W., Rembitzki, I. V., Koppenburg, A. G., Ellermann, A., Liebau, C., Brüggemann, G. P., & Best, R. (2013). Treatment of acute ankle ligament injuries: A systematic review. *Archives of Orthopaedic and Trauma Surgery*, *133*(8), 1129–1141. https://doi.org/10.1007/s00402-013-1742-5

Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., & Elkins, B. (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy : NAJSPT*, *4*(2), 92–99. http://www.ncbi.nlm.nih.gov/pubmed/21509114%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC2953327

Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *Journal of Orthopaedic and Sports Physical Therapy*, *36*(12), 911–919. https://doi.org/10.2519/jospt.2006.2244

Pourgharib Shahi, M. H., Selk Ghaffari, M., Mansournia, M. A., & Halabchi, F. (2021). Risk Factors Influencing the Incidence of Ankle Sprain Among Elite Football and Basketball Players: A Prospective Study. *Foot and Ankle Specialist*, *14*(6), 482–488. https://doi.org/10.1177/1938640020921251

Pourkazemi, F., Hiller, C. E., Raymond, J., Black, D., Nightingale, E. J., & Refshauge, K. M. (2018). Predictors of recurrent sprains after an index lateral ankle sprain: a longitudinal study. *Physiotherapy (United Kingdom)*, *104*(4), 430–437. https://doi.org/10.1016/j.physio.2017.10.004

Powden, C. J., Dodds, T. K., & Gabriel, E. H. (2019). the Reliability of the Star Excursion Balance Test and Lower Quarter Y-Balance Test in Healthy Adults: a Systematic Review. *International Journal of Sports Physical Therapy*, *14*(5), 683–694. https://doi.org/10.26603/ijspt20190683

Powers, C. M., Ghoddosi, N., Straub, R. K., & Khayambashi, K. (2017). Hip strength as a predictor of ankle sprains in male soccer players: A prospective study. *Journal of Athletic Training*, *52*(11), 1048–1055. https://doi.org/10.4085/1062-6050-52.11.18

Psaila, M., & Ranson, C. (2017). Risk factors for lower leg, ankle and foot injuries during basic military training in the Maltese Armed Forces. *Physical Therapy in Sport*, *24*, 7–12. https://doi.org/10.1016/j.ptsp.2016.09.004

Purevsuren, T., Kim, K., Batbaatar, M., Lee, S. K., & Kim, Y. H. (2018). Influence of ankle joint plantarflexion and dorsiflexion on lateral ankle sprain: A computational study. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, *232*(5), 458–467. https://doi.org/10.1177/0954411918762955

Rabin, A., Kozol, Z., & Finestone, A. S. (2014). Limited ankle dorsiflexion increases the risk for mid-portion Achilles tendinopathy in infantry recruits: A prospective cohort study. *Journal of Foot and Ankle Research*, *7*(1), 48–49. https://doi.org/10.1186/s13047-014-0048-3

Ranganathan, P., Aggarwal, R., & Pramesh, C. (2015). Common pitfalls in statistical analysis: Odds versus risk. *Perspectives in Clinical Research*, *6*(4), 222. https://doi.org/10.4103/2229-3485.167092

Read, P. J., Oliver, J. L., De Ste Croix, M. B. A., Myer, G. D., & Lloyd, R. S. (2018). A prospective investigation to evaluate risk factors for lower extremity injury risk in male youth soccer players. *Scandinavian Journal of Medicine and Science in Sports*, *28*(3), 1244–1251. https://doi.org/10.1111/sms.13013

Reiman, M. P., & Manske, R. C. (2009). *Functional testing in human performance*. Human kinetics.

Reinstein, D. Z., Gobbe, M., & Archer, T. J. (2012). Anterior segment biometry: A study and review of resolution and repeatability data. *Journal of Refractive Surgery*, *28*(7), 509–520. https://doi.org/10.3928/1081597X-20120620-02

Řezaninová, J., Hrazdira, L., Moc Králová, D., Svoboda, Z., & Benaroya, A. (2018). Advanced conservative treatment of complete acute rupture of the lateral ankle ligaments: Verifying by stabilometry. *Foot and Ankle Surgery*, *24*(1), 65–70. https://doi.org/10.1016/j.fas.2016.12.001

Rice, H., Nunns, M., House, C., Fallowfield, J., Allsopp, A., & Dixon, S. (2017). A narrow bimalleolar width is a risk factor for ankle inversion injury in male military recruits: A prospective study. *Clinical Biomechanics*, *41*, 14–19. https://doi.org/10.1016/j.clinbiomech.2016.11.001

Rnold, C. A. M. A., Arkentin, K. A. D. W., & Hilibeck, P. H. D. C. (2010). *T r v h d m l -e m s o a*. *24*(3), 815–824.

Robert-Lachaine, X., Mecheri, H., Larue, C., & Plamondon, A. (2017). Validation of inertial measurement units with an optoelectronic system for whole-body motion analysis. *Medical and Biological Engineering and Computing*, *55*(4), 609–619. https://doi.org/10.1007/s11517-016-1537-2

Robinson, A. H. N., & Keith, T. (2016). Osteoarthritis of the ankle. *Orthopaedics and Trauma*, *30*(1), 59–67. https://doi.org/10.1016/j.mporth.2015.11.003

Roos, K. G., Kerr, Z. Y., Mauntel, T. C., Djoko, A., Dompier, T. P., & Wikstrom, E. A. (2017). The Epidemiology of Lateral Ligament Complex Ankle Sprains in National Collegiate Athletic Association Sports. *American Journal of Sports Medicine*, *45*(1), 201–209. https://doi.org/10.1177/0363546516660980

Rosenthal, R., & Rosnow, R. L. (2008). Essentials of Behavioral Research. In *McGraw-Hill Series in Psychology.*

Rota, M., & Antolini, L. (2014). Finding the optimal cut-point for Gaussian and Gamma distributed biomarkers. *Computational Statistics and Data Analysis*, *69*, 1–14. https://doi.org/10.1016/j.csda.2013.07.015

Schilz, C., & Sammito, S. (2021). Soldiers' physical activity of daily life: a systematic literature review. *Journal of Public Health (Germany)*, 1–8. https://doi.org/10.1007/s10389-021-01586-y

Schuberth, J. (2002). A.S. Banks, M.S. Downey, D.E. Martin and S.J. Miller, Editors, McGlamry's Comprehensive Textbook of Foot and Ankle Surgery (3rd Edition), Lippincott Williams & Wilkins, New York (2001) ISBN 0-683-30471-2 2304 pp, $ 369. *Journal of Foot & Ankle Surgery - J FOOT ANKLE SURG*, *41*, 199. https://doi.org/10.1016/S1067-2516(02)80073-4

Schwartz, O., Malka, I., Olsen, C. H., Dudkiewicz, I., & Bader, T. (2018). Overuse Injuries in the IDF's Combat Training Units: Rates, Types, and Mechanisms of Injury. *Military Medicine*, *183*(3–4), E196–E200. https://doi.org/10.1093/milmed/usx055

Self, B. P., Harris, S., & Greenwald, R. M. (2000). Ankle biomechanics during impact landings on uneven surfaces. *Foot and Ankle International*, *21*(2), 138–144. https://doi.org/10.1177/107110070002100208

Shaffer, K. (2007). Clinical Anatomy by Systems by Richard S. Snell. In *Clinical Anatomy* (Vol. 20, Issue 2). Lippincott Williams & Wilkins. https://doi.org/10.1002/ca.20419

Shah, S., Thomas, A. C., Noone, J. M., Blanchette, C. M., & Wikstrom, E. A. (2016). Incidence and Cost of Ankle Sprains in United States Emergency Departments. *Sports Health*, *8*(6), 547–552. https://doi.org/10.1177/1941738116659639

Skinner, D. V. (Ed.). (1997). Cambridge textbook of accident and emergency medicine. Cambridge University Press, 1997:814

Smith, M. D., Vicenzino, B., Bahr, R., Bandholm, T., Cooke, R., Mendonça, L. D. M., Fourchet, F., Glasgow, P., Gribble, P. A., Herrington, L., Hiller, C. E., Lee, S. Y., Macaluso, A., Meeusen, R., Owoeye, O. B. A., Reid, D., Tassignon, B., Terada, M., Thorborg, K., … Delahunt, E. (2021). Return to sport decisions after an acute lateral ankle sprain injury: Introducing the PAASS framework - An international multidisciplinary consensus. *British Journal of Sports Medicine*, *55*(22), 1270–1276. https://doi.org/10.1136/bjsports-2021-104087

Solomonow, M. (2009). Ligaments: A source of musculoskeletal disorders. *Journal of Bodywork and Movement Therapies*, *13*(2), 136–154. https://doi.org/10.1016/j.jbmt.2008.02.001

Spink, M. J., Fotoohabadi, M. R., & Menz, H. B. (2010). Foot and ankle strength assessment using hand-held dynamometry: Reliability and age-related differences. *Gerontology*, *56*(6), 525–532. https://doi.org/10.1159/000264655

Stratford, P. W., & Riddle, D. L. (2012). When minimal detectable change exceeds a diagnostic test-based threshold change value for an outcome measure: Resolving the conflict. *Physical Therapy*, *92*(10), 1338–1347. https://doi.org/10.2522/ptj.20120002

Strowbridge, N. F., & Burgess, K. R. (2002). Sports and training injuries in British soldiers: the Colchester Garrison Sports Injury and Rehabilitation Centre. *Journal of the Royal Army Medical Corps*, *148*(3), 236–243. https://doi.org/10.1136/jramc-148-03-03

Tajima, A. (2012). The relationship between chronic ankle instability and functional movement impairment in Division I female athletes. *ProQuest Dissertations and Theses*, 50. https://www.lib.uwo.ca/cgi-bin/ezpauthn.cgi?url=http://search.proquest.com/docview/1009888678?accountid=15115%5Cnhttp://vr2pk9sx9w.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info:ofi/enc:UTF-8&rfr_id=info:sid/ProQuest+Dissertations+%26+These

Terada, M., & Gribble, P. A. (2015). Jump landing biomechanics during a laboratory recorded recurrent ankle sprain. *Foot and Ankle International*, *36*(7), 842–848. https://doi.org/10.1177/1071100715576517

Thompson, C., Schabrun, S., Romero, R., Bialocerkowski, A., van Dieen, J., & Marshall, P. (2018). Factors Contributing to Chronic Ankle Instability: A Systematic Review and Meta-Analysis of Systematic Reviews. *Sports Medicine*, *48*(1), 189–205. https://doi.org/10.1007/s40279-017-0781-4

Thorborg, K., Petersen, J., Magnusson, S. P., & Hölmich, P. (2010). Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scandinavian Journal of Medicine and Science in Sports*, *20*(3), 493–501. https://doi.org/10.1111/j.1600-0838.2009.00958.x

Tilson, J. K., Sullivan, K. J., Cen, S. Y., Rose, D. K., Koradia, C. H., Azen, S. P., Duncan, P. W., Wu, S. S., Dobkin, B. H., & Nadeau, S. E. (2010). Meaningful gait speed improvement during the first 60 days poststroke: Minimal clinically important difference. *Physical Therapy*, *90*(2), 196–208. https://doi.org/10.2522/ptj.20090079

Trojian, T. H., & McKeag, D. B. (2006). Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine*, *40*(7), 610–613. https://doi.org/10.1136/bjsm.2005.024356

Tropp, H. (2002). Functional ankle instability revisited. *Journal of Athletic Training*, *37*(4), 512–515.

Ty Hopkins, J., McLoda, T., & McCaw, S. (2007). Muscle activation following sudden ankle inversion during standing and walking. *European Journal of Applied Physiology*, *99*(4), 371–378. https://doi.org/10.1007/s00421-006-0356-9

Vaes, P., Duquet, W., & Van Gheluwe, B. (2002). Peroneal reaction times and eversion motor response in healthy and unstable ankles. *Journal of Athletic Training*, *37*(4), 475–480. http://www.ncbi.nlm.nih.gov/pubmed/12937570%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC164380

Valderrabano, V., Hintermann, B., Horisberger, M., & Tak, S. F. (2006). Ligamentous posttraumatic ankle osteoarthritis. *American Journal of Sports Medicine*, *34*(4), 612–620. https://doi.org/10.1177/0363546505281813

Verhagen, E. A. L. M., van Mechelen, W., & de Vente, W. (2000). The Effect of Preventive Measures on the Incidence of Ankle Sprains. *Clinical Journal of Sport Medicine*, *10*(4). https://journals.lww.com/cjsportsmed/Fulltext/2000/10000/The_Effect_of_Preventive_Measures_on_the_Incidence.12.aspx

Vuurberg, G., Hoorntje, A., Wink, L. M., Van Der Doelen, B. F. W., Van Den Bekerom, M. P., Dekker, R., Van Dijk, C. N., Krips, R., Loogman, M. C. M., Ridderikhof, M. L., Smithuis, F. F., Stufkens, S. A. S., Verhagen, E. A. L. M., De Bie, R. A., & Kerkhoffs, G. M. M. J. (2018). Diagnosis, treatment and prevention of ankle sprains: Update of an evidence-based clinical guideline. *British Journal of Sports Medicine*, *52*(15), 956. https://doi.org/10.1136/bjsports-2017-098106

Wang, C., Fang, Y., Guo, S., & Chen, Y. (2013). Design and kinematical performance analysis of a 3-RUS/RRR redundantly actuated parallel mechanism for ankle rehabilitation. *Journal of Mechanisms and Robotics*, *5*(4), 41003. https://doi.org/10.1115/1.4024736

Wang, H., Yu, H., Kim, Y. H., & Kan, W. (2021). Comparison of the effect of resistance and balance training on isokinetic eversion strength, dynamic balance, hop test, and ankle score in ankle sprain. *Life*, *11*(4). https://doi.org/10.3390/life11040307

Waterman, B. R., Belmont, P. J., Cameron, K. L., Deberardino, T. M., & Owens, B. D. (2010a). Epidemiology of Ankle Sprain at the United States Military Academy. *American Journal of Sports Medicine*, *38*(4), 797–803. https://doi.org/10.1177/0363546509350757

Waterman, B. R., Belmont, P. J., Cameron, K. L., Deberardino, T. M., & Owens, B. D. (2010b). Epidemiology of Ankle Sprain at the United States Military Academy.

American Journal of Sports Medicine, *38*(4), 797–803. https://doi.org/10.1177/0363546509350757

Waterman, B. R., Owens, B. D., Davey, S., Zacchilli, M. A., & Belmont, P. J. (2010). The epidemiology of ankle sprains in the United States. *Journal of Bone and Joint Surgery*, *92*(13), 2279–2284. https://doi.org/10.2106/JBJS.I.01537

Watts, B. L., & Armstrong, B. (2001). A randomised controlled trial to determine the effectiveness of double Tubigrip in grade 1 and 2 (mild to moderate) ankle sprains. *Emergency Medicine Journal*, *18*(1), 46–50. https://doi.org/10.1136/emj.18.1.46

Weinhandl, Smith, & Dugan. (2011). The effects of repetitive drop jumps on impact phase joint kinematics and kinetics. *Journal of Applied Biomechanics*, *27*(2), 108–115. http://www.embase.com/search/results?subaction=viewrecord&from=export&id=L361786619%0Ahttp://journals.humankinetics.com/AfcStyle/DocumentDownload.cfm?DType=DocumentItem&Document=03_Weinhandl_JAB_2009_0104_108-115.pdf

Wells, G. A., Shea, B., & O'connell, D. (2010). *The Newcastle–Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa (ON): Ottawa Health Research Institute* (Issue July 2014). http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp

Wiersma, P. H., & Griffioen, F. M. M. (1992). Variations of three lateral ligaments of the ankle. A descriptive anatomical study. *The Foot*, *2*(4), 218–224. https://doi.org/10.1016/0958-2592(92)90051-P

Wilczyński, B., Zorena, K., & Ślęzak, D. (2020). Dynamic knee valgus in single-leg movement tasks. Potentially modifiable factors and exercise training options. a literature review. *International Journal of Environmental Research and Public Health*, *17*(21), 1–17. https://doi.org/10.3390/ijerph17218208

Wilkinson, D. M., Blacker, S. D., Richmond, V. L., Horner, F. E., Rayson, M. P., Spiess, A., & Knapik, J. J. (2011). Injuries and injury risk factors among British army infantry soldiers during predeployment training. *Injury Prevention*, *17*(6), 381–387. https://doi.org/10.1136/ip.2010.028233

Wilkinson, D. M., Rayson, M. P., & Bilzon, J. L. J. (2008). A physical demands analysis of the 24-week British Army Parachute Regiment recruit training syllabus. *Ergonomics*, *51*(5), 649–662. https://doi.org/10.1080/00140130701757367

Willems, T. M., Witvrouw, E., Delbaere, K., Philippaerts, R., De Bourdeaudhuij, I., & De Clercq, D. (2005a). Intrinsic risk factors for inversion ankle sprains in females - A prospective study. *Scandinavian Journal of Medicine and Science in Sports*, *15*(5), 336–345. https://doi.org/10.1111/j.1600-0838.2004.00428.x

Willems, T. M., Witvrouw, E., Delbaere, K., Philippaerts, R., De Bourdeaudhuij, I., & De Clercq, D. (2005b). Intrinsic Risk Factors for Inversion Ankle Sprains in Male Subjects. *Scandinavian Journal of Medicine and Science in Sports*, *15*(5), 336–345. https://doi.org/10.1111/j.1600-0838.2004.00428.x

Willems, T., Witvrouw, E., Delbaere, K., De Cock, A., & De Clercq, D. (2004). Relationship between gait biomechanics and inversion sprains: A prospective study of risk factors. *Gait and Posture*, *21*(4), 379–387. https://doi.org/10.1016/j.gaitpost.2004.04.002

Williams, G. N., Molloy, J. M., DeBerardino, T. M., Arciero, R. A., & Taylor, D. C. (2003). Evaluation of the Sports Ankle Rating System in young, athletic individuals with acute lateral ankle sprains. *Foot & Ankle International*, *24*(3), 274–282. https://doi.org/10.1177/107110070302400314

Witchalls, J., Blanch, P., Waddington, G., & Adams, R. (2012). Intrinsic functional deficits associated with increased risk of ankle injuries: A Systematic review with meta-analysis. *British Journal of Sports Medicine*, *46*(7), 515–523. https://doi.org/10.1136/bjsports-2011-090137

Witvrouw, E., Vanden Borre, K., Willems, T. M., Huysmans, J., Broos, E., & De Clercq, D. (2006). The significance of peroneus tertius muscle in ankle injuries: A prospective study. *American Journal of Sports Medicine*, *34*(7), 1159–1163. https://doi.org/10.1177/0363546505286021

Wright, I. C., Neptune, R. R., Van Den Bogert, A. J., & Nigg, B. M. (2000). The influence of foot positioning on ankle sprains. *Journal of Biomechanics*, *33*(5), 513–519. https://doi.org/10.1016/S0021-9290(99)00218-3

Yeung, M. S., Chan, K. M., So, C. H., & Yuan, W. Y. (1994). An epidemiological survey on ankle sprain. *British Journal of Sports Medicine*, *28*(2), 112–116. https://doi.org/10.1136/bjsm.28.2.112

Yildiz, Y., Aydin, T., Sekir, U., Hazneci, B., Komurcu, M., & Kalyon, T. A. (2003). Peak and end range eccentric evertor/concentric invertor muscle strength ratios in chronically unstable ankles: Comparison with healthy individuals. *Journal of Sports Science and Medicine*, *2*(3), 70–76.

Yoshida, M., Aoki, N., Taniguchi, K., Yoshida, M., & Katayose, M. (2018). Kinematic analysis of the ankle joint on the side-hop test in subjects with ankle sprains. *Translational Sports Medicine*, *1*(6), 265–272. https://doi.org/10.1002/tsm2.44

Zambraski, E. J., & Yancosek, K. E. (2012). Prevention and rehabilitation of musculoskeletal injuries during military operations and training. *Journal of Strength and Conditioning Research*, *26*(SUPPL. 2), 101–106. https://doi.org/10.1519/jsc.0b013e31825cf03b

Zhang, Z. (2000). A flexible new technique for camera calibration. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *22*(11), 1330–1334. https://doi.org/10.1109/34.888718

Ziai, P., Benca, E., Wenzel, F., Schuh, R., Krall, C., Auffahrt, A., Hofstetter, M., Windhager, R., & Buchhorn, T. (2016). Peroneal tendinosis as a predisposing factor for the acute lateral ankle sprain in runners. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(4), 1175–1179. https://doi.org/10.1007/s00167-015-

3562-3

Appendices

Appendix A

Assessment of quality of a cohort study – Newcastle Ottawa Scale	
Selection (tick one box in each section)	
1. Representativeness of the intervention cohort	
a) truly representative of the average, elderly, community-dwelling resident ★	☐
b) somewhat representative of the average, elderly, community-dwelling resident ★	☐
c) selected group of patients, e.g. only certain socio-economic groups/areas	☐
d) no description of the derivation of the cohort	☐
2. Selection of the non intervention cohort	
a) drawn from the same community as the intervention cohort ★	☐
b) drawn from a different source	☐
c) no description of the derivation of the non intervention cohort	☐
3. Ascertainment of intervention	
a) secure record (eg health care record) ★	☐
b) structured interview ★	☐
c) written self report	☐
d) other / no description	☐
4. Demonstration that outcome of interest was not present at start of study	
a) yes ★	☐
b) no	☐
Comparability (tick one or both boxes, as appropriate)	
1. Comparability of cohorts on the basis of the design or analysis	
a) study controls for age, sex, marital status ★	☐
b) study controls for any additional factors (e.g. socio-economic status, education) ★	☐
Outcome (tick one box in each section)	
1. Assessment of outcome	
a) independent blind assessment ★	☐
b) record linkage ★	☐
c) self report	☐
d) other / no description	☐
2. Was follow up long enough for outcomes to occur	
a) yes, if median duration of follow-up >= 6 month ★	☐
b) no, if median duration of follow-up < 6 months	☐
3. Adequacy of follow up of cohorts	
a) complete follow up: all subjects accounted for ★	☐
b) subjects lost to follow up unlikely to introduce bias: number lost <= 20%, or description of those lost suggesting no different from those followed ★	☐
c) follow up rate < 80% (select an adequate %) and no description of those lost	☐
d) no statement	☐

Appendix B

University of Salford
MANCHESTER

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
University of Salford,
Manchester
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk

20 May 2019

Dear Khalid,

RE: ETHICS APPLICATION–HSR1819-083 – Between day reliability of clinical, biomechanical and physiological measurements of ankle function

Based on the information that you have provided, I am pleased to inform you that application HSR1819-083 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Andrew Clark
Deputy Chair of the Research Ethics Panel

Appendix C

نموذج الموافقة

عنوان الدراسة:

بين اليوم موثوقية القياسات السريرية والميكانيكية الحيوية والفسيولوجية لوظيفة الكاحل.

١. لقد تم شرح مشاركتي في الدراسة والغرض منها بشكل كامل لي. لقد تم شرح أهداف ومخاطر البحث لي. ☐

٢. لقد قرأت وفهمت ورقة معلومات المشاركين (الإصدار ١,١ - ٩ مايو ٢٠١٩) وأفهم ما هو متوقع مني. لقد أتيحت لي الفرصة للنظر في المعلومات وطرح الأسئلة التي تمت الإجابة عليها بشكل مرض. ☐

٣. أفهم أن مشاركتي طوعية وأنني حر في الانسحاب في أي وقت، دون إبداء أي سبب، ودون أن تتأثر حقوقي. ☐

٤. أفهم أنه سيتم الاحتفاظ ببياناتي ، ما لم أطلب سحب بياناتي بعد أسبوعين من انتهاء الجلسة.

٥. أفهم أن عملية الفحص لتحديد ما إذا كنت مناسبا ليتم اختياري كمشارك ستشمل إكمال استبيان الفحص الطبي للتقرير الذاتي. ☐

٦. أوافق على معالجة معلوماتي الشخصية لأغراض هذه الدراسة البحثية. أفهم أنه سيتم التعامل مع هذه المعلومات على أنها سرية للغاية وسيتم التعامل معها وفقا لأحكام اللائحة العامة لحماية البيانات في الاتحاد الأوروبي (GDPR) لعام ٢٠١٨. ☐

٧. أوافق على التطوع كمشارك في الدراسة الموضحة في ورقة المعلومات وإعطاء الموافقة الكاملة. ☐

٨. أفهم أن المعلومات حول الدراسة والبيانات الناتجة عنها مجهولة المصدر وسيتم الاحتفاظ بالبيانات لمدة ثلاث سنوات ويمكن استخدامها في الدراسات المستقبلية. ☐

٩. أفهم أنه سيتم استخدام بياناتي مجهولة المصدر في أطروحة الباحث وغيرها من المنشورات الأكاديمية والعروض التقديمية للمؤتمرات. ☐

بيان المشارك:

أنا.. عمر.......... أوافق على أن المشروع البحثي المذكور أعلاه قد تم شرحه لي بما يرضيني وأوافق على المشاركة في الدراسة. لقد قرأت كل من الملاحظات المكتوبة أعلاه وورقة معلومات المشاركين حول المشروع وأفهم ما تنطوي عليه الدراسة البحثية.

التوقيع:التاريخ:

اسم الشاهد:

التوقيع:التاريخ:

بيان المحقق:

أنا.. تأكيد أنني شرحت بعناية طبيعة البحث المقترح ومطالبه وأي مخاطر متوقعة (حيثما ينطبق ذلك) للمشارك.

التوقيع:التاريخ:

تفويض التوقيعات

المعلومات المقدمة أعلاه هي على حد علمي واعتقادي دقيقة. أفهم بوضوح التزاماتي وحقوق المشاركين في البحث ، خاصة فيما يتعلق بتوظيف المشاركين والحصول على موافقة صحيحة.

توقيع كبير المحققين

.... تاريخ:

اسم كبير المحققين وتفاصيل الاتصال به:

البروفيسور ريتشارد جونز

r.k.jones@salford.ac.uk

٠١٦١٢٩٥٢٢٩٥

Appendix D

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
University of Salford,
Manchester
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk

16 October 2019

Dear Khalid,

RE: ETHICS APPLICATION–HSR1920-001 – Prospective investigation of clinical, biomechanical and physiological measurements of ankle function.

Based on the information that you have provided, I am pleased to inform you that application HSR1920-001 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Andrew Clark
Deputy Chair of the Research Ethics Panel

Appendix E

<u>استبيان</u>

١- **<u>المعلومات الشخصية</u>**

١- **الرمز:** ....

٢- **العمر:**...............................

٣- **الوزن:**............................

٤- **الطول:** ....

٥- **القدم المفضلة:** القدم اليمنى 1 القدم اليسرى 1

٢- **<u>معلومات اضافية</u>**

أ- فضلا حدد مستوى نشاطك الحالي:

نشيط 1 متوسط 1 غير نشيط 1

ب- فضلا حدد نوع شدة التمرين البدنية الذي تمارسه في الميدان:

شديدة 1 متوسطة 1 خفيفة 1 أخرى 1 . ...

ت- فضلا اعط مثال على اهم التمارين الأسبوعية في الميدان.

....

ث- إذا كنت تدخن، كم عدد السجائر التي تدخن في اليوم (........)

** فضلا أجب على الأسئلة التالية بـ <u>(نعم أو لا)</u> :*

.٣	هل تتناول حاليا اي دواء قد يؤثر على قدرتك على المشاركة في القياسات اللياقية والبدنية؟	**نعم**	**لا**
.٤	هل تعاني من اضطرابات القلب والأوعية الدموية؟ أو سابقا عانيت من اي وقت مضى مثل الم في الصدر، أو مشاكل في القلب، والكوليسترول الخ. ؟	**نعم**	**لا**
.٥	هل تعاني أوعانيت في وقت مضى من ارتفاع/انخفاض ضغط الدم؟	**نعم**	**لا**

٦.	هل احتجت لاستشارة وتوصية طبيب للقيام بنشاط بدني محدد؟	**نعم**	**لا**
٧.	هل اصبت بالزكام أو الحمى في الأسبوعين الماضيين؟	**نعم**	**لا**
٨.	هل فقدت اي وقت مضى التوازن بسبب الدوخة او الدوران، أو هل فقدت اي وقت مضى الوعي ؟	**نعم**	**لا**
٩.	هل تعاني من اضطرابات تنفسية؟ علي سبيل المثال الربو، التهاب القصبات الخ.	**نعم**	**لا**
١٠	هل تتلقي حاليا المشورة من مستشار طبي أو اخصائي العلاج الطبيعي **عدم** المشاركة في النشاط البدني بسبب الام الظهر أو اي مشاكل العضلات والمفاصل أو العظام ؟	**نعم**	**لا**
١١	هل تعاني ، ام انك عانيت من مرض السكري من قبل ؟	**نعم**	**لا**
١٢	هل تعاني ، ام انك عانيت من اي وقت مضي من الصرع/النوبات ؟	**نعم**	**لا**
١٣	هل اصبت في التواء القدم والكاحل من قبل؟ إذا كان الجواب **نعم، يرجى الإجابة علي السؤال** رقم ١٤.	**نعم**	**لا**
١٤	هل تواجه التواء في القدم والكاحل بصفة متكررة؟ **نعم 1 لا 1** متى كان متى كانت اصابتك الأخيرة في التواء القدم والكاحل؟ < شهران ◯ ٢-٤ شهرا ◯ ٤-٦ شهرا ◯ ٦-٩ شهرا ◯ ٩-١٢ شهرا ◯ ١٢-١٨ شهرا ◯ ١٨-٢٤ شهرا ◯ اي قدم أصيبت بالإلواء؟ **القدم اليمنى 1 القدم اليسرى 1 كلاهما 1**	**نعم**	**لا**
١٥	هل لديك أي سبب لم يذكر أعلاه، لا يجب ان تقوم بنشاطات بدنية؟ علي سبيل المثال إصابة في الراس	**نعم**	**لا**

	(خلال ١٢ شهر الماضي)، أوصداع الكحول، أو إصابة العين أو اي شيء آخر.		
١٦	هل لديك اي حساسية من شريط عاكس لاصق على الجلد لمدة ١٠ دقائق لغرض البحث العلمي؟	**نعم**	**لا**

Appendix F

ورقة معلومات المشاركين

عنوان الدراسة

بين اليوم موثوقية القياسات السريرية والميكانيكية الحيوية والفسيولوجية لوظيفة الكاحل.

أود أن أدعوكم للمشاركة في دراسة بحثية في جامعة حائل. قبل أن تقرر ، تحتاج إلى فهم سبب إجراء البحث وما الذي سينطوي عليه بالنسبة لك. لذا ، يرجى قضاء بعض الوقت في قراءة المعلومات التالية بعناية. يمكنك طرح أسئلة حول أي شيء تقرأه إذا لم يكن هذا واضحا بالنسبة لك أو ترغب في الحصول على مزيد من المعلومات.

ما هو الغرض من الدراسة؟

نحن نخطط لدراسة مستقبلية كبيرة تبحث في عوامل الخطر الناجمة عن التواء الكاحل. في السابق ، كانت المعدات المستخدمة باهظة الثمن وتستغرق وقتا طويلا ولن تسمح بجمع عينة كبيرة بسرعة. لذلك ، نود في هذه الدراسة تقييم موثوقية القياسات الميكانيكية الحيوية والوظيفية والفسيولوجية التي من المخطط استخدامها في الاختبار واسع النطاق. سنقوم بتقييم موثوقية التدابير في وقتين مختلفين لضمان إمكانية استخدامها بدقة.

هل أنا مؤهل للدراسة؟

نحن نبحث عن الأفراد الذين هم أحرار من إصابة الأطراف السفلية (على مدى عام واحد) ونشطون بدنيا إذا كنت كلاهما من هؤلاء ، فستكون مؤهلا للدراسة.

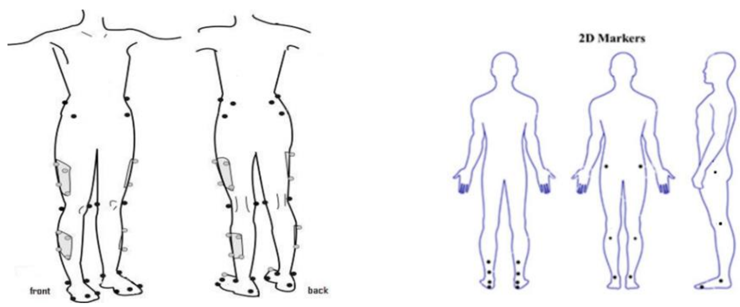
هل يجب على المشاركة؟

الأمر متروك لك لتقرر المشاركة أم لا. بعد قراءة ورقة المعلومات هذه ، سنشرح لك الدراسة ونراجع ورقة المعلومات هذه. إذا كنت لا تزال على استعداد للمشاركة ، فسوف نطلب منك التوقيع على نموذج موافقة. ومع ذلك ، إذا كنت لا ترغب في المشاركة ، فلن تضطر إلى ذلك. يمكنك أيضا الانسحاب من الدراسة بمجرد موافقتك في أي وقت ، دون إعطاء سبب لذلك.

ماذا سيحدث لي إذا شاركت؟

سيطلب منك زيارة مختبر تحليل الحركة في أي من مختبر تحليل الحركة في جامعة حائل مرتين منفصلتين (ستكون جلسة التقييم الأولى في الزيارة الأولى وجلسة التقييم الثانية بعد أسبوع). سيطلب منك أداء مهام الهبوط والقفز الجانبي وتقييم قوة العضلات ونطاق الحركة (ROM) لأطرافك السفلية والتحقيق في خصائص عضلات الكاحل والأربطة عن طريق الموجات فوق الصوتية. ستكون كل جلسة اختبار حوالي ٢ ساعة وسيتم تكرارها بعد سبعة أيام. سيتم تسجيل قياسات ديموغرافية بسيطة مثل كتلتك وطولك إلى جانب الفحوصات السريرية الروتينية لأطرافك السفلية. سيتم إرفاق علامات عاكسة (الشكل ١)

بمواقع مختلفة من أطرافك السفلية لتتبع حركات الأطراف السفلية أثناء المهام إلى جانب أقطاب كهربائية صغيرة لقياس نشاط عضلاتك. في المحطة الأولى ، سيطلب منك الهبوط من ارتفاع الصندوق (٣٠ سم) والقفز الجانبي. خلال المهام ، ستقوم أنظمة الحركة D٢ و D٣ (أربع كاميرات فيديو ل D٢ و ١٠ كاميرات فيديو ل D٣) بتسجيل حركة أطرافك السفلية.



الشكل ١: موقف علامات D٣ و D٢

ثم سيطلب منك الانتقال إلى المحطة الثانية حيث سيتم تقييم قوتك باستخدام مقياس الدينامومتر المحمول (HHD)). مع الأجهزة ، سيطلب منك تطبيق قوة قصوى لمدة ٥ ثوان في اتجاهات مختلفة دون أي حركة في الطرف. أولا ، من وضع ضعيف مع تمديد الورك والركبة ، سيطلب منك تطبيق أقصى قدر من القوة باستخدام عضلات الكاحل في أربع حركات ضد HHD (الشكل ٢) لمدة ٥ ثوان وتكرارها لمدة ٣ مرات مع راحة ١٠ ثانية بينهما. سيتم بعد ذلك استخدام نفس الإجراء لتقييم خاطفي الورك والباسطات مع تغيير وضع المشارك للوقوف على خاطف الورك والوضع المحمول باليد على نفس المستوى مقابل اتجاه القوة. سيتم تقييم خاطفي الورك والباسطة من وضع الوقوف مع وضع HHD أفقيا بالقرب من الركبة الانضمام في اختطاف الورك ونفس الإجراء مع باسطة الورك بعد وضع HHD الخلفي فوق مفصل الركبة. ثم سيطلب منك إجراء نفس التقييم لمدة ٥ ثوان.

الشكل ٢: HHD.

<u>ما الذي أحتاج إلى إحضاره معي؟</u>

يجب عليك إحضار ملابسك الرياضية (قصيرة وقميص) في يوم التجربة.

ما هي العيوب والمخاطر المحتملة للمشاركة؟

هناك خطر متأصل في أي نوع من الاختبارات ، ولكن الاختبار لهذه الدراسة سيكون في بيئة مختبرية خاضعة للرقابة وهي مهام يتم تنفيذها بشكل متكرر وبالتالي فإن الخطر ضئيل للغاية.

هل ستبقى بياناتي سرية؟

نعم، يتم الحرص الشديد على حماية سرية المعلومات المقدمة لنا. المعلومات التي يتم جمعها هي لأغراض البحث ويتم التعامل معها وفقا للائحة العامة لحماية البيانات في الاتحاد الأوروبي (GDPR) لعام ٢٠١٨. سيتم التعامل مع أي معلومات يتم الحصول عليها فيما يتعلق بهذه الدراسة على أنها مميزة وسرية. سيتم إخفاء هوية جميع المعلومات البحثية بحيث لا يمكن التعرف عليك ، إلا من خلال نموذج ورقي واحد مكرر سيتم تخزينه بشكل آمن في خزانة ملفات قابلة للقفل في جامعة حائل. سيتمكن فريق البحث الذي يحتاج إلى مراجعة سير بحثنا من الوصول إلى النماذج التي يمكن تحديدها. سيتم تحليل البيانات لإكمال الدراسة على النحو المبين أعلاه. سنحتفظ أيضا بالبيانات لمدة ٣ سنوات على الأقل وقد نستخدمها في الدراسات المستقبلية. على سبيل المثال ، قد نرغب في الجمع بين البيانات من هذه الدراسة وبيانات الدراسات المستقبلية لتمكيننا من استخدام تقنيات تحليل أكثر قوة.

هل هناك أي نفقات ومدفوعات سأحصل عليها؟

ستحصل على ١٠٠ ريال سعودي لكل جلسة للمشاركة في تعويضك عن وقتك وسيعطى ذلك في نهاية الدورة الثانية.

ماذا سيحدث إذا لم أستمر في الدراسة؟

أنت حر في الانسحاب من الدراسة في أي وقت. سنستخدم البيانات التي تم جمعها بالفعل في التحليل المستقبلي ما لم تطلب منا عدم القيام بذلك في غضون أسابيع ٢ من حضورك إلى مختبر تحليل الحركة.

ماذا سيحدث لنتائج الدراسة البحثية؟

سيتم استخدام نتائج الدراسة في أطروحة الدكتوراه للباحث وتقديمها أيضا للنشر في المجلات الطبية وفي المؤتمرات. بالإضافة إلى ذلك ، ستساعد النتائج على إثراء دراسة مستقبلية تبحث في هذه القضايا على مدى فترة طويلة. إذا كنت ترغب في ذلك ، يمكننا أن نرسل لك ملخصا للنتائج عند الانتهاء من الدراسة. لن يتم تحديد هويتك في أي تقرير / منشور ما لم تكن قد أعطيت موافقتك.

بمن أتصل إذا كان لدي أي أسئلة؟

إذا كان لديك أي أسئلة حول هذه الدراسة يرجى الاتصال ب:

Xxxxxxx

xxxxxx

بمن أتصل إذا كانت لدي شكوى؟

إذا كان لديك قلق بشأن أي جانب من جوانب هذه الدراسة ، فيجب أن تطلب التحدث إلى الباحثين الذين سيبذلون قصارى جهدهم للإجابة على أسئلتك. إذا كنت لا تزال غير سعيد وترغب في تقديم شكوى رسمية ، فيمكنك القيام بذلك عن طريق الاتصال برئيس الموافقة الأخلاقية للبحوث الصحية :

البروفيسورة سوزان ماكاندرو

رئيس لجنة الموافقة الأخلاقية للبحوث الصحية

s.mcandrew@salford.ac.uk

0161 295 2778

شكرا جزيلا لكم على الوقت الذي استغرقتموه لقراءة هذه الوثيقة وشكرا جزيلا على مشاركتكم.

XXXXXXXXXXXX

العنوان: XXXXXXXXXXXX

XXXXXXXXXXXXXXXXXXXX

الهاتف: XXXXXXXXX , البريد الإلكتروني: XXXXXXXXXX

Appendix G

The results of biomechanical variable during lateral hopping at 200ms Pre IC and 300ms post IC showed ICC ranged between 0.67 to 0.98 with SEM ranging between 1.61 to 5.90. Knee pre IC minimum showed maximum ICC 0.98 with SEM 1.26 and knee post IC maximum showed minimum ICC 0.67 with SEM 3.25.

Table 4.13 : The results for the lateral hop (LH) data pre-IC 200 ms to post-IC 300 ms.

2D during LH (º)	ICC	Mean 1	Mean 2	SD	SEM	MDD
Pre-IC min ankle x	0.71	-9.97	-8.36	6.69	3.60	9.98
Pre-IC max ankle x	0.74	6.23	7.53	6.34	3.24	8.97
IC ankle x	0.87	-6.53	-5.57	7.37	2.66	7.36
Post-IC min ankle x	0.85	-3.69	-2.51	6.96	2.70	7.48
Post-IC max ankle x	0.73	18.47	20.32	5.63	2.93	8.11
Pre-IC min ankle y	0.70	-6.77	-8.75	10.78	5.90	16.36
Pre-IC max ankle y	0.81	30.15	28.35	8.06	3.52	9.74
IC ankle y	0.75	3.25	1.56	5.42	2.71	7.51
Post-IC min ankle y	0.82	-1.82	-3.36	5.18	2.20	6.10
Post-IC max ankle y	0.84	9.82	8.57	4.89	1.95	5.42

Pre-IC min knee x	0.98	25.92	24.81	8.88	1.26	3.48
Pre-IC max knee x	0.97	76.20	75.66	11.16	1.93	5.36
IC knee x	0.97	24.95	24.80	8.91	1.54	4.28
Post-IC min knee x	0.92	22.54	22.02	7.08	2.00	5.55
Post-IC max knee x	0.90	45.26	45.61	7.49	2.37	6.57
Pre-IC min knee y	0.89	-12.66	-13.62	8.87	2.94	8.15
Pre-IC max knee y	0.79	-0.02	-0.94	7.81	3.58	9.92
IC knee y	0.92	-7.34	-6.02	5.68	1.61	4.46
Post-IC min knee y	0.86	-10.44	-12.30	6.57	2.46	6.81
Post-IC max knee y	0.67	-0.49	-2.52	5.66	3.25	9.02

LH: *Lateral hop.* ***°:*** *Degree.* ***Pre-IC:*** *Pre-initial contact of the ground.* ***Post-IC:*** *Post-initial contact of the ground.* ***IC:*** *initial contact of the ground.* ***x:*** *Sagittal angles.* ***y:*** *Frontal angles.* ***Max:*** *maximum angle during the phase.* ***Min:*** *Minimum angle during the phase.*

Table 4.13 : The results for the single leg landing (SLL) data pre-IC 200 ms to post-IC 300 ms.

The results of biomechanical factors during single leg landing at 200ms pre-IC and 300 ms post-IC showed ICC ranging between 0.64 to 0.97 and SEM from 0.75 to 4.69. Knee IC in sagittal plane showed maximum ICC 0.97 with SEM 0.75 and ankle post maximum IC in frontal plane showed minimum ICC 0.64 with SEM 2.83.

2D during SLL (º)	**ICC**	**Mean 1**	**Mean 2**	**SD**	**SEM**	**MDD**
Pre-IC min ankle x	0.90	-23.51	-21.76	6.12	1.93	5.36
Pre-IC max ankle x	0.94	1.44	1.33	5.71	1.40	3.88
IC ankle x	0.88	-18.91	-16.69	6.21	2.15	5.97
Post-IC min ankle x	0.87	-12.94	-10.70	5.81	2.10	5.81
Post-IC max ankle x	0.84	22.28	22.78	5.12	2.05	5.67
Pre-IC min ankle y	0.74	-12.72	-12.75	9.19	4.69	12.99
Pre-IC max ankle y	0.80	10.31	8.83	7.03	3.14	8.71
IC ankle y	0.68	5.10	3.48	5.30	3.00	8.31
Post-IC min ankle y	0.85	-15.89	-17.10	6.77	2.62	7.26
Post-IC max ankle y	0.64	1.67	-0.21	4.71	2.83	7.84

Pre-IC min knee x	0.96	7.12	7.91	4.58	0.92	2.54
Pre-IC max knee x	0.83	53.06	56.89	7.24	2.99	8.28
IC knee x	0.97	10.57	10.69	4.36	0.75	2.09
Post-IC min knee x	0.96	13.17	13.23	4.44	0.89	2.46
Post-IC max knee x	0.93	51.93	52.67	6.46	1.71	4.74
Pre-IC min knee y	0.79	-4.65	-5.47	4.11	1.88	5.22
Pre-IC max knee y	0.75	1.30	1.02	3.87	1.93	5.36
IC knee y	0.82	-2.34	-2.32	4.18	1.77	4.92
Post-IC min knee y	0.82	-6.80	-7.32	5.57	2.36	6.55
Post-IC max knee y	0.78	2.21	2.05	4.77	2.24	6.21

SLL: Single leg landing. **°***: Degree.* ***Pre-IC:*** *Pre-initial contact of the ground.* ***Post-IC:*** *Post-initial contact of the ground.* ***IC:*** *initial contact of the ground.* ***x:*** *Sagittal angles***.** ***y:*** *Frontal angles.* ***Max:*** *maximum angle during the phase.* ***Min:*** *Minimum angle during the phase.*

Appendix H

Supportive course and modules

Course	Date
○ Induction	08-08-2018
○ Ethics	24-10-2018
○ Delays Europe training for EMG	14-03-2019
○ Qualisys Workshop	02-10-2018
○ Ultrasound course	17-07-2019

Appendix I

Research Poster

Participants needed for research study

We are looking for individuals who are physically active without any previous lower extremity, ankle, back injuries or surgery to take part in our study at the University of Ha'il.

We need volunteers to participate in some physical tests, which involve Landing and lateral hopping, and a measurement of your ankle and hip muscle strength.




Your participation would involve one session for approximately 2 hours and will be repeat seven days later at motion analysis laboratory

If you would like to take part or if you have any further questions, please contact me:

XXXXXXXX

XXXXXXXXX@edu.salford.ac.uk

Appendix J

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	
METHODS			
Protocol and registratio	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	

n			
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	

Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	

Section/topic	**#**	**Checklist item**	**Reported on page #**
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence	

		intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

Page 2 of 2

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic

Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.