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The Effects of a Lateral Ankle Sprain on Balance and Jumping Performance in Varsity Athletes

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The Effects of a Lateral Ankle Sprain on Balance and Jumping Performance in Varsity Athletes

By

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THESIS

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ABSTRACT

The objective of this study was to investigate the effects of a lateral ankle sprain(s) on balance and jumping performance in varsity athletes. Clinicians often use subjective balance and jumping tasks during the rehabilitation process as criteria for returning an athlete to sport. There is a high recurrence rate of lateral ankle sprains with ongoing reports of mechanical and/or functional ankle instability often leading to chronic ankle instability. Perhaps including objective kinetic and kinematic measurements in the course of rehabilitating an ankle sprain injury may provide further information regarding the recovery process of the athlete.

Participants in this study included varsity athletes with and without a history of ankle sprains. A total of 65 participants (age 19.9 ± 1.43 years) were baseline tested using a balance and jumping task. This study was unique in design as it used a repeated measures model where each participant acted as their own control. Twelve (12) athletes (age 19.7 ± 1.5 years) were asked to repeat the baseline testing at two different time points after sustaining a lateral ankle sprain: 1) immediately following injury and 2) at time of return-to-play. Participants were tested using static and dynamic tasks while barefoot for a total of 17 trials. Twelve (12) infrared markers were placed on the participants to estimate centre of mass motion. The static task was a single leg balance task with eyes closed for thirty seconds. The dynamic task was a single leg jump and landing movement with eyes open. Objective measures used to compare baseline results to return-to-play results for the standing task included: the root mean square (RMS) of the centre of pressure (COP), centre of pressure velocity (COPv), centre of mass (COM), centre of mass velocity (COMv) in both medial / lateral (M/L) and anterior / posterior (A/P) directions and the COM-COP maximum for both M/L and A/P. Objective measures used for the jump task

included: force loading rates, force impulses, jump height and time-to-stabilize after landing. Athletes completed two self-reported outcome instruments, The Foot and Ankle Disability Index which evaluates functional activities of daily living and sport-specific tasks prior to injury and at return-to-play.

This study provides evidence that athletes who sustained a lateral ankle sprain did not demonstrate any significant deficits when assessed in the return to play phase for the standing balance task. The jumping and landing task provides support that the impulse created during take-off during baseline (0.230 BW*s) was higher compared to return-to-play (0.223 BW*s). The second impulse measured upon landing was also higher at baseline (0.24 BW*s) and lower after sustaining a lateral ankle sprain at return-to-play (0.22 BW*s). This suggests that the athletes may employ an alternate landing strategy in order to dissipate force away from the ankle when landing. The overall performance of the task as measured by jump height did not change.

The sport scale portion of the questionnaire yielded significant findings. The return-to play scores (84.5 ±17.14) were significantly lower as compared to baseline scores (96.2 ± 9.23), ($p=0.0498$).

These measurable results show that athletes who have sustained a lateral ankle sprain did not return to their baseline pre-injury state with respect to the chosen standing and jump performance variables. Previous research has found deficits after sustaining an injury however those studies typically compare to a control group as opposed to the same individual. Since ankle sprains are the most common musculoskeletal injury, these are important findings for both the athlete and clinicians. These results suggest that incorporating a more quantifiable and sophisticated evaluation using functional movements post-injury could identify existing deficits and thereby be addressed more comprehensively prior to returning an athlete to competition.

Further research investigating biomechanical and functional changes that occur after injury may lead to improved rehabilitation protocols.

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GLOSSARY OF TERMS

Analysis of variance (ANOVA)
- An inferential statistical procedure used to test differences between means

Centre of Mass (COM)
- Point around which the mass and weight of a body are equally balanced, no matter how the body is positioned. Determined by finding the weighted average of the centre of mass of each body segment

Center of Pressure (COP)
- Represents a single point of application where all of the ground reaction forces are being applied back on the foot. Pressure is equal and opposite to the force being applied to the ground and is measured by a force plate

Chronic Ankle Instability (CAI)
- Denotes the occurrence of repeated bouts of lateral ankle instability resulting in numerous ankle sprains (Hertel, 2002)

Content validity
- The extent to which the domain of interest is comprehensively sampled by the items in the measure (Eechaute, 2007)

Construct Validity
- The extent to which scores relate to other measures in a manner that is consistent with theoretically derived hypothesis concerning the domains that are measured (Eechaute, 2007)

Eversion
- An anatomical term defining movement of the foot occurring at the subtalar joint. The sole of the foot faces away from the midline of the body

Force platform
- An instrument that measures reaction forces in three-dimensions and moments about three axes

Functional ankle instability (FAI)
- Refers to a subjectively perceived instability during daily or sportive activities (Gehring, 2013)

Ground reaction force (GRF)
- Reactive forces provided by the ground that are equal in magnitude and opposite in direction to forces applied to the ground by an individual (Newton's III law). Measured using a force plate in the antero-posterior, medio-lateral and vertical components and reported in Newtons

Impact peak
- The initial peak on a vertical ground reaction force

Impulse
- The product of a force and the time interval over which the force acts; expressed as Ns (Hall, 2007)

Inversion
- An anatomical term defining movement of the foot occurring at the subtalar joint. The medial aspect of the foot faces towards the midline of the body

Kinematics

- The description of a body's motion without referring to the forces that caused the motion. The form, pattern, or sequencing of movement with respect to time

Kinetic

- The description of a body's motion with respect to the forces that caused the motion

Lateral Ankle Instability

- The existence of an unstable ankle due to lateral ligamentous damage caused by excessive supination or inversion of the rearfoot. This term does not differentiate whether the instability is acute or chronic (Hertel, 2002)

Mechanical ankle instability (MAI)

- This occurs as a result of anatomical changes after an initial ankle sprain, which lead to insufficiencies that predispose the ankle to further episodes of instability (Hertel, 2002)

Postural Control

- Involves controlling the body's position in space for orientation and stability

Postural Stability

- The ability to control the centre of mass in relation to the base of support

Postural Sway

- The phenomenon of constant displacement and correction of the position of the centre of gravity within the base of support

Proprioception

- The ability to sense stimuli arising within the body regarding position, motion and equilibrium

Prospective Study

- A study that starts in the present and continues forward in time

Rate of Loading

- How quickly the body has to absorb ground reaction forces

Reliability

- The extent to which the same results are obtained or repeated administrations of the same measure when no change in physical functioning has occurred (reliability) or the extent to how precise the scores are on repeated measurements (Eechaute, 2007)

Root mean square (RMS)

- A measure of variability. The larger the RMS, the more a person sways

Stability

- Resistance to disruption of equilibrium

Subtalar joint

- Formed by the inferior surface of the talus and the superior surface of the calcaneus. Movements of inversion and eversion occur at this joint

Talocrural joint

- A hinge joint formed between the inferior surface of the tibia and the superior surface of the talus. Movements at this joint are plantarflexion and dorsiflexion

Time to stabilization

- The time it takes for a system to return to the original or another state of posture when perturbed

1.0 INTRODUCTION

Optimal athletic performance relies on the finely-tuned integration of the body's many systems to produce highly skilled dynamic movement. An injury may jeopardize an athlete's ability to perform and compete at a high level. One of the most common musculoskeletal injuries experienced in a physically active population is a lateral ankle sprain (LAS) (Beynnon et al., 2006). In the United States, the occurrence of ankle sprains has been estimated at 23,000 – 25,000 per day (Wikstrom & Hubbard, 2010). More specifically, in an interscholastic and intercollegiate sporting environment, studies indicate that lateral ankle sprains account for 60% of all athletic injuries (Hootman et al., 2007). Due to the innocuous nature of this injury, many individuals, perhaps as high as 55%, do not follow a rehabilitation program designed by a healthcare professional (Wikstrom et al., 2013). Therefore the actual incidence of LAS may in fact be significantly higher.

The most commonly observed mechanism for a lateral ankle sprain in sport is landing from a jump with a plantar flexed and inverted ankle joint that exceeds physiological motion. This type of an excessive inversion mechanism accounts for approximately 85% of all ankle sprain injuries (Wexler, 1998). Alarmingly, the rate of recurrent injury is quite high with a potential re-injury rate ranging from 20-74% (Wikstrom & Hubbard, 2010) and upwards of 80% among athletes (Smith, 1986). If managed inappropriately, a lateral ankle sprain can lead to compensations that continue to stress the injured ligaments (Wikstrom et al., 2013). This type of injury may lead to complications such as chronic ankle instability or post-traumatic ankle osteoarthritis (OA) that adversely affects daily activities and sport performance.

There are a number of adverse implications following a lateral ankle sprain. Potential consequences of repeated lateral ankle sprains include a decreased ability to perform in sport and lateral or chronic ankle instability. Lateral ankle instability is thought to be caused by lateral ligamentous laxity due to excessive supination of the rearfoot (Hertel, 2002). Chronic ankle instability (CAI) is defined as "the occurrence of repetitive bouts of lateral ankle instability resulting in numerous ankle sprains" (Hertel, p.364, 2002). Multiple ankle sprains may change an athlete's body posture and affect their athletic performance negatively. As residual symptoms can linger, an athlete may not be able to train and compete fully. An ankle sprain can also affect an athlete's activities of daily living resulting in school or work absenteeism.

The purpose of this research study was to examine balance and jumping performance in varsity athletes after sustaining a lateral ankle sprain when returning to sport participation as compared to baseline measurements. The impetus of this study was to understand the effects of ankle injuries on biomechanical outcome measures and how this may inform a therapist's return-to-play decision for an athlete. The secondary purpose of this investigation was to build upon the existing evidence of the clinical use of a self-assessed outcome instrument.

1.1 Single Leg Stance

The ability to maintain balance during sport is critical for optimizing performance. Postural stability or balance is defined as the ability to control the centre of mass in relation to the base of support (Shumway-Cook, 2007). Factors that contribute to stability during a single leg stance include body alignment and muscle tone. The centre of pressure (COP) is a displacement measure indicating the path of the resultant ground reaction force vector on the force platform (Hamill, 1995). During a static one-legged stance eyes-closed task the displacement of the COP and the COP velocity in the medial / lateral and anterior / posterior directions can provide a measure of the individual's ability in maintaining stability in a single leg stance. COP is calculated using vertical forces divided by the moments that are the product of that vertical force multiplied by the distance from the axis. COP displacement is indicative of where the forces applied onto a supporting surface are distributed. During a single leg stance, the COP lies within that foot. The location of the COP under the foot is a reflection of the neural control of the ankle muscles (Winter, 1990).

COP velocity assesses temporal qualities of postural control where change of position is divided by time change. This is an indicator of how quickly a person shifts and is able to control the centre of pressure. The sensorimotor system, the system responsible for regulating balance, typically relies on input from three afferent systems: vestibular, somatosensory, and visual. When a person closes his or her eyes, the absence of visual information poses a greater threat to balance control thus increasing the difficulty level of the task. Research has established that there is a significant increase in COP displacement when eyes are closed, therefore a single leg balance task presents a greater challenge to a participant's ability to maintain postural control (Akbari et al., 2006, Ross et al., 2011).

The COM-COP provides information regarding the relationship between these two variables. The COP controls the COM and the comparison between the two can assess and describe the stability of an individual. Wikstrom (2010) conducted a systematic review and meta-analysis looking at 12 studies that assessed static balance for both the injured and non-injured ankle post-injury. Their findings provided "strong evidence that balance is bilaterally impaired after an acute lateral ankle sprain" (Wikstrom et al., p. 407, 2010). Interestingly, participants experiencing chronic ankle instability did not present with bilateral balance deficits. The suggestion from this article was to advise patients to perform balance training on both ankles following a lateral ankle sprain.

1.2 Single Leg Jump

A single leg jump is a common skill performed in many different sports that is likely affected by ankle sprains. The take-off portion of this task is proactive in that it is a voluntary initiated internal perturbation that is controlled and expected. The landing however may be unexpected due to changes in landing surface or a perturbation from an opponent. Analyzing this skill in this present study provides information regarding ground reaction forces during the take-off phase as well as the landing phase. Additionally, a jumping task performed in a laboratory setting is more functional in mimicking a dynamic sport specific movement. It was anticipated that participants would utilize feed-forward control. This refers to postural responses that are made in anticipation of a voluntary movement such as a jump. A single leg counter-movement jump was selected as the type of jump which maximizes jump height due to the stretch-shortening cycle as compared to a squat jump. This pre-stretch or eccentric loading of muscles during the countermovement of a jump has been shown to enhance force production during the jump itself (Linthorne, 2011). An upward arm swing was included as it has been found that the motion of the arms contributes 12-13% of the total upward momentum when jumping maximally (Lees & Barton, 1996).

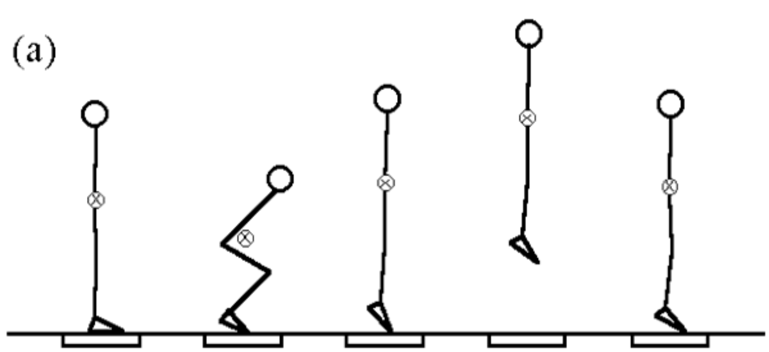


Figure 1: Sequence of movements in a countermovement jump
Reference: Linthorne, 2011, p.1199

The single leg jump and landing task can be divided into five phases (Linthorne, 2011).

1) The first phase is the counter movement production when the participant flexes the hip, knee and ankle and the centre of mass accelerates downward. The arms move behind the body in glenohumeral extension.

2) This is followed by the push-off or impulse phase where the participant moves upward by extending the hip and knees. The impulse is the product of force and the time interval over which the force acts (Hall, 2007). It is the area underneath the force-time curve that represents the force that the body is creating for the countermovement prior to jumping. This is the force required to move the centre of mass from the ground and allow the participant to overcome body weight. The arms move forward into glenohumeral flexion. The rate of loading during this phase is an important performance measure as it indicates how quickly an athlete can load and unload which may translate to more efficient movement. The rate of loading upon landing is equally as important as a higher rate indicates an inability to control the rate of weight acceptance and could result in increased stress on articular cartilage which covers the joint surfaces (Caulfield & Garrett, 2004). Over time this could lead to degenerative changes in the cartilage and eventual osteoarthritis.

3) The next phase is the flight phase when the ground reaction forces are equal to zero. The participant is essentially a projectile in free flight. The maximum peak of the jump is achieved in this phase followed by the descent of the flight phase where the participant’s centre of mass is moving downward and speed is increasing.

4) This is followed by the impact phase or landing phase where the foot first contacts the ground which is defined by a large vertical peak force. Ground contact during landing is

initiated by the forefoot. If the peak is higher, it is indicative that the participant is not dissipating energy well.

5) Lastly is the stabilization phase where the ground reaction forces become close to or equal to body weight as the participant attempts to return to a stable, motionless position. A system is said to be stable if it returns to the original or another state of posture or motion when perturbed.

1.3 Foot and Ankle Disability Index (FADI) + Sport Scale

It is important to gain an awareness of an athlete's subjective perception of the recovery process from injury and how he or she is managing activities of daily living as well as more challenging physical activities. Although clinicians may focus on physical impairments such as strength deficits or decreased range of motion, it is imperative that subjectively perceived functional limitations are also addressed. In a study that reviewed the reliability and sensitivity of patient's subjective concerns, Hale noted that "because functional limitations and disability are commonly most important to the patient, it is essential that clinicians quantify dysfunction at this level" (Hale & Hertel, p.35, 2005). Hale investigated the reliability and sensitivity of the FADI using recreationally active individuals. It was found that the FADI demonstrated construct validity; it was reliable in detecting functional limitations in subjects with chronic ankle instability (CAI) and the index was responsive to improvements in function after completion of a rehabilitation program (Hale & Hertel, 2005). Self-reported outcome instruments can be either discriminative (identify individuals with a disorder) or evaluative (measure change over time) (Kirshner, 1985). Two evaluative questionnaires were administered to participants in hopes of gleaning insight into an athlete's perception of functional abilities throughout rehabilitation, daily activities, and return to play (appendix D & E).

1.4 Literature Review

There is a substantial body of literature that has investigated prevention, diagnosis, and treatment of lateral ankle sprains. Much of the research focuses on the many changes that occur following an ankle sprain. There is a myriad of studies looking at risk factors that are predictive of ankle sprains (Beynnon et al., 2002). Additionally, research has examined many varying intervention programs relating to immobilization, rehabilitation and exercises after an ankle sprain occurs (van Os et al., 2005). Due to the anatomical and physiological complexity of this injury, research tends to focus on isolated outcome measures as opposed to overall function and performance. For example, many studies have investigated the change in variables such as; strength, muscle reaction times, postural stability, proprioception and biomechanics following an ankle sprain injury (Hiller et al., 2011). There have been a limited number of studies comparing an athlete's pre-injury balance abilities to those same abilities following a lateral ankle sprain.

The ankle joint is comprised of two main joints; the talocrural joint and the subtalar joint. The talocrural joint is a uniaxial, modified hinge, synovial joint. The dome shaped superior aspect of the talus articulates within the mortise of the distal ends of the tibia, fibula and the transverse ligament. This joint is surrounded by a fibrous capsule. When describing movements of a joint, a distinction is made between osteokinematic movement and arthokinematic movement (Donatelli & Wooden, 2010). Osteokinematic movement defines the overall motion of two bones, for example; flexion and extension. Arthrokinematic movement is the motion that actually occurs at a joint between two bones, for example: roll, spin and glide. These accessory movements are involuntary but necessary to achieve full range of motion. The osteokinematic motions at the talocrural joint are dorsiflexion and plantar flexion with normal ranges being 20 degrees and 50 degrees respectfully. During non-weight-bearing dorsiflexion, the talus wedges into the mortise via a posterior roll and glide. During non-weight-bearing plantar flexion, the talus glides and rolls anteriorly.

There are two articulations between the calcaneus and the talus; one anterior and one posterior. The posterior joint is termed the subtalar joint or talocalcanean joint. It is the articulation between the concave posterior calcaneal facet on the inferior surface of the talus and the convex posterior facet on the superior surface of the calcaneus. It is also surrounded by a fibrous capsule and supported by lateral, medial and interosseous talocalcaneal ligaments. The anterior joint is the talocalcaneonavicular joint. The normal range of motion at the subtalar joint is 20 degrees of inversion and 10 degrees for eversion (Standring, 2005). However, the osteokinematics of the subtalar joint are pronation and supination. Pronation is a combination of calcaneal eversion, abduction of the forefoot and dorsiflexion on the talus. Supination is a combination of calcaneal inversion, adduction of the forefoot and plantar flexion on the fixed talus. Normal pronation and supination are necessary during weight-bearing activities to provide shock absorption, foot adaptability to uneven terrain as well as a rigid foot for a powerful lever for propulsion during walking or running (Magee, 1997). Prolonged pronation or supination during gait may cause problems up the whole kinetic chain.

Also important when discussing the ankle joint is the inferior (distal) tibiofibular joint. This is a syndesmodic joint between the distal tibia and the lateral malleolus. The convex surface of the fibula articulates with a concave notch in the tibia. It is a fibrous joint without a joint capsule that has small accessory movements. For example, during dorsiflexion, the fibula should glide superiorly, laterally and anteriorly. Conversely, the fibula moves inferiorly, medially and posteriorly with plantar flexion. The tibia moves in the opposite direction of the fibula (Donatelli & Wooden, 2010). These movements allow for proper shock absorption of forces when the foot contacts the ground. Without proper accessory movements, shock is absorbed elsewhere in the body.

The anatomy of the lateral ligamentous complex consists of three main ligaments: the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL) and the posterior talofibular ligament (PTFL) (Standring, 2005; Figure 1). These ligaments in conjunction with the peroneal muscles play a major stabilizing role in prevention of excessive inversion at the subtalar joint. These lateral ligaments provide three main functions. First, they provide proprioceptive information for joint function; therefore, any injury to the ligaments may diminish this proprioceptive function. Second, these ligaments contribute to the stability of the talocrural and subtalar joints by preventing excessive motion particularly in the unloaded or planter flexed ankle joint. Lastly, these ligaments act as a guide to direct motion (Safran, 1999).

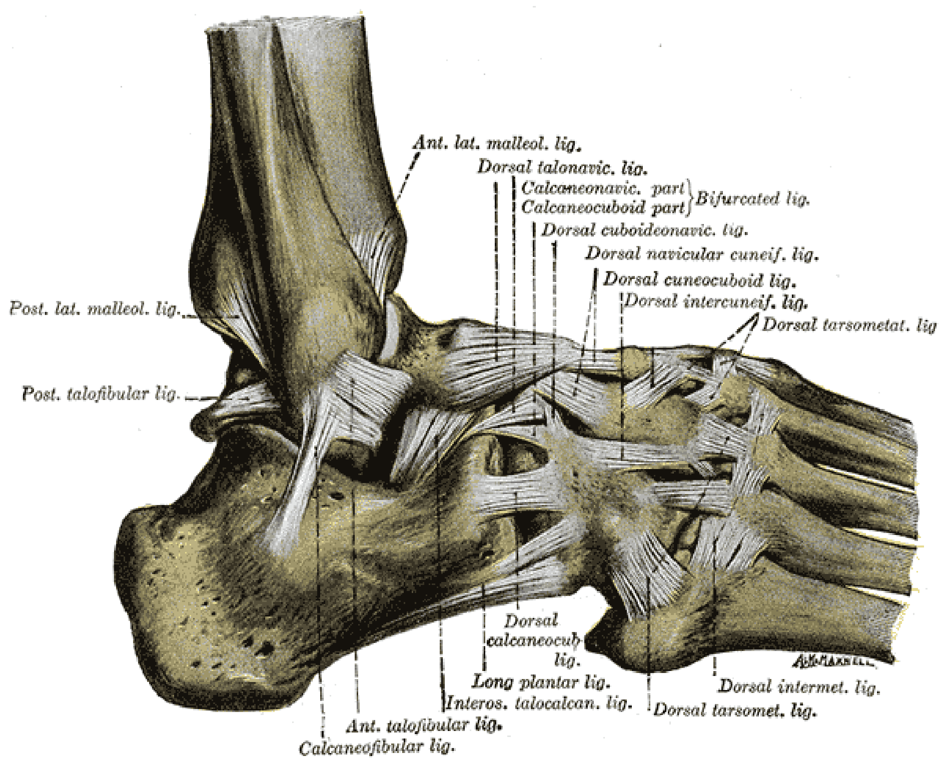


Figure 2: Ligaments of the Lateral Ankle Complex
Reference: Gray, Henry. *Anatomy of the Human Body.* Philadelphia: Lea & Febiger, 1918; Bartleby.com, 2000. www.bartleby.com/107/

A lateral ankle sprain is defined as an injury that stretches or tears fibres of a ligament(s). The degree of injury is typically graded I, II or III with grade one being mild, grade two being moderate, and grade three being severe (Mangwani et al., 2001). A lateral ankle sprain may not be limited to a disruption of the ligaments alone. Other structures such as muscle, tendon, capsule or bone can be damaged resulting in joint dysfunction throughout the ankle complex (Denegar & Miller, 2002). For instance, if an ATF ligament heals in a shortened position after sustaining a lateral ankle sprain, the fibula may not be able to glide superiorly with ankle dorsiflexion. Mechanically, it is critical to be able to achieve 10 degrees of dorsiflexion during mid-stance of gait. In a closed kinetic chain activity such as gait, dorsiflexion of the ankle occurs in midstance as an anterior roll of the tibia over a fixed foot. If this range is not available, the body will compensate often with the midtarsal joint unlocking or to provide more range of motion. The medial longitudinal arch will collapse to facilitate movement of the bodyweight overtop the stance leg. The foot then does not have time to re-supinate prior to toe-off. This results in a push-off phase with an unstable foot instead of a rigid lever. This leads to over-pronation which may lead to injuries such as plantar fasciitis, sesamoiditis or shin pain. Therefore, the glide of the tibia allows for stability of the normal ankle joint throughout the entire range of motion during gait. These mechanics directly influence articular cartilage nutrition, normal load distribution and joint lubrication.

Additionally, swelling can occur as a result of the stretching and / or tearing of the lateral ligaments of the ankle after a sprain. This swelling may spread proximally towards the interosseous membrane which is a structure that stabilizes the tibia and fibula together. The interosseous membrane carries the neural networks, blood supply and venous vessels to and from the foot and ankle. A restriction in motion of the tibia or fibula may compromise blood flow and neural innervation to the ankle.

As described, the anatomy and function of the ankle is quite complex. The transmission of ground reaction forces through the horizontal structure of the foot then change to vertical forces that travel through the ankle and lower leg. Therefore the foot and ankle serve as a very complex biomechanical structure that adapts to ascending forces coming from the ground and the descending force of gravity. A lateral ankle sprain injury may not only damage tissues but may also disrupt function.

Recording and tracking athletic injuries can be helpful in identifying trends and providing recommendations for injury prevention strategies. The National Collegiate Athletic Association (NCAA) collects standardized injury and exposure data for collegiate sports through an Injury Surveillance System (Hootman et al., 2007). In a summary of fifteen sports during the 1988-2004 seasons, ankle ligament sprains were the most common injury accounting for 15% of all reported injuries (Hootman et al., 2007). These were recorded during both practices and games. When looking at time trends in injury rates for ankle ligament sprains, the rates across sports appeared relatively stable. However, one in five ankle sprains resulted in ten or more days of time lost from sport indicating that this is an injury that requires appropriate treatment in order to avoid long-term sequelae (Hootman et al., 2007).

There have been a number of studies that have attempted to identify potential intrinsic and / or extrinsic risk factors that predict who will sprain an ankle (Beynnon et al., 2002, Willems et al., 2005, McHuge et al., 2006). A clear understanding of risk factors must be had in order to develop appropriate prevention programs. This body of literature has examined a number of intrinsic and extrinsic variables (Willems et al., 2005). Intrinsic factors or characteristics related to the individual include; balance or postural sway, hip and ankle strength, body mass index and gender. Extrinsic risk factors or environmental variables include; field conditions, volume of training, position played and foul play as predictors of ankle injuries. The majority of research has taken a retrospective approach to risk factor identification. That is, intrinsic factors have been evaluated after an ankle sprain has occurred. It is unknown however if deficits were present prior to injury occurrence (Willems et al., 2005).

McGuine (2000) looked at 210 high school basketball players over the course of two competitive seasons with the purpose of determining if a preseason measurement of balance while in a single leg stance with eyes open and closed could predict susceptibility to an ankle injury. Higher postural sway scores as defined by the average degrees of sway per second correlated with a 7-fold increase in ankle injuries as compared to athletes who had low sway scores. In contrast, Beynnon (2001) evaluated a number of collegiate level soccer, lacrosse, and field hockey players in their preseason. They did not demonstrate a relationship between postural sway scores and risk of ankle sprain. Therefore this body of predictive research is relatively inconclusive. Consistent predictors for an ankle sprain injury have not been identified, most likely because it is a multifactorial injury. The goal of this previous research was to identify potential athletes who may be at a higher risk of an ankle sprain injury and provide an intervention that could reduce the incidence of injury.

Not all clinicians have access to sophisticated equipment such as force plates; therefore a common non-instrumented clinical test used to evaluate balance is the Star Excursion Balance Test (SEBT; Figure 3). In this test, the participant maintains a base of support with one leg while reaching maximally in eight different directions with the opposite leg while maintaining balance on the stance leg (Hertel et al., 2006). The 8 directions extend out in a circle and reach distance is recorded for each direction (Hale et al., 2007). An additional balance assessment frequently used is the Balance Error Scoring System (BESS). It consists of three stance conditions (double, single and tandem) tested on compliant and non-compliant surfaces. Error scores such as changes in body position or touching down with the non-weight bearing leg are subjectively recorded by the examiner (Docherty et al., 2006). These evaluations are not typically performed on a force plate or tracked via a motion capture system therefore they lack accuracy as the clinician manually measures and records findings. The SEBT and the BESS may be a helpful test in a clinical setting but they do not provide enough quantitative data.

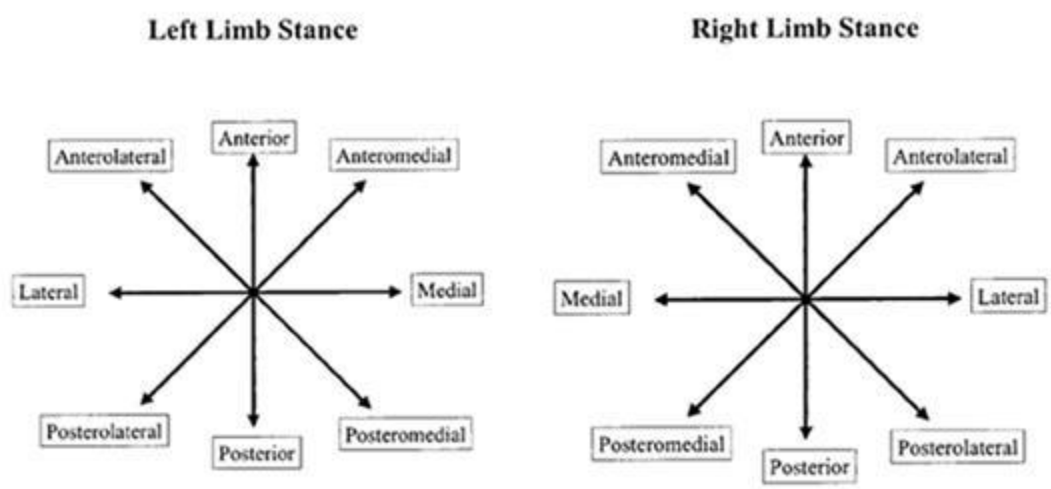


Figure 3: Star Excursion Balance Test
Reference: http://www.efdeportes.com/ Revista Digital - Buenos Aires - Año 14 - Nº 135 - Agosto de 2009

Another shortcoming of the current literature is that much of the ankle sprain research looks at low level activities such as gait initiation (Monaghan et al., 2005). The forces that occur in gait do not adequately represent the amplitude of force that the ankle joint will experience during athletic performance. Landing from a jump requires an athlete to dissipate extremely high ground reaction forces (GRF) in a short period of time. The ability to properly control and absorb these forces during functional activities may play a pivotal role in injury prevention.

Landing from a jump differs from running in that initial ground contact when landing from a jump is initiated with the forefoot. The forces involved in landing from a jump can vary between 2 to 12 times a person's body weight (Hargrave et al., 2003). In sport, it is common to observe an asymmetrical landing when only one foot contacts the ground which requires that single leg to absorb all of the forces. Additional external factors such as uneven playing surfaces or unexpected opponent contact may decrease an athlete's stability when landing from a jump.

There are a variety of studies that have examined jumping and landing (Wikstrom, 2007, Hargrave et al., 2003, Brown et al., 2012). Many of the jump studies utilize a drop jump technique (stepping off a box) which analyzes landing patterns only but fail to provide information on loading patterns or countermovement prior to jumping (Caufield & Garrett, 2004). These studies have chosen seemingly arbitrary box heights ranging from 32 cm to 40 cm. Other jump studies have employed various jumping techniques. Wikstrom (2007) had participants stand 70 cm from a force plate, jump off two legs and jump 50% of their maximal vertical leap and land on one leg. Caulfield (2004) examined ground reaction forces that occurred during a jump landing task in a functional ankle instability (FAI) group. Force plate data were collected 150ms post impact. Significant findings included a peak lateral force occurring 13 ms earlier versus a control group. There was also an increase of laterally directed forces measuring 5-15% of a person's body mass in the FAI group. These findings demonstrate that differences exist that may predispose a person to a repeated ankle sprain due to an increased load on the lateral ligamentous structures. These results were compared to a healthy population so it is unknown when and how these changes occurred in a functionally unstable group and how these findings would translate to athletic performance.

Motion of the proximal joints; knee, hip and trunk have been analyzed during landing from a jump in participants classified as having unstable ankles (Brown et al., 2012). Findings revealed that the FAI group showed less variability in knee and hip motions during a single leg jump landing. This may be a protective mechanism to avoid stress or injury at the ankle joint. The majority of studies compare a chronic ankle instability group to a healthy age-matched group as opposed to a repeated measures design in which the same participant is re-tested after sustaining a lateral ankle sprain.

A meta-analysis looking at 55 studies on ankle sprains summarized the current literature on the time to stabilization after jump and landing tasks (Hiller, 2011). The nature of many sports requires an athlete being able to jump high, land, stabilize and recover quickly. This meta-analysis found several studies that established a significantly higher time to stabilization when landing from a jump in participants with recurrent ankle sprains as compared to a healthy control group although there was little consensus on how this variable is best measured.

Lateral ankle sprains may appear as a seemingly mild musculoskeletal injury however the potential negative consequences of mismanagement can result in compensatory movement patterns and less than optimal healing of the injured ligaments. In a 2013 study looking at the treatment of lateral ankle sprains, Wikstrom noted that "if not managed appropriately, a cascade of negative alterations to both joint structure and a person's movement patterns continue to stress the injured ligament (Wikstrom et al., p.385, 2013). Figure 4 illustrates clearly that an ankle sprain may be more than a simple musculoskeletal injury with only local consequences. Indeed there may be ramifications in other systems such as the sensorimotor system that can lead to a continuum of disability (Wikstrom et al., 2013).

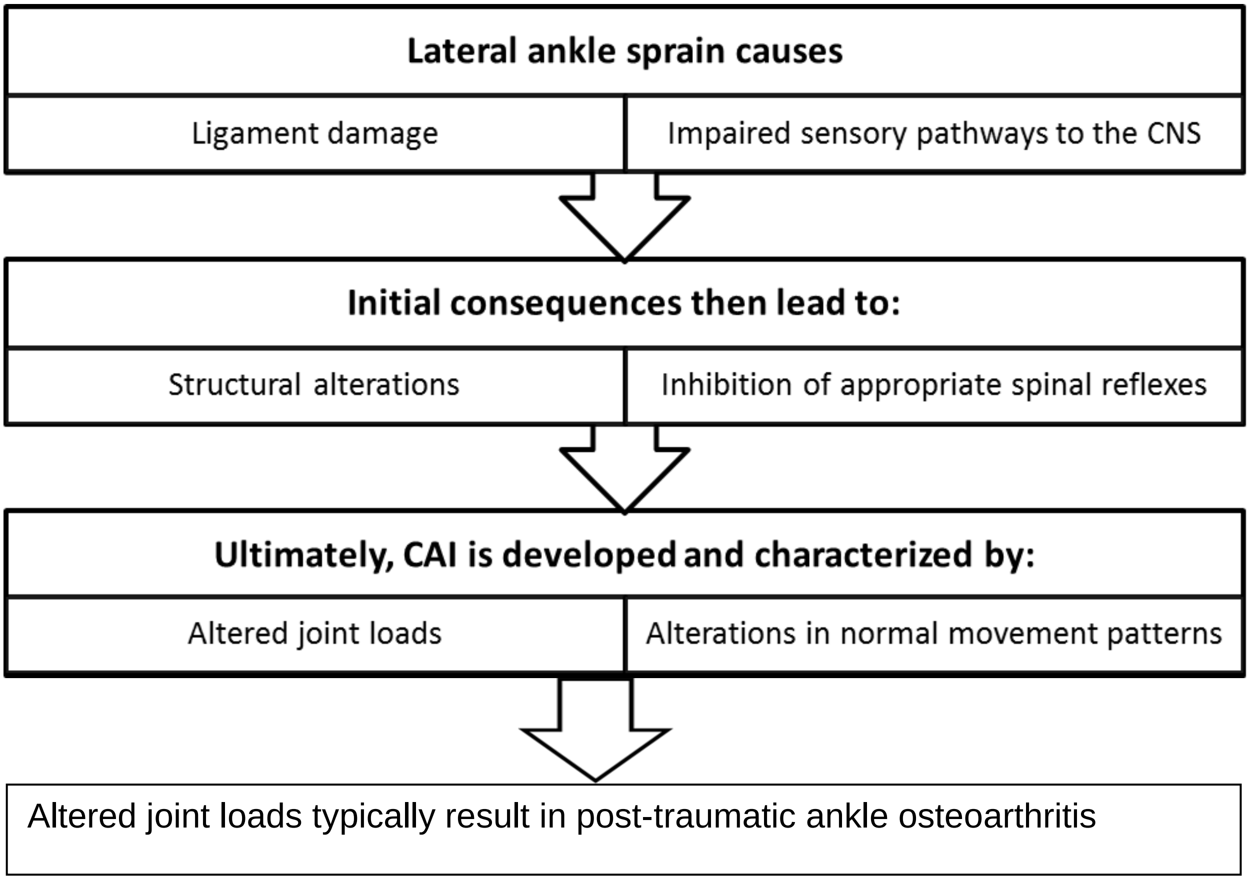


Figure 4: Hypothetical cascade of events that causes the development of CAI and post-traumatic ankle OA (Adapted from McKeon, 2012)

Chronic ankle instability (CAI) has been well researched but not well understood. CAI encompasses mechanical and functional instability (Figure 5). Mechanical instability includes pathologic laxity, arthro-kinematic restrictions as well as degenerative and synovial changes in the ankle joint. Functional instability consists of strength deficits, impaired proprioception and impaired neuromuscular and postural control (Hertel, 2002). It has been found that residual symptoms such as pain, swelling, decreased range of motion, weakness and instability can affect 55 – 72% of individuals up to 18 months after experiencing an ankle sprain (Hertel, 2002). The persistence of symptoms following an ankle sprain may prove frustrating for an athlete and result in missed practices and competitions as well as continued therapeutic treatment just to remain active (Denegar & Miller, 2002).

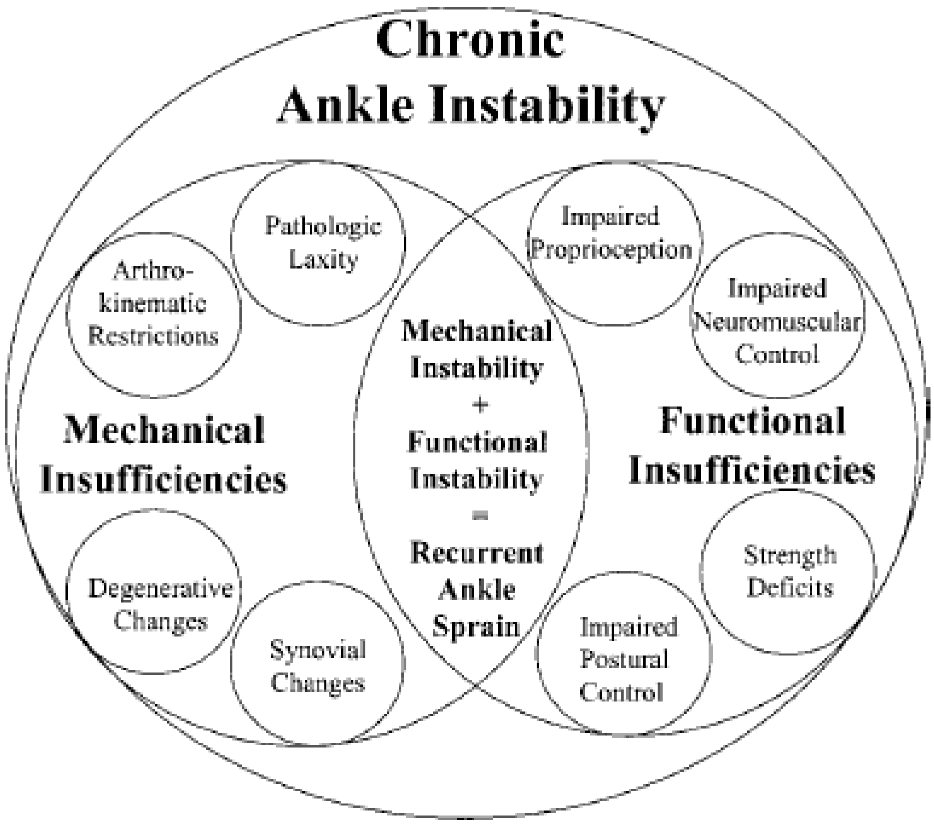


Figure 5: Chronic Ankle Instability (CAI) Diagram describing the paradigm of mechanical and functional insufficiencies that contribute to CAI. (From Hertel, 2002)

The literature cites a multitude of self-reported outcome instruments examining foot and ankle related conditions each with their own advantages and disadvantages (Martin & Irrgang, 2007). These questionnaires can be divided into two categories; one being discriminative and the other evaluative (Carcia et al., 2008). Discriminative tools are used to identify general foot and ankle-related disorders. Whereas evaluative instruments are used to measure change in health or injury status over time as well as measure the effectiveness of a treatment intervention (Martin & Irrgang, 2007). Some of the most common region-specific instruments are as follows;

- The Foot and Ankle Disability Index (FADI) + Sport Scale
- The Functional Ankle Ability Measure (FAAM)
- The Functional Ankle Outcome Score (FAOS)
- The Cumberland Ankle Instability Tool (CAIT)

Although there may not be a universally accepted instrument, the FADI was chosen because it specifically evaluated differences between baseline and return-to-play testing in athletes who sustained a lateral ankle sprain. The FAAM is identical to the FADI with the exception of excluding the items that assess pain and the ability to sleep. However, those items were deemed important as pain is a common subjective complaint reported by athletes. Removing those items allowed the FAAM to be used for more generalized musculoskeletal disorders of the lower leg, ankle and foot (Martin et al., 2005). The FAOS is an evaluative tool for assessing symptoms in individuals with generalized foot and ankle disorders (Eechaute et al., 2007). The CAIT was not selected in this research as it is discriminative in purpose. It provides cut-off values indicating functional ankle instability (FAI).

The Foot and Ankle Disability Index (FADI) is a region-specific self-report of function that was designed to assess functional limitations relating to chronic ankle instability (Martin, 1999). The FADI is a 26 item instrument listing various activities of daily living and provides a Likert-type scale of rating from zero (unable to do) to four (no difficulty at all) (Martin, 1999). It includes measures of signs (e.g., range of motion and strength) as well as symptoms (e.g., pain). Twenty two of the items address general daily activities and four items ask about pain also rated on a scale of zero (unbearable) to four (no pain). The FADI scores are recorded as a percentage of 104 points with 100% representing no dysfunction and lower scores representing greater disability. An additional sport scale was included that consisted of 8 items of increased physical exertion such as running, jumping, landing and cutting. The FADI sport scale is a population-specific subscale that appears to be more sensitive at detecting deficits in athletes (Hale & Hertel, 2005). These items are rated on the same Likert scale as the FADI and are recorded as a percentage of 32 points. In reviewing the reliability and responsiveness of these scales, it was concluded that they appear to be reliable in detecting functional limitations in subjects with chronic ankle instability (CAI) and responsive which detects changes in function after rehabilitation over time (Hale & Hertel, 2005).

1.5 Rationale for this study

There is a need to objectively examine an athlete in a healthy, non-injured state and then compare that same athlete to him / herself following a lateral ankle sprain. This thesis examines balance and jumping performance in varsity athletes after sustaining a lateral ankle sprain when returning to sport participation as compared to baseline measurements. The impetus of this study was to understand the effects of lateral ankle injuries on biomechanical outcome measures using functional tasks. The tasks in this research attempted to perturb the balance system and quantify the athlete’s response. The secondary purpose of this investigation was to build upon the existing evidence of the clinical use of a self-assessed outcome instrument.

1.6 Objectives

The overall arching research question was to determine if a varsity athlete returns to play at the same level of balance and jump performance as he / she was at baseline following a lateral ankle sprain.

1. Does a lateral ankle sprain have an effect on balance as evaluated by a single leg balance task?
2. Is there a difference in the pre-injury rate of loading patterns and force production as compared to post-injury data for the same participant during a single leg jump task?
3. Is it possible to quantify an athlete's subjective concerns using a region-specific questionnaire addressing functional capacity and correlate it to significant outcome measures?

1.7 Hypotheses

Upon return to play after sustaining a lateral ankle sprain, an athlete will experience the following as compared to their own pre-injury scores:

1. Decreased balance when standing on one leg with eyes closed. More specifically, an athlete sustaining a lateral ankle sprain will experience balance deficits in centre of pressure (COP) medial / lateral (M/L) and anterior / posterior (A/P) displacement and COP velocity M/L and A/P during a single-leg static balance task with eyes closed post-injury as compared to baseline data.
2. Decreased push-off capabilities during a jump. An athlete sustaining a lateral ankle sprain will produce an increased amount of impulse when cleared to return to play. An athlete sustaining a lateral ankle sprain will demonstrate a decreased rate of loading prior to jumping post-injury as compared to baseline data.
3. Decreased ability to stabilize after landing from a jump. An athlete sustaining a lateral ankle sprain will demonstrate an increased time to stabilization after completing a jump task.

4. Decreased performance in jump height. An athlete sustaining a lateral ankle sprain will demonstrate a decreased jump height post-injury even when return to play criteria has been met as measured by change in centre of mass.

5. Decreased subjective perception of daily and sport-related functional abilities. An athlete will score lower on the Foot and Ankle Disability Index + Sport Scale in comparison to pre-injury.

2.0 METHODOLGY

2.1 Participants:

Sixty five young healthy adult athletes were recruited from a sample of convenience from four Wilfrid Laurier University varsity teams (men's football, men's basketball, men's and women's rugby) and two Kitchener-Waterloo local club soccer teams to participate in this study (Table 2.1). Athletes were recruited from collision sports (football and rugby) and non-collision sports (basketball and soccer). The researcher approached the athletic therapists affiliated with the previously mentioned teams with an information letter and invitation to participate form to distribute to the athletes. These completed forms were collected by the researcher and potential participants were contacted in order to schedule a testing date. Overall, their ages ranged from 17 to 24 years (age, 20.0 ± 1.5 years). Weight ranged from 55.3 kg to 145.7 kg (weight, 86.1 ± 17.1 kg) and height ranged from 1.6 m to 2.03 m (height 1.83 ± 0.11 m). There were 58 males and 7 females who volunteered. Participant's baseline demographic and anthropometric data are presented in Table 2.1. Written informed consent, approved by the Wilfrid Laurier University Ethics Review Board, was obtained prior to participation. Prior to the experimental procedure, each participant completed an exclusionary questionnaire (Appendix C). Exclusion criteria included any significant history of neurological, vestibular or orthopaedic abnormalities as well as any other condition that may impair balance such as a symptomatic concussion. Prior to the experiment, the participant's lower leg length was measured to determine the starting position from the force plate for all trials. Lower leg length (cm) was measured from the lateral tibial plateau to the distal lateral malleolus while the participant was in a standing position. The starting position was in relation to leg length of the individual because the height of the participants varied greatly. Additional anthropometric measurements were taken; leg length, foot length and width to allow for normalization of the data (Appendix G).

Table 2.1 Participant's baseline demographic means and standard deviations

	SPORTS TEAMS						
Study (N=65)	***Laurier Women's Rugby***	***Laurier Men's Rugby***	***Laurier Men's Football***	***Laurier Men's Basketball***	***KW United Men's Soccer***	***KW United Women's Soccer***	***Totals***
Males	0	4	14	18	22	0	58
Females	3	0	0	0	0	4	7
Age (yrs)	21.0 (1.0)	19.5 (0.8)	20.2 (1.4)	19.2 (1.4)	20.4 (1.6)	19.5(0.6)	19.9 (1.4)
Height (m)	1.63 (0.08)	1.84 (0.08)	1.84 (0.07)	1.90 (0.08)	1.79 (0.079)	1.68 (0.06)	1.82 (0.10)
Weight (kg)	65.8 (5.2)	88.6 (16.1)	99.3 (19.7)	85.1(11.5)	79.1(8.8)	63.1 (5.5)	84.1 (16.1)
Foot Length (m)	0.23 (0.010)	0.27 (0.033)	0.28 (0.018)	0.28 (0.018)	0.27 (0.017)	0.24 (0.009)	0.27 (0.02)
Heel width (m)	0.057 (0.006)	0.062 (0.009)	0.063 (.0100)	0.062(0.007)	0.06 (0.007)	0.059(0.006)	0.062 (0.008)

2.2 Role of the Researcher

In order to ensure complete transparency and minimize researcher bias, the researcher acknowledges her employment as a certified athletic therapist at Wilfrid Laurier University. In this role, the researcher may have had knowledge of some of the participants and their previous injury history. However, the athletes in the target population for this study did not receive therapeutic treatment from the researcher for an ankle sprain injury nor was the researcher involved in any return to play decisions. The researcher did not have access to the athletes' confidential medical files. The researcher maintained confidentiality at all times and did not disseminate any specific results to the treating therapists. The researcher is a qualified health care professional belonging to a national governing body that outlines a specific code of ethical conduct (Canadian Athletic Therapists Association, Code of Ethics and Code of Conduct). The researcher did not have a personal vested interest in the outcome of this study.

2.3 Data Acquisition

Data were collected in three stages: baseline; immediately after injury when able to weight-bear; and at return to play. All participants (n=65) were tested at baseline when no ankle injury was present or reported. Injured participants (n=14) were asked to return for additional testing. This occurred immediately after sustaining a lateral ankle sprain, when the individual was able to weight bear normally with walking, and then again at return to play. A certified athletic therapist, as identified in the letter of information, at Wilfrid Laurier University provided the researcher with notification of injury (Appendix A). All inversion ankle sprains were included regardless of whether the injury occurred during contact or non-contact. Further details included: side of injured ankle; mechanism of injury; and degree of severity of the injury, which included the ability to weight bear. The first follow-up test occurred once the athlete returned to normal weight bearing activities including gait as per the athletic therapist's recommendations. The testing at that time included completion of The Foot and Ankle Disability Index (FADI) + sport scale and the static single leg stance test (Appendix E and F). If an athlete experienced any discomfort or aggravation of his / her injury, the trial was stopped.

A second follow-up appointment was scheduled when the athlete received clearance to return to participation in their varsity activity from his / her athletic therapist. At this time, the participant repeated the FADI + sport scale and the static single leg stance task as well as the single leg jumping task that was performed in the baseline testing. All tests were performed bilaterally.

2.3.1 Kinetic Data

Ground reaction forces were recorded during balancing and jumping trials using a single embedded force plate (Advanced Mechanical Technology Inc., Model OR6-5 Biomechanics Platform - strain gauge technology, cables, amplifier, computer's analog-to-digital data acquisition card and the NetForce collection software, Watertown, MA) (Figure 6). Raw ground reaction force data was collected at 200Hz. The participant's mass (kg), height (cm) and body weight (Newtons) were determined prior to the trials. The force plate is a recognized biomechanical measurement tool that has been used in numerous studies (Ross et al., 2011, Kristianslund, 2011). The axis system was set up with positive y in the anterior direction along the anterior / posterior axis and positive x in the rightward direction along the medial / lateral axis. The vertical force was represented by positive z.

Figure 6: AMTI force plate used in the experiment
Reference: www.amti.biz; Advanced Mechanical Technology, Inc. Watertown, MA, USA

2.3.2 Kinematic Data

Kinematic data were collected using an Optotrak three-dimensional motion capture system (Certus System, Northern Digital Inc., Waterloo, ON) to determine the centre of mass. Data were sampled at a collection frequency of 100Hz. The Optotrak position sensor (i.e., camera) was positioned three metres from the force plate (Figure 7). This distance was sufficient for capturing the motion of all the markers.

Figure 7: Optotrak Position Sensor from the three dimensional Motion Capture System
Reference: www.ndigital.com; Northern Digital Inc., Waterloo, Ontario

A standard 12 infrared light-emitting diode (IRED) marker set-up in the frontal plane was used. IREDs were placed anteriorly on the participant and marker number and position were as follows; 1 – forehead, 2 – distal clavicles, 1 – xyphoid, 2 – anterior inferior iliac spines, 2 – tibial tubercles, 2 – talus, 2 – dorsum of the base of the first metatarsal (Figure 7). These IREDs were used by the Optotrak system to record the position of each of the listed marker positions in three-dimensional space. These markers were applied using a double-side adhesive disc and transpore tape that was removed easily. Participants were asked to walk around prior in order to ensure the markers were securely affixed. After data collection, a cubic spline interpolation was used to fill in small gaps by using data points before and after the gaps.

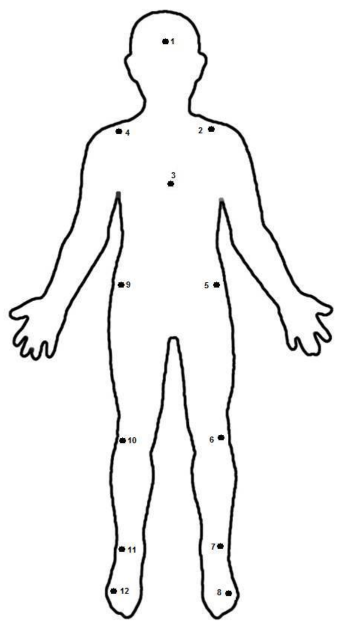


Figure 8: Twelve (12) frontal infrared (IRED) marker anterior placement protocol

2.4 Experimental Protocol

Upon entering the lab, participants read a summary of the experimental procedures and then signed and dated an informed consent form (Appendix B). Participants completed an exclusion screening questionnaire (Appendix C). If eligible for the study, the participant completed a medical history questionnaire (Appendix D), the Foot and Ankle Disability Index (FADI) + sport scale (Appendix E and F). When completing the FADI survey, the participants indicated which ankle was symptomatic or painful. The medical history questionnaire ascertained background information relating to the participant's activity level; frequency and duration as well as type of activity. Additional questions asked about previous ankle sprains, severity of injury, treatment received, taping and or bracing. A summary table of this information can be found in the results section (Table 3.3). This information was acquired directly from the athletes themselves and not through access to their medical files. The premise was to have each individual establish his/her own baseline regardless of ankle sprain history and then compare each person to him or herself. A detailed explanation of the experimental tasks was provided to each participant prior to commencement of the experiment.

Anthropometric data were collected including: height, weight, leg length, lower leg length, and foot length and heel width. The next component of the baseline testing session consisted of the participant receiving instructions on the balancing and jumping tasks. Participants were asked to dress in shorts and a t-shirt to ensure maximal comfort and freedom of movement. All tasks were performed barefoot and no additional support such as tape or bracing was provided. Participants were outfitted with 12 Infrared light Emitting Diodes (IREDs). Participants performed one practice trial for each condition prior to the testing. All testing was done bilaterally and in a block randomized order in an attempt to control for practice effects and minimize fatigue. The participants stood barefoot on the force plate in quiet stance and were weighed in Newtons. The force plate and motion analysis system were setup to collect data simultaneously when manually triggered, via the First Principles collection software, as the participant was given a verbal command to begin the trial.

Trials consisted of three different conditions: 1) quiet double and single limb stance with eyes open; 2) one leg standing with eyes closed; and 3) one leg jumping with eyes open. For the single leg stance trials, participants were required to stand on a force plate on a single leg with eyes closed for 30 seconds. They were instructed to remain as motionless as possible while keeping their eyes closed. The weight bearing leg was slightly flexed at the knee with the foot in a neutral toe in / out position. Any balance errors such as touching down with the other foot, shuffling on the weight bearing leg or opening the eyes were noted by the researcher. Participants were instructed to keep their eyes closed during the one leg standing trials, however if they could not maintain their balance and they thought they were falling, they could open their eyes to ensure safety.

For the one leg jumping task, participants did not receive any cues regarding landing other than to make contact with the force plate with the entire foot and remain in the landing position as motionless as possible until further instructed. They were told to utilize a jumping technique that allowed for the highest jump possible and they were encouraged to use maximal effort. The participants were allowed to practice the task in advance of data collection to become familiar with the technique. The jumping task began with the participant standing barefoot off of the force plate. Then they stepped onto the force plate where they performed a maximal exertion counter movement jump at a self-imposed height resulting in the participant landing back onto the force plate with one foot and attempting to stabilize as quickly as possible. In a counter movement jump, the participant began in an upright standing posture, made an initial downward movement by flexing the hips and knees, and then immediately extended the hips and knees to jump vertically off of the ground. Participants were instructed to swing their arms during the jump and were instructed to fully flex the glenohumeral joint and extend their elbows. Prior to data acquisition, participants were permitted to practice each test condition until they felt comfortable and confident with the testing protocol. The participants performed a total of three quiet stance trials with their eyes open in a consecutive order. The first quiet stance trial was a double leg stance for 60 seconds followed by a single leg stance for 45 seconds for each leg. The purpose of these quiet stance trials was to ensure data collection was synchronized and operational as well as familiarizing the participant to the task of stepping onto the force plate. Using a pre-determined order of trials, the participants performed one leg balancing trials with eyes closed for 30 seconds or a one leg jump–and-land trial with eyes open for 5 seconds. The trials were performed consecutively but alternated between right and left leg as well as between standing and jumping in order to minimize fatigue. Two blocks of trial orders were used in an alternating manner (Table 2.2). The participant was not informed of the order of tasks in advance. They were given the instructions for each task following completion of the task before.

Table 2.2: Chart of the trial orders

Trial order 1:				
2 leg quiet stance (EO) 1 leg quiet stance Right (EO) 1 leg quiet stance Left (EO)	Single leg stance 1x Right (EC) 1x Left (EC)	Single leg jump 2x Left (EO) 2x Right (EO)	Single leg stance 2x Left (EC) 2x Right (EC)	Single leg jump 2x Right (EO) 2x Left (EO)
Trial order 2:				
2 leg quiet stance (EO) 1 leg quiet stance Right (EO) 1 leg quiet stance Left (EO)	Single leg stance 2x Left (EC) 2x Right (EC)	Single leg jump 2x Right (EO) 2x Left (EO)	Single leg stance 1x Right (EC) 1x Left (EC)	Single leg jump 2x Left (EO) 2x Right (EO)

Note: EO = eyes open, EC = eyes closed

The total number of quiet stance trials was three (eyes open). The total number of single leg stance trials (eyes closed) was six (3 for each leg). The total number of single leg jump trials (eyes open) was eight (4 for each leg). The total number of trials was 17. No fall incidences occurred. Participants did not receive any feedback from the researcher during or after the testing. To ensure that each participant's protocol was consistent, the researcher employed a detailed trial recording sheet for each participant (Appendix G).

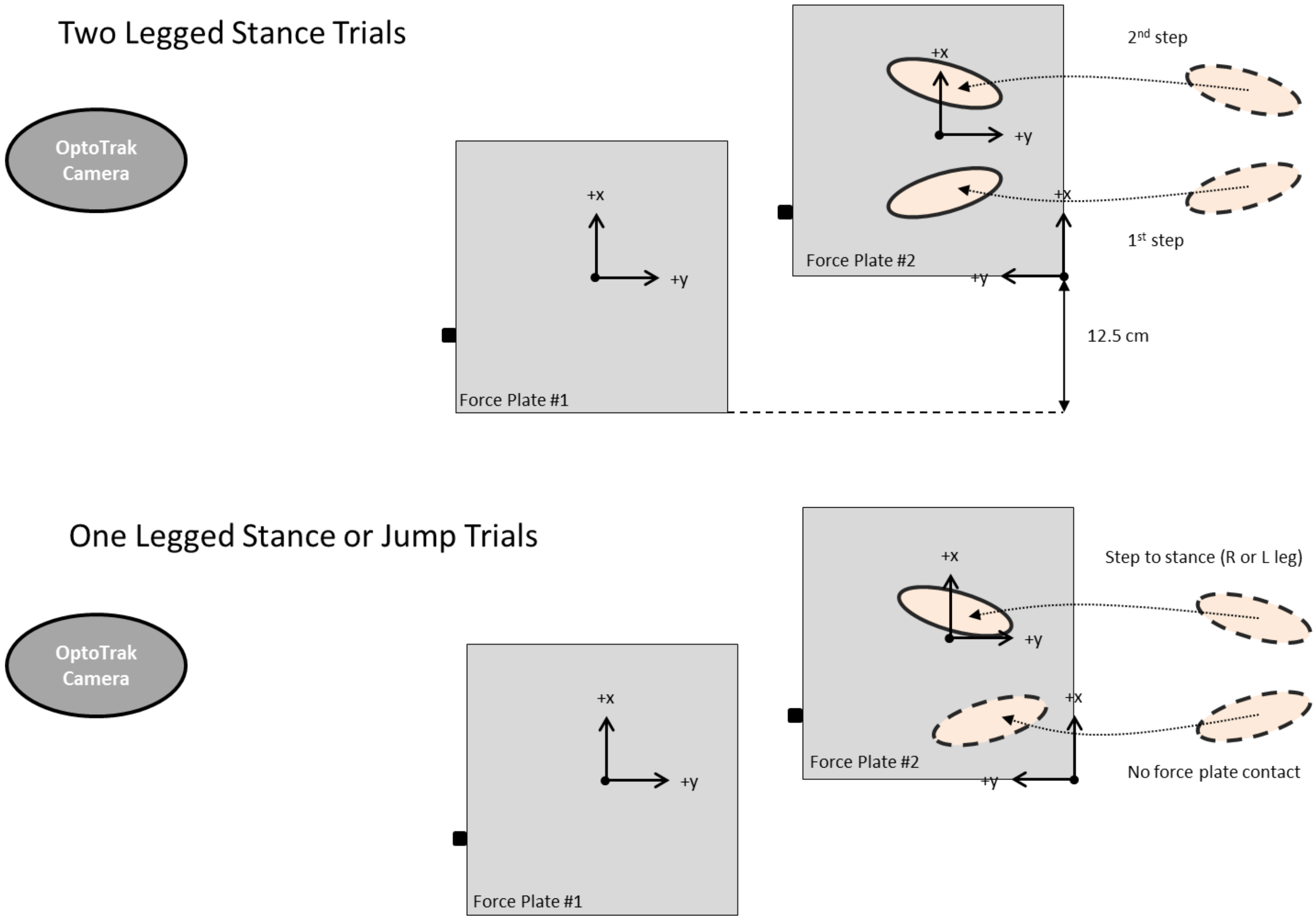


Figure 9: This figure illustrates the location of a participant's feet in relation to the force plate #2 and OptoTrak camera during stance trials. A participant began each trial standing on the floor and took a step forward with a designated foot onto force plate #2. The axis system is illustrated on the force plate with +x representing medial / lateral and +y representing anterior / posterior.

2.5 Variable Definitions

- Single leg standing trial, eyes closed (30 seconds)

A systematic approach was taken to identify a section of the collected data that was used for analysis. When a participant stepped onto the force plate, there may have be some anticipatory adjustments. To identify a stable position, a combination of shear forces was examined and when these forces reached a level of less than 10 Newtons, it was indicative of the person settling into a stable position. The A/P and M/L shear forces were added together and the point where they came as close to zero as possible was identified.

The starting point was determined by moving forward one second or 200 frames. At this point, the mean and standard deviation were calculated and compared to the minimum value. Identifying the smallest amount of deviation through a minimum value represents the smallest amount of vertical force oscillation. This was the starting point and data were analyzed from this point moving forward for 20 seconds. This is an appropriate time interval away from the shear forces and allows the analysis to focus on the oscillations as represented by the vertical forces. The number of touchdowns by the contralateral limb were noted and corroborated with the visual observations noted during data collection.

Once the appropriate window of data was identified, the following calculations were taken; centre of mass (COM) root mean square (RMS), (A/P, M/L), centre of mass velocity RMS (A/P, M/L), centre of pressure (COP) RMS (A/P, M/L) centre of pressure velocity RMS (A/P, M/L) and the COM – COP maximum (A/P, M/L). The centre of pressure is a length measurement therefore all data were normalized using foot length measurement and reported in metres.

- Rate of Loading:
    1. The first rate of loading (Figure 10: Rate of loading 1) was calculated starting after the participant stepped onto the force plate at a point when the force reached 100% of the participant's body weight to a maximum peak value prior to the flight phase. This is in preparation for take-off. This loading rate is indicative of the muscle activation / force to produce upward acceleration of the body after the countermovement. These data were normalized to body weight (BW, N/s/N).
    2. The second loading rate (Figure 10: Rate of loading 2) was measured upon impact in the landing phase to the maximum peak. This was calculated from initial foot contact on the force plate during landing to first force plate maximum after landing. A threshold of greater than ten percent body weight indicated landing. The magnitude of the landing force was divided by the participant's body weight in Newtons and expressed as BW. This normalization of a participant's mass allows for comparisons between individuals to be observed.
- Impact Peak:

  Two maximum impact peaks were identified. One maximum point (Figure 10: the peak of Loading Rate 1) was identified during the take-off phase of the jump and the other (Figure 10: the peak of Loading Rate 2) was identified during the landing phase of the jump which was defined as the highest force recorded in the Fz (vertical) direction during landing.
- Impulse:

1. This was measured by taking the area under the vertical force-time curve when the force exceeds body weight to the point where the force goes below body weight prior to take-off of the flight phase (Figure 10: Impulse 1).
2. This was measured by taking the area under the vertical force-time curve during the landing phase from the first body weight crossing to the next cross below body weight after landing (Figure 10: Impulse 2).

The magnitude of the peak (maximum point) was identified during the take-off phase and the landing phase.

- Centre of Mass Change:

  Centre of mass change was calculated using the standing centre of mass value taken at the start of the trial. This value was subtracted from the maximum center of mass value taken at the maximum height of the jump. The difference was calculated during the flight phase and represents the value of the height of the vertical jump measured in metres.

- Time to stabilization:

This value, measured in milliseconds was calculated using 100ms intervals upon landing (200 samples / second). The maximum and minimum root mean square (RMS) value was calculated and time to stabilize was identified when the RMS passed a threshold of 80% difference between the minimum and maximum. These were reported in both the anterior / posterior and medial / lateral directions.

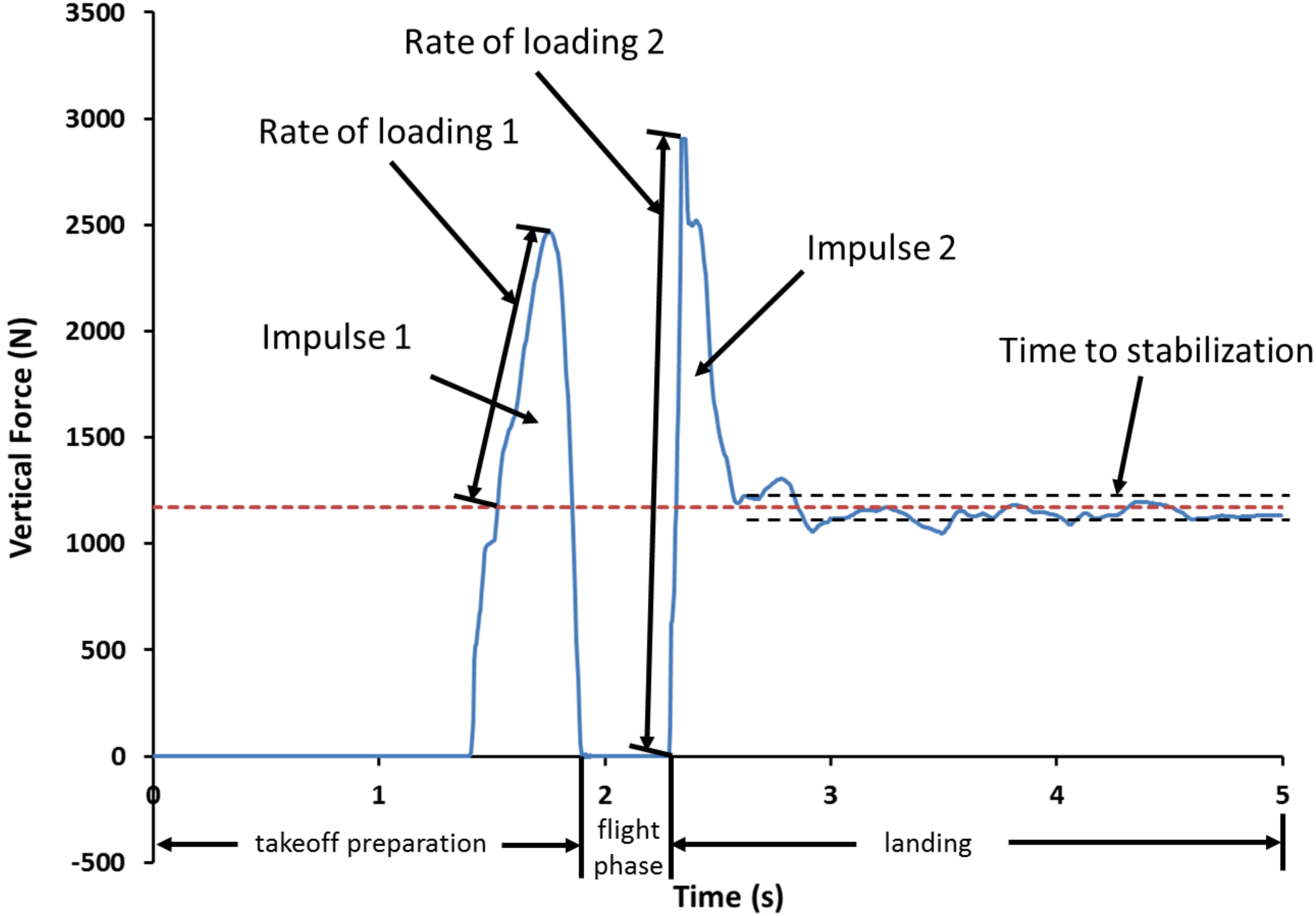


Figure 10: Phases of a jump illustrating the vertical force patterns (measured in Newtons) during 3 phases: preparation for take-off, flight phase and landing phase.

3.0 RESULTS

3.1 Analysis Procedures

This controlled study was performed in a laboratory setting. The independent variables were time (pre-injury baseline, post-injury return-to-play) and ankle (injured and non-injured). The dependent variables were the biomechanical outcomes and the questionnaire results. Data analysis was performed using a custom program created in Microsoft Visual Basic. The program accessed data files which allowed for customized calculations of outcome measures such as COP RMS, COP RMS velocity, COP minimum and maximum values, range, impulse, loading rates and centre of mass.

Centre of mass (COM) was calculated from the data obtained from the 12 IRED marker set-up. Prior to analysis, all data were examined using the optofix program. This program allowed for an interpolation of data to fill in small gaps due to the camera not seeing the markers at all times. Next, a four segment model was used for the COM calculation of standing height and maximum jump height. The segments included the head, trunk + arms, right leg and left leg. This was a consistent model used throughout all trials. Trial data were examined for outliers and any trials where the COM data were unusable were excluded. COM data may have been missing due to movement of a participant that obscured the view of the marker or the height of the participant may have caused the head marker to fall outside the collection parameters.

3.2 Statistical Analysis

Post experiment, a one-way (non-injured vs. eventually injured leg at baseline) and a two-way (main effects/interactions of time (baseline vs. return-to-play) and ankle (non-injured vs. eventually injured) repeated measures within-subject factor analysis of variance (ANOVA) was conducted using customized statistical analysis software (SAS). All data were scrutinized in untransformed, log transformed and rank transformed outputs to identify a normal distribution. This was important to satisfy the assumption of an ANOVA that the data was normally distributed. The normality of the data was tested using the Shapiro-Wilk test. Tukey's post-hoc analyses were examined to identify main effects using $p<0.05$ as the significance level. Standing trial data were analyzed using three time points when available; baseline, intermediate stage and return to play. The outcome measures included analysis of the main effects of the COM RMS, COMv RMS, COP RMS, COPv RMS and COM-COP maximum in both the A/P and M/L directions. Outliers in the data were examined to ensure that the participant met the criteria in the one leg stance trials which were to remain in one leg stance for the duration of the thirty seconds. Unsuccessful trials occurred when the participant stepped down with the non-test leg either on or off the force plate. These trials were identified and removed as they were deemed unsuccessful. Each jumping variable was analysed comparing the injured ankle to the uninjured ankle at two time points; baseline and return to play. Force loading patterns provided data on rates of loading, impulse, peak force and time to stabilization. Centre of mass data were used to determine differences in jump height after injury as compared to baseline measurements. All force plate data were normalized to body weight and centre of mass data was normalized to height.

A one-way ANOVA was used to analyse the questionnaire data. The main effect of time (baseline, return-to-play) was examined using the scores from the survey. A summary of the injured participant's demographic and anthropometric information was compiled (Table 3.1). During the follow-up period, twelve of the sixty-five athletes sustained a lateral ankle sprain with two of those athletes spraining the same ankle twice. Eight (57% of all ankle sprains) occurred with the men’s basketball team, 3 (21%) during men’s football, 2 (14%) during women’s soccer and 1 (7%) during men’s rugby. The two repeat participants were from men’s basketball.

Table 3.1: Injured participants demographic means and standard deviations

	SPORTS TEAMS						
Study (N=12)	***Laurier Women's Rugby***	***Laurier Men's Rugby***	***Laurier Men's Football***	***Laurier Men's basketball***	***KW United Men's Soccer***	***KW United Women's Soccer***	***Totals***
Males	0	1	3	6	0	0	10
Females	0	0	0	0	0	2	2
Age (yrs)	0	19	19.3 (1.5)	20 (1.9)	0	19.5 (0.7)	19.7 (1.5)
Height (m)	0	1.78	1.84 (0.05)	1.93 (0.07)	0	1.64 (0.06)	1.85 (0.12)
Weight (kg)	0	73.0	115.8 (16.2)	89.6 (11.6)	0	61.6 (8.8)	90.1 (21.7)
Foot Length (m)	0	0.25	0.29 (0.012)	0.29 (0.018)	0	0.23 (0.004)	0.28 (0.027)
Heel width (m)	0	0.053	0.068 (0.013)	0.064 (0.009)	0	0.06 (0)	0.063 (0.009)

Table 3.2 summarizes additional information collected from participants after a lateral ankle sprain (LAS) injury occurred. The injury rate in this study was 21.5%. As noted, nine of the LAS happened on the right ankle and five occurred on the left ankle. In 50% of the ankle sprains, the dominant leg was affected. The degree of injury was reported as assessed by a certified athletic therapist. All injuries with the exception of one were classified as first degree or mild with one incident being a second degree sprain. All participants reported previous ankle sprains ranging from once to greater than five (Table 3.3). Participation in a rehabilitation program was not mandatory nor was it monitored. In this study, nine participants attended some type of therapy program whereas five did not participate. The use of ankle braces was also documented with seven participants reporting wearing a brace at the time of injury and seven were not. Finally, the presences of symptoms (pain, instability) at the time of testing were reported with eight participants experiencing at least one or more symptoms and six reported being asymptomatic.

Table 3.2: Injured participants characteristics

Participant	***Injured ankle R / L***	***Degree of Injury***	***Injury History***[1]	***Therapy***[2]	***Ankle Brace***	***Residual Symptoms***[3]
1	Right	1st	1	Yes	Yes	Yes
2	Left	1st	1	Yes	Yes	No
3	Left	1st	Multiple	Yes	No	No
4	Left	2nd	Multiple	Yes	No	No
5	Right	1st	>5	No	Yes	Yes
6	Right	1st	1	No	Yes	No
7	Right	1st	2-3x	Yes	Yes	Yes
8	Left	1st	1	No	Yes	Yes
9	Right	1st	2	Yes	No	Yes
10	Right	1st	3	No	No	Yes
11	Right	1st	2	No	Yes	Yes
12	Left	1st	1	Yes	No	Yes
13	Right	1st	2	Yes	No	No
14	Right	1st	2	Yes	No	No
Summary:	Right – 9 Left - 5			Yes – 9 No - 5	Yes – 7 No - 7	Yes – 8 No - 6

1. Self-reported history of previous lateral ankle sprains
2. Self-reported attendance to a rehabilitation program administered by a certified athletic therapist
3. Self-report at baseline indicating that the participant is currently experiencing residual symptoms from a previous ankle sprain

Table 3.3: Summary of medical history forms

Participant	*Injured Ankle*	*Previous sprains Right / Left*	*Previous Treatment*	*Brace / Tape*	*Dominant Leg*
1	Right	1 1	Yes	Brace - both	Unknown
2	Left	1 1	Yes	Brace – both	Right
3	Left	Multiple R & L	No	No brace, tape left	Right
4	Left	Multiple R & L	No	No brace, tape left	Right
5	Right	R & L >5 each	Yes	Brace – both	Left
6	Right	1 1	No	Brace – both	Right
7	Right	2-3 1	Yes	Brace – L	Unknown
8	Left	2 1	No	Brace – R	Right
9	Right	2 1	Yes	Neither	Right
10	Right	3 1	Yes	Neither	Right
11	Right	2 3	Yes	Brace – both	Right
12	Left	1 1	Yes	Neither	Left
13	Right	2 0	Yes	Neither	Right
14	Right	2 0	Yes	Neither	Right
Summary:	Right = 9 Left = 5			Brace /tape = 7 Neither = 5	

This study did not influence the return-to-play decision for the athlete. As indicated in Table 3.4, the average number of days to the intermediate testing session after injury occurred was 3.83 days. Six participants were tested in this intermediate phase. Not all athletes were tested in this phase for reasons including; a rapid return to play, another injury occurred (i.e. concussion) and scheduling conflicts. All athletes were tested in the return-to-play phase including the two athletes who re-injured the same ankle twice during the data collection period of this study. Those two participants sustained a second ankle sprain to the previously sprained ankle approximately 11 months and 1 month respectively after their first injury. The average number of days to the return-to-play follow up testing period was 37.23. The range in this period was quite large (4 – 112 days) again mostly due to the athlete sustaining another injury or unwillingness to perform testing during their competitive season. There were two athletes in particular who sustained a concussion upon return-to-play and therefore did not meet the inclusion criteria of the study at that time. They were re-tested approximately 3 months later (101 and 112 days) when their concussion symptoms resolved. With these 2 outliers removed, the average number of days to return-to-play testing was 22.9 days (± 16.0) with a range of 4 – 58 days. All athletes returned to sport within two weeks of sustaining a lateral ankle sprain with the average being 5.36 days.

Table 3.4: Follow-up testing timelines

Average number of days to intermediate testing after injury	3.83 ± 2.14 (n=6) range = 1 – 6 days
Average number of days to return-to-play testing after injury	37.23 ± 33.96 (n=14) range = 4 – 112 days
Average number of days to return-to-play	5.36 ± 4.36 (n=14) range = 1 – 14 days

The means and standard deviations for the single leg standing results are displayed using metres as the unit of measurement. The data was reported in metres to allow for a clear conceptualization of the information and comparison to previous work. The analysis of the single leg standing results looked at two main comparisons. The first analysis compared the participant's (N=12) eventually injured ankle to their non-injured ankle at baseline, both in the anterior / posterior and medial / lateral directions (Table 3.5 and Table 3.6). The purpose was to identify any deficits that may have predisposed the athlete to injury at the beginning of the study as the participant's uninjured ankle was acting as their own control. A one-way ANOVA was used to analyze this data. There were no statistically significant differences at baseline between the ankle that did not become injured and the ankle that eventually sustained a lateral ankle sprain.

Table 3.5: Single leg standing results (anterior / posterior) at baseline comparing the ankles of the participants who eventually sustained a lateral ankle sprain

	Uninjured	Injured	P Value
Centre of Mass A/P RMS (m)	0.252 (0.028)	0.254 (0.029)	0.9957
Centre of Mass Velocity A/P RMS (m/s)	0.034 (0.011)	0.103 (0.174)	0.2717
Centre of Pressure A/P RMS (m)	0.203 (0.027)	0.208 (0.024)	0.4506
Centre of Pressure Velocity A/P RMS (m/s)	0.213 (0.094)	0.260 (0.156)	0.4233
COM-COP A/P maximum (m)	0.042 (0.056)	0.034 (0.036)	0.0608

* - significant difference between injured and uninjured ankle ($p<0.05$)

Table 3.6: Single leg standing results (medial /lateral) at baseline comparing the ankles of the participants who eventually sustained an ankle injury

	Uninjured	Injured	P value
Centre of Mass M/L RMS (m)	0.181 (0.044)	0.198 (0.069)	0.6396
Centre of Mass Velocity M/L RMS (m/s)	0.053 (0.023)	0.126 (0.199)	0.5805
Centre of Pressure M/L RMS (m)	0.262 (0.040)	0.235 (0.050)	0.1910
Centre of Pressure Velocity M/L RMS (m/s)	0.214 (0.058)	0.215 (0.060)	0.8748
COM-COP M/L maximum (m)	0.048 (0.058)	0.049 (0.072)	0.3877

* - significant difference between injured and uninjured ankle ($p<0.05$)

The second standing analysis examined the interaction effect between the baseline and return-to-play data for the uninjured and injured ankle (Table 3.7 and Table 3.8). The uninjured ankle acted as a control limb in this study. This analysis tested for the effect of time between baseline and follow-up testing and the effect of injury. There were no significant interaction effects.

Table 3.7: Single leg standing results (anterior / posterior) for the uninjured and injured ankle at baseline and return to play

	BASELINE		**RETURN TO PLAY**		
	Uninjured	Injured	Uninjured	Injured	P value[1]
Centre of Mass A/P RMS (m)	0.252 (0.028)	0.254 (0.029)	0.247 (0.027)	0.239 (0.032)	NS
Centre of Mass Velocity A/P RMS (m/s)	0.034 (0.011)	0.103 (0.174)	0.047 (0.070)	0.124 (0.458)	NS
Centre of Pressure A/P RMS (m)	0.203 (0.027)	0.208 (0.024)	0.208 (0.061)	0.180 (0.043)	**Visit 0.008***
Centre of Pressure Velocity A/P RMS (m/s)	0.213 (0.094)	0.260 (0.156)	0.598 (0.675)	0.725 (0.876)	**Visit 0.0323***
COM-COP A/P maximum (m)	0.042 (0.056)	0.034 (0.036)	0.029 (0.014)	0.031 (0.040)	**Injury 0.0186***

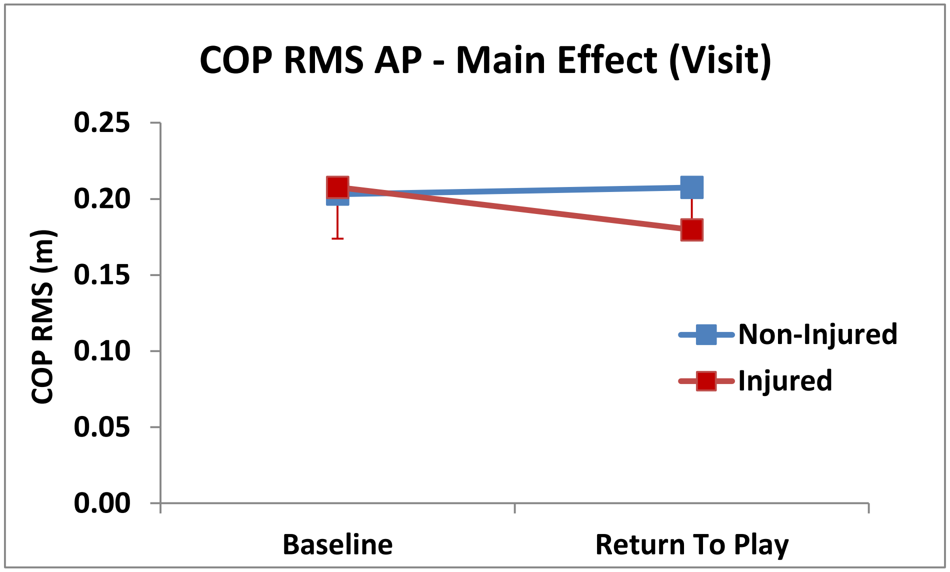
* - significant difference between baseline and return to play / non-injured and injured ($p<0.05$)
1- P value of main effect of visit, main effect of injury taken from least squared Tukeys adjustment for multiple comparisons; interaction effect of visit*injury taken from repeated measures 2-way ANOVA
NS = non-significant

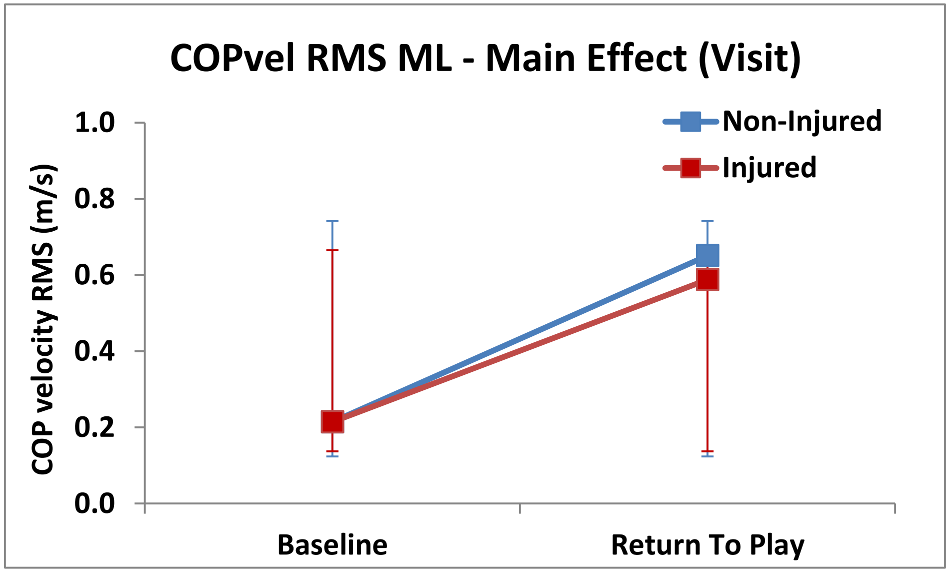
Table 3.8: Single leg standing results (medial / lateral) for the uninjured and injured ankle at baseline and return to play

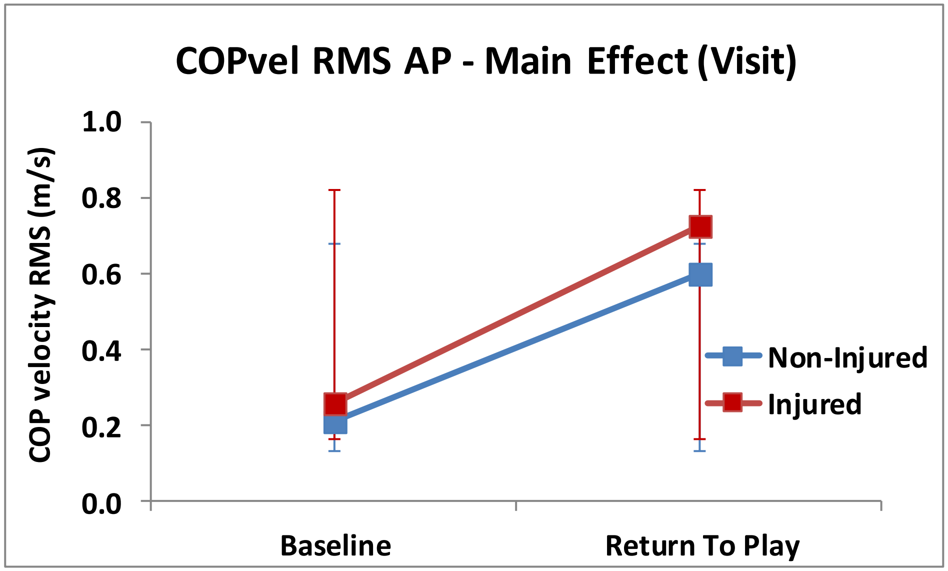
	BASELINE		**RETURN TO PLAY**		
	Uninjured	Injured	Uninjured	Injured	P value
Centre of Mass M/L RMS (m)	0.181 (0.044)	0.198 (0.069)	0.198 (0.043)	0.218 (0.065)	NS
Centre of Mass Velocity M/L RMS (m/s)	0.053 (0.023)	0.126 (0.199)	0.065 (0.075)	0.146 (0.524)	NS
Centre of Pressure M/L RMS (m)	0.262 (0.040)	0.235 (0.050)	0.283 (0.084)	0.255 (0.164)	NS
Centre of Pressure Velocity M/L RMS (m/s)	0.214 (0.058)	0.215 (0.060)	0.651 (0.813)	0.588 (0.606)	**Visit 0.0421***
COM-COP M/L maximum (m)	0.048 (0.058)	0.049 (0.072)	0.045 (0.030)	0.048 (0.055)	NS

* - significant difference between baseline and return to play / non-injured and injured ($p<0.05$)
1- P value of main effect of visit, main effect of injury taken from least squared Tukeys adjustment for multiple comparisons; interaction effect of visit*injury taken from repeated measures 2-way ANOVA
NS = non-significant

Using Tukey's post-hoc analysis, the main effects of visit (baseline / return-to-play) and injury (sprain / no sprain) were examined. Four main effects were identified (Figure 11). The COP RMS y showed a main effect of visit (p=0.008). The COP velocity RMS AP showed a main effect of visit (p=0.0323). The COP velocity RMS ML showed a main effect of visit (p=0.0421). The COM-COP maximum AP showed a main effect of injury (p=0.0186).


COP RMS AP - Main Effect (Visit)
COP RMS (m)
0.25
0.20
0.15
0.10
0.05
0.00
Non-Injured
Injured
Baseline
Return To Play


COPvel RMS ML - Main Effect (Visit)
COP velocity RMS (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
Non-Injured
Injured
Baseline
Return To Play


COPvel RMS AP - Main Effect (Visit)
COP velocity RMS (m/s)
1.0
0.8
0.6
0.4
0.2
0.0
Baseline
Return To Play
Non-Injured
Injured

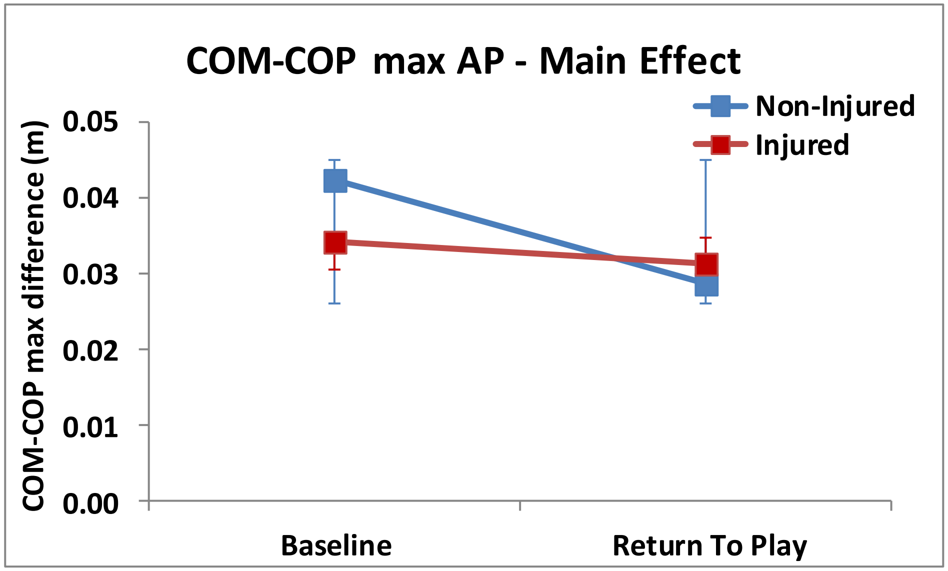

COM-COP max AP - Main Effect
COM-COP max difference (m)
0.05
0.04
0.03
0.02
0.01
0.00
Baseline
Return To Play
Non-Injured
Injured

Figure 11: Main effects of standing conditions. (COP = centre of pressure, vel = velocity, COM = centre of mass, RMS = root mean square, max = maximum, AP = anterior / posterior, ML = medial / lateral, m = metres, m/s = metres per second)

The analysis of the jumping results looked at two main comparisons. The first analysis compared the participant's injured ankle to their non-injured ankle at baseline (Table 3.9). The purpose was to identify any differences at the beginning of the study as the participant's uninjured ankle was acting as their own control. There was one participant who was excluded from the jumping analysis as he reported pain while jumping despite being returned to play (N=11).

Table 3.9: Jump task results at baseline comparing the ankles of the participants who eventually sustained a lateral ankle sprain

	Uninjured	Injured	P value
Rate of Loading 1 (BW/s)	3.66 (1.75)	3.83 (1.88)	0.6695
Rate of Loading 2 (BW/s)	38.76 (10.21)	36.99 (10.29)	0.8996
Impulse 1 (BW*s)	0.22 (0.04)	0.23 (0.03)	0.9349
Impulse 2 (BW*s)	0.21 (0.04)	0.24 (0.05)	**<0.0001***
Jump Height (m)	0.27 (0.05)	0.27 (0.06)	0.4344
Time to Stabilize M/L (s)	0.81 (0.41)	1.03 (0.49)	0.2427
Time to Stabilize A/P (s)	0.84 (0.49)	0.84 (0.46)	0.9865

* - significant difference between injured and uninjured ankle ($p<0.05$)

The only statistically significant finding at the time of baseline testing was the second impulse ($p=0.0001$). This impulse was measured upon landing from a single leg jump. This was indicative of the force a participant produced after the flight phase when his / her foot contacts the force plate. At baseline, the participants who eventually injured their ankle produced a significantly greater force (0.24 BW*s) in comparison to the ankle that did not sustain an injury (mean = 0.21 BW*s). This finding demonstrated that there was a greater force during the landing portion of the jump on their eventually injured ankle, during baseline testing, as compared to their uninjured ankle.

Although not statistically significant, the participants that went on to injury their ankle showed an increased time to stabilize after landing from a jump (mean = 1.03 seconds) in comparison to the ankle that did not become injured (mean = 0.81 seconds).

The second analysis was done using a two-way repeated measure ANOVA to exam the interaction effects of time (baseline / return to play) and injury (Table 3.10). Again, the uninjured ankle acted as a control in this study.

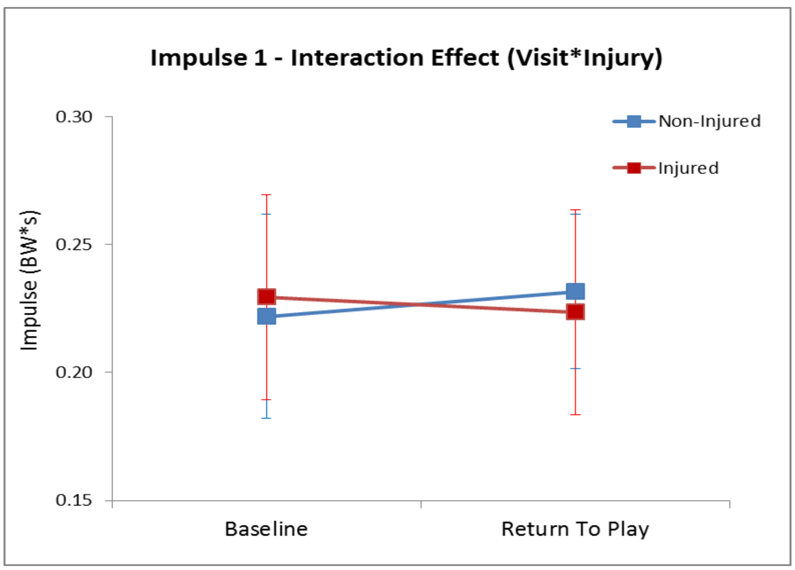
Table 3.10: Jump task results for the injured and uninjured ankle at baseline and return to play

	BASELINE		**RETURN TO PLAY**		
	Uninjured	Injured	Uninjured	Injured	P value
Rate of Loading 1 (BW/s)	3.66 (1.75)	3.83 (1.88)	3.17 (1.64)	2.93 (1.36)	NS
Rate of Loading 2 (BW/s)	38.76 (10.2)	41.36 (12.3)	36.99 (10.3)	42.04 (11.0)	NS
Impulse 1 (BW*s)	0.22 (0.04)	0.23 (0.03)	0.23 (0.04)	0.22 (0.04)	**Visit*Injury 0.0418***
Impulse 2 (BW*s)	0.21 (0.04)	0.24 (0.05)	0.22 (0.04)	0.22 (0.05)	**Visit*Injury 0.0135***
Jump Height (m)	0.27 (0.05)	0.27 (0.06)	0.26 (0.09)	0.27 (0.07)	**Visit 0.0438***
Time to Stabilize M/L (s)	0.81 (0.41)	1.03 (0.49)	0.81 (0.52)	1.14 (0.66)	NS
Time to Stabilize A/P (s)	0.84 (0.49)	0.84 (0.46)	0.79 (0.50)	0.74 (0.44)	NS

* - significant difference between baseline and return to play ($p<0.05$)
1- P value of main effect of visit, main effect of injury taken from least squared Tukeys adjustment for multiple comparisons; interaction effect of visit*injury taken from repeated measures 2-way ANOVA
NS = non-significant

These results yielded statistically significant findings when looking at the impulses. The first impulse measured during the take-off phase showed a statistically significant difference between baseline (0.23 BW*s) and return-to-play (0.22 BW*s). The second impulse measured upon landing showed a statistically significant difference from baseline (0.24 BW*s) to return-to-play (0.22 BW*s).

Although not statistically significant, participants returning to play after sustaining a lateral ankle sprain experienced a lower rate of loading in the preparatory phase of a jump (2.93 BW/s) as compared to the baseline values (3.83 BW/s). This rate of loading was measured from the point in which the participant reached their body weight on the force plate to the first maximal peak prior to the jump. Therefore, the slower rate of loading indicated that the participant applied a similar amount of force over a longer period of time since there was no change in peak force before jumping. That is, they took longer to generate the same impulse. There was a main effect of visit for jump height although there was not a significant interaction effect.



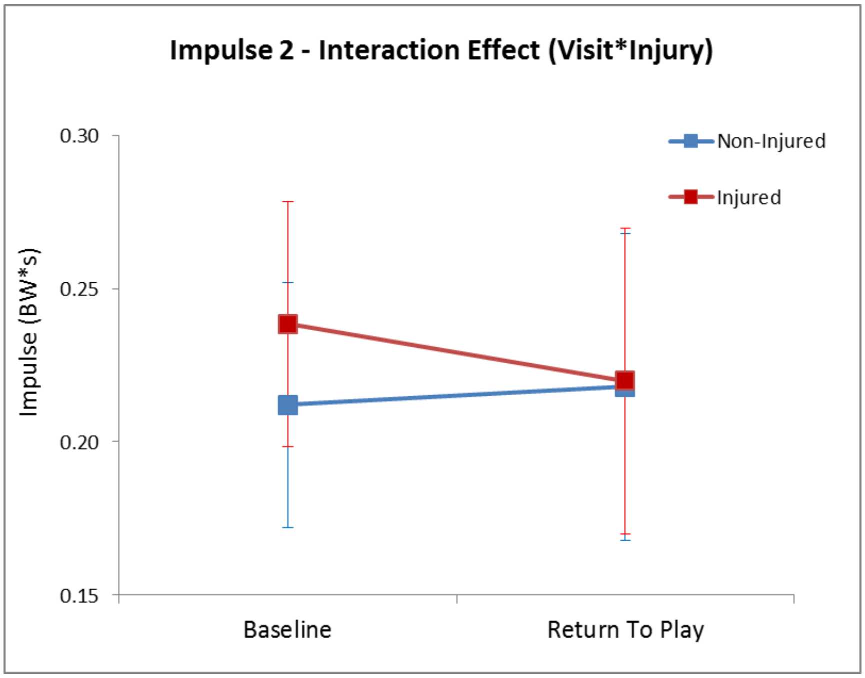


Figure 12: Interaction effects of jump conditions. (BW = body weight, s = seconds, m = metres)

Table 3.11: The Foot and Ankle Disability Index + Sport Scale Results

	Activities of Daily Living				Sport Scale			
Participant	Baseline	Intermediate	RTP	P value	Baseline	Intermediate	RTP	P value
1	100		98		100		85	
2	100	89	100		100	59	100	
3	98	79	100		100	56	100	
4	98	78	96		100	47	66	
5	99	94	99		100	75	97	
6	98		69		100		41	
7	99		99		97		94	
8	***72***		***89***		***47***		***84***	
9	100	85	90		100	69	94	
10	98		97		88		94	
11	***68***		***83***		***47***		***75***	
12	97	71	96		69	72	*75*	
13	100		97		100		84	
14	100		94		100		84	
Average	98.9	82.7	94.6	**0.0949**	96.2	63	84.5	**0.0498***
St dev	1.08	6.7	8.53		9.23	10.8	17.14	
Minimum	68	71	69		47	47	41	
Maximum	100	94	100		100	75	100	

Note: Numbers expressed as a percentage of raw scores
* - significant difference between baseline, intermediate and return to play ($p<0.05$)

Although the typical purpose of the chosen self-reported outcome instrument is to evaluate the effectiveness of treatment interventions after sustaining an injury, in this study, the focus was directed towards an athlete's ability to return to baseline scores upon return-to-play. The analysis for this data was done at a group level although several outliers were identified. These two participants reported lower scores at baseline versus return-to-play, both in the activities of daily living questionnaire and in the sport scale (bold italics in table 3.11). These outliers were excluded in the data analysis.

The reported scores of both the FADI and FADI + sport scale were summed and expressed as a percentage for comparison purposes. The instrument assessing activities of daily living was administered at the beginning of the study, in the intermediate phase and again when the athlete returned to play. Baseline values reported an average of 98.9% (±1.08), intermediate scores from six participants averaged 82.7% (±6.7) whereas the follow up questionnaire showed an average of 94.58% (±8.53). The difference between these groups was statistically significant when analyzing across the three timelines ($p=0.0359$). When the baseline scores were directly compared to the return to play values, the difference was non-significant ($p=0.0949$).

The questionnaire scores of the participants who did not sustain a lateral ankle sprain were examined ($n=53$). The non-injured athletes values on the FADI averaged 98.15 (±3.97) percent with a range from 84 – 100. Thirty-six of the fifty-three participants reported a one hundred percent score at baseline testing. In contrast, the participants who eventually sprained their ankle averaged 94.8 (±10.6) with a range from 68 – 100 at baseline (Table 3.11). Those participants who eventually sustained an ankle sprain had a lower baseline average score on the FADI compared to the individuals who did not incur an injury.

The sport scale portion of the questionnaire revealed statistically significant findings when comparing all three time points and comparing baseline scores to return-to-play (Table 3.11). With outliers removed, baseline values showed an average of 96.17% (±9.23). Intermediate scores from six participants averaged 63% (±10.8). Upon return to play, participants reported residual deficits averaging 84.5% (±17.14). The difference between these groups was statistically significant when analyzing across the three time points (baseline, intermediate, return-to-play) (p=0.0127). When the baseline scores were directly compared to the return to play values, the difference was also significant (p=0.0498). The non-injured athletes scores on the sport scale averaged 95.84 (±7.93) with a range of 72-100. As with the FADI, thirty-six of the fifty-three participants reported a one hundred percent score at baseline testing. The participants who eventually sprained their ankle averaged 89.1 (±19.8) percent with a large range of 47 – 100.

4.0 DISCUSSION

The primary purpose of this study was to investigate whether athletes returned to their baseline performance following a lateral ankle sprain using quantitative biomechanical outcome measures. Acute ankle sprains have been reported as the most common injury sustained by athletes. Moreover, lateral ankle sprains involving the lateral ligaments (ATFL, CFL and PTFL) account for up to 85% of all ankle sprains (McCriskin, et al., 2015). This injury can result in sequelae of ankle instability and dysfunction resulting in lost time from training and competition. It was hypothesized that all outcome measures would worsen at the return to play stage as demonstrated by a decrease in the participant's ability to perform a single leg stance balance task and a jumping task.

The baseline comparison between the non-injured ankle and the eventually injured ankle yielded no statistically significant findings for the single leg stance trials. Although each athlete presented with this / her own unique injury history, they did not demonstrate any noteworthy deficits that would perhaps predispose them to a future ankle injury. It is interesting to note that the mean and standard deviation of the COM velocity RMS in both the A/P (BL uninjured = 0.034m, BL injured = 0.103m) and M/L (BL uninjured = 0.053m, BL injured = 0.126m) was higher in the ankle that eventually sustained an injury. This suggests that the participant's COM was moving faster when standing on the injured ankle in comparison to the uninjured ankle. However, the focus of this study was not an investigation of predisposing factors that may contribute to a lateral ankle sprain. Research has attempted to identify potential risk factors for lateral ankle sprains although significant controversy remains. Prospective studies in particular are lacking as certain variables such as baseline ligament laxity cannot be evaluated after an injury has occurred (Beynnon et al., 2002). There are many inconsistencies in the literature with respect to measuring balance, for example; duration of stance, eyes open / eyes closed and the type of equipment used. There does not appear to be a recognized gold standard in assessing balance in this population.

The single leg standing results comparing the uninjured ankle to the injured ankle identified no significant interaction effects of visit and injury however, four main effects were significant. The absence of interaction effects may be reflective of the single leg balancing task itself. Although participants closed their eyes to increase the difficulty of the task, perhaps their experience in training and sport participation allowed them to maintain their balance. The task complexity could be made more demanding by adding a compliant surface to stand on thereby increasing the challenge to the somatosensory system. An additional challenge could be added to change the focus from simply balancing to a dual focus task where perhaps the upper body is involved.

Three of the main effects were noted in the anterior / posterior direction (COP RMS, COP velocity RMS and COM-COP max). This concept has been supported in the literature with subjects with functional ankle instability producing significantly higher dynamic postural stability scores in the anterior / posterior plane (Wikstrom et al., 2007). It has been theorized that individuals with functional ankle instability allow their centre of mass (COM) to approach their stability margins and therefore it takes a greater amount of time to decelerate their COM (Ross & Guskiewicz, 2004). This could explain the increase in COP as it attempts to corral and control the COM. Also, participants sustaining a lateral ankle sprain may produce more movement in the A/P planes and limit movement in the M/L planes in attempt to protect the healing lateral ligaments. The higher values for COP RMS and COP velocity RMS were noted in both the uninjured and injured ankle at the return-to-play stage which demonstrated higher variability. The COM-COP maximum A/P decreased in the return-to-play stage which is indicative of the COM acceleration moving less. These results are somewhat contradictive and warrant further investigation.

The COP velocity RMS in the medial / lateral direction showed a significant main effect of visit. Specifically, return to play data for both the uninjured and injured were significantly higher with large standard deviations as compared to the baseline values. The data was carefully scrutinized and examined for error or outliers to explain these differences. Effect sizes were checked for all significant results using Cohen’s d effect size analysis which proved to be moderate for this variable.

When looking at the jumping results at baseline comparing the ankles of the participants who eventually sustained a lateral ankle sprain (Table 3.9), the only statistically significant difference comparing baseline (0.21 BW*s) and return-to-play (0.24 BW*s) measurements was landing impulse. Again, these findings were not interpreted as a predictor of an ankle sprain. A higher impulse is indicative of a greater momentum production. The rate of loading and overall jump height remained unchanged at baseline comparing the ankles of the participants who went on to sprain their ankle.

The jump task results comparing the uninjured and injured ankle at baseline and return-to-play revealed two statistically significant interaction effects and one main effect. The majority of jumping research has focused on the landing portion of the skill as measured by a variety of tasks including drop jumps and stop jump maneuvers. (Brown et al., 2012, Caulfield & Garrett, 2004). Jumping research also investigates a wide range of variables including joint positions of the lower extremity as well as muscle activation patterns (Lin et al., 2011). There was little research examining a single leg maximum effort jump as used in this study with the focus on kinetic variables.

Impulse measured during take-off and landing decreased in the return-to-play phase in the athlete who sustained a lateral ankle sprain. The amount of impulse created will dictate momentum. The quickest way to decrease momentum during landing is rotation at the ankle joint. This variable was not specifically measured in this study. It is possible that the impulse force was dissipated to other joints using a compensatory landing strategy. Additionally, the change in landing impulse may also be attributed to rest from activity and compliance to a rehabilitation program or a combination of both.

There was a main effect of jump height and visit. That is, when the injured and uninjured participant groups were collapsed, there was a statistically significant decrease in jump height in the return-to-play phase that was more evident in the uninjured group. There was not a significant interaction effect of these variables when looking at the comparison between the injured and uninjured participants. Decreased jump height can be attributed to many variables such as fatigue, motivation to perform the task and boredom. Attempts were made to control for these variables with rest times and encouragement.

It is of interest to note the time to stabilize in the medial / lateral directions increased in the return-to-play stage after sustaining a lateral ankle sprain although not statistically significantly. The participants took longer to stabilize in the M/L axis (1.14 seconds) as compared to their baseline (1.03 seconds). Conversely, the time to stabilize in the anterior / posterior directions somewhat decreased in the return-to-play phase (0.74 seconds) as compared to baseline (0.84 seconds). The medial / lateral stability in the ankle plays an important role in preventing or minimizing an inversion mechanism which can lead to an ankle sprain. This particular variable may indicate that the participant was challenged with controlling their medial / lateral stability upon landing from a jump prior to sustaining an injury. The analysis focused on the M/L data as the stability in these directions play a critical role in injury avoidance particularly lateral ankle sprains. Typically, the anterior / posterior directions have a larger base of support and the threat to losing balance in young, healthy athletes is minimal.

Self-reported outcome instruments that are frequently used in research may have a place in a clinical setting as well. The questionnaires used in this study would assist in acquiring athlete feedback during the rehabilitation process. Athletes in particular may not be forthcoming in expressing their concerns due to pressures (perceived or not) to return to sport as quickly as possible following an injury. As previously mentioned, an ankle sprain in particular is often thought of as a 'minor' injury and the athlete wants to be taped or braced and returned to play rapidly. The significant results of the sport scale questionnaire analysis in this study suggest that an athlete's report of functional abilities should be considered.

With activities of daily living, the athletes noted minimal change after sustaining a lateral ankle sprain. The sport scale portion that assesses high level function such as running, jumping and cutting revealed that the majority of athletes either felt pain or reduced ability as compared to their pre-injury condition. Only 2 out of 14 athletes reported feeling 100% upon return to play whereas 7 of athletes felt 100% prior to sustaining a lateral ankle sprain. The remaining 10 athletes reported continuing difficulty with sport-related activities despite being returned to competition by a certified therapist.

Current return-to-play practices are largely subjective and left to a therapist's discretion as there are no specific protocols in place with respect to rehabilitation of lateral ankle sprains. Other injuries such as a post-operative anterior cruciate ligament repair or concussion offer benchmark goals at specific time points and / or step-by-step progressions for return-to-play. The criteria for return-to-play for the majority of musculo-skeletal injuries are quite general and include; full pain-free range of motion, full strength and an ability to perform functional movements. Although those specific metrics were not evaluated in this study, the chosen biomechanical outcome measures looked to evaluate balance and jumping performance in a more detailed manner. This precise information can only enhance the rehabilitation process and return-to-play decisions. Quantitative biomechanical data can provide a therapist, an athlete and a coach a better understanding of any deficits that may exist following a lateral ankle sprain injury.

4.1 Clinical Relevance

Increasing our knowledge with respect to potential residual deficits following a lateral ankle sprain may potentially improve rehabilitation protocols thereby reducing the risk of re-injury and the residual symptoms experienced by an athlete.

Clinicians often rely on manual testing, simple measurement tools such as a goniometer, subjective assessment of strength and patient feedback during rehabilitation of an injury. Balancing exercises are often prescribed in a very general manner that may not effectively target the deficits an athlete is experiencing. Adding perturbations to challenge an athlete's postural stability may be appropriate but the parameters for these perturbations are unclear. Proprioception, the body's awareness of itself in space should be a key element in every rehabilitation program. This study provides more detailed information as to what is occurring not only in the COP but more specifically in the A/P and M/L directions. This type of data could help guide a therapist to provide very specific exercises that address specific deficits.

Being able to access sophisticated equipment such as force plates and motion capture cameras would enhance the metrics available to the patient and the therapist. The therapeutic goal is to achieve full recovery. Therefore, a comprehensive rehabilitation program should include not only proprioceptive tasks but also range of motion, strengthening and functional exercises. It is often difficult to know if this goal has been achieved without the use of advanced equipment. This type of research can provide more evidence-based knowledge for the field of rehabilitation.

Although a clinical examination can assess physical variables such as range of motion and strength, the psychological readiness and confidence of an athlete preparing to return to sport may or may not be addressed depending on the clinician. This is critical on many levels. If the athlete is tentative in his/her movements, there may be an increased risk of re-injury or a compensatory injury. Performance may also suffer which can be very frustrating for the athlete. The questionnaires used in this study do not specifically address the psychological readiness of an athlete. Nonetheless, this type of questionnaire may initiate discussion around this topic and alert clinicians to potential concerns. A certified athletic therapist may be limited by scope of practice in addressing these concerns however, the questionnaire may highlight the apprehensions an athlete is experiencing and a referral can be made to an appropriate sport psychology consultant.

4.2 Limitations

Sample size was a main limitation in this study. Due to the unpredictable nature of lateral ankle sprain injuries, there was an element of waiting to see if someone who completed a baseline test would incur an ankle sprain that met the inclusion criteria. Repeating this study with a larger sample size would improve the statistical power of the findings. The timing of data collection in this study presented as another limitation. Ideally, once an athlete experienced an injury, the first follow-up appointment should have been scheduled. This acute phase was not collected in all participants for a variety of reasons including; occurrence of another injury, immediate return to play and scheduling conflicts.

Participants selected for this study completed a screening questionnaire and medical history questionnaire. The limitation in any self-reported questionnaire is the reliance on the participant's memory as to the accuracy of the information. In this study, participants were asked to recall episodes of previous ankle sprains as well as any previous diagnostics and treatment.

Although this information was not used in any statistical analysis, it was recorded and presented (Table 3.3).

The use of technology, specifically the force plate and Optotrak systems presented several technical challenges. The IRED markers were placed on the skin and the athlete's clothing. The marker placement could have been compromised as the markers may have moved with the clothing as opposed to the actual bony landmarks. In an attempt to minimize movement, the markers were meticulously placed and secured to the participant in order to minimize extraneous movements. However, at times during the jump movement, the markers had to be re-secured to the participant to ensure proper data collection.

This study did not control for any specific type of rehabilitation program following injury. Therapeutic intervention was left to the athletic therapists' discretion. The athlete's compliance to a rehabilitation program was not evaluated. Perhaps monitoring the frequency, duration and intensity of a rehabilitation program may offer insight as to what techniques and exercises have a positive effect on the outcome measures.

There are limitations with respect to the centre of pressure (COP) variables that were measured. Also, this study used the kinematic data (COM) solely for the purpose of evaluating jump height. Therefore, joint angles specifically at the ankle, knee and hip were not measured. The COP measures themselves cannot elicit the adaptation mechanisms that a person may employ to improve balance. So although a participant may be able to accomplish a task they may not be employing the most efficient strategy. The single leg jump and landing task was selected in an attempt to mimic a functional movement common in many sports. However, the results from this study cannot be generalized to other types of jumps, cutting or change of direction activities.

The potential limitation of researcher bias was controlled for in several ways. As the researcher, there was no involvement in the assessment, treatment or return to play decision for the athlete. The data were analyzed after the completion of all data collection so information regarding any deficits the athlete may have had was not relayed to the treating athletic therapist. A strict testing protocol was followed in order to ensure that every participant received the same instructions and cues.

4.3 Future Directions

This study was designed to investigate if varsity athletes return to their baseline measurements of balance and jumping upon resuming play following a lateral ankle sprain. To our current knowledge, this prospective type of repeated measures design has not been completed previously. As the results of this study demonstrate, athletes do return to the same level of performance with respect to the majority of the variables related to balance and jumping ability. This type of study design could be employed with a larger athlete population looking at lateral ankle sprains of varying degrees. Perhaps more serious injuries (3^{rd} degree sprains) may produce more significant biomechanical changes. It would also be interesting to track the time lost from sport, both practices and games, as a result of a lateral ankle sprain. This type of prospective research could also be utilized for other musculo-skeletal injuries as well. Obtaining baseline data and being able to compare during a return-to-play phase could offer valuable insight to the effectiveness of a rehabilitation program for any injury.

Second, the use of the self-report outcome instruments is commonly used in research studies but may have a place in a clinical setting as well. These questionnaires may help an athlete communicate specific concerns or disabilities and quantify them on an ordinal scale. Thus, the therapist has a greater understanding of the limitations that an athlete may be experiencing. This questionnaire may also open a door for discussion around any psychological barriers an athlete is experiencing as a result of sustaining an injury.

Third, the choice of a single leg jump task is an isolated skill whereby the hip, knee and ankle joint moments occur in the sagittal plane. It would be interesting to examine lateral or cutting-type movements to stress the lower extremity function and specifically the ankle in a more sport-specific way. Additionally, muscle activity was not recorded during this experiment. It may be valuable to understand the muscle recruitment strategies not only at the ankle but also the hip that one employs to maintain balance before and after injury. This would address the concept that a lateral ankle sprain may not be an isolated lower extremity injury but it may in fact have a relationship with the proximal stabilizing musculature.

Lastly, it would be of benefit to disseminate these findings to clinicians in order to increase knowledge with respect to return-to-play decisions. It is clear in the body of research that "it is imperative to remember that an ankle sprain is not simply a local joint injury; it can result in a constrained sensorimotor system that leads to a continuum of disability and life-long consequences such as high injury recurrence and decreased quality of life if not managed properly" (Wikstrom, p. 390, 2013). Ankle sprains are clearly multifactorial in nature. Although a therapist may not have access to the laboratory equipment used in this study, the results may encourage further thought with respect to returning an athlete to play too early following a seemingly innocuous ankle sprain.

5.0 CONCLUSION

In summary, this research demonstrated two significant biomechanical changes; impulse during take-off and impulse during landing of a jump. These changes occurred after sustaining a lateral ankle sprain when tested at the return-to-play stage as compared to baseline testing. Although the results of this study did not show dramatic deficits in the biomechanical outcomes post-injury, this type of research is important for the field of rehabilitation therapy. Rehabilitation is often difficult to study in terms of the numerous variables that may be difficult to control; however, the attempt to quantify recovery outcomes following injury is meaningful for the athlete and the therapist. Increased collaboration between researchers and healthcare professionals can only strengthen the knowledge base with respect to injury recovery and rehabilitation.

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APPENDIX A: Invitation to Participate

WILFRID LAURIER UNIVERSITY
INFORMATION LETTER
Balance Control Testing

Study: Quantifying Balance Control in Varsity Athletes

You are invited to participate in a study as a varsity athlete (between the ages of 17-25) with or without a previous ankle sprain. The objective of this study is to use functional tasks to analyze changes in balance control in varsity athletes. Individuals will be asked to participant in several balancing tasks. The balancing task will require the participant to stand on a force plate on one leg with eyes closed. The force plate will collect data pertaining to biomechanical variables of balance. Twelve markers will be attached to the participant to track movement using a motion analysis system. The participant will also perform a series of single leg jumping and landing tasks. The tasks used in the study will help quantify existing clinical tools used by therapists to evaluate return to play readiness.

Baseline testing will take approximately 45 minutes. Participants may be required to complete additional testing over the course of their season to track their changes in balance control. Participants will be asked to complete additional testing if they incur an ankle sprain. All results will be for the use of research only and will have no influence on your athletic therapist's recommendations in return to play.

This study has been reviewed and approved by the Ethics Review Board (REB #3308).

Contact Information

Jennifer Childs

Email – jchilds@wlu.ca

Phone- 519-884-0710 ext: 2178

Potential participant name: ____

Email address: ____

Phone number (optional): ____

Sport / position: ____

APPENDIX B: Letter of information

LETTER OF INFORMATION

The effects of a lateral ankle sprain on balance and jumping performance

Lead researcher: Jennifer Childs M. Sc. candidate

Supervisor: Dr. Stephen Perry, Associate Professor, Kinesiology & Physical Education

You are invited to participate in a research study examining the effects of a lateral ankle sprain injury on an athlete's ability to perform balance, jumping and landing tasks. This project is being coordinated with the athletic therapists at Wilfrid Laurier University, Teresa Hussey and Jamie Carlson and has the endorsement of the Athletic Director, Peter Baxter. Past research has demonstrated deficits in balance following an ankle sprain. We are interested to see whether a lateral ankle sprain has a detrimental effect on an athlete's ability to balance, to push-off for a jump and to stabilize when landing from a jump when they return to play following a rehabilitation program. We are also investigating the jump height of an athlete before and after injury. The study will extend previous research by establishing a baseline measure prior to injury and then comparing the athlete to him / herself after injury. Identifying performance changes as a result of an ankle sprain will help understand what deficits are present and potentially provide information to rehabilitation clinicians as to what should be considered when returning an athlete to sport.

This research study is being conducted by a Jennifer Childs (M. Sc. Candidate, Department of Kinesiology & Physical Education) under the supervision of Dr. Stephen Perry (Ph. D., Associate Professor, Department of Kinesiology & Physical Education).

INFORMATION

The full extent of your participation involves reading the letter of information, signing the informed consent form, completing a medical history questionnaire and two additional questionnaires that ask about specific activities relating to an ankle sprain injury. These measures will take about 15 minutes to complete. Then you will have markers adhered on specific body locations so that motion during these tests can be recorded. As a participant in this study, you will then be asked to complete a series of standing trials with eyes open on a force plate. This will be followed by single leg balancing with eyes closed on a force plate. The balancing task will be performed three times for 30 seconds each time on each leg. Throughout the time that you are balancing, data will be collected from the force plate and motion analysis systems. The force plate information will be used to calculate balance control during the task. The motion analysis information will be used to calculate the centre of mass. Participants will then perform four trials of maximal effort single leg jumps and landings on the same force plate. Rest periods will be incorporated into the trials to avoid fatigue and muscle soreness. Overall, the study will take about 45 minutes to complete.

Participants will also be asked to complete a second and third session of testing if they incur an ankle sprain injury. A number of athletes that do not experience an ankle injury will also be invited for re-testing to act as a control group. Individuals will not be videotaped for this experiment.

RISKS

There are few foreseeable risks associated with participating in this study. You will begin with the single leg balancing task after an ankle sprain as soon as you are able to weight bear normally in walking without the use of a brace support as determined by medical personnel. If you experience any discomfort or aggravation of your injury, the trial will be stopped. The jumping and landing portion of the study will be conducted once you have been medically cleared by your athletic therapist to resume participation in sport. It is possible when testing athletes' balance and jump abilities, they might become concerned about their performance. Each athlete will be tested individually to avoid competition with others. Any results found will be for the use of research only, and will have no impact or influence on the athletic therapist's recommendations to return to play. All information you provide is considered extremely confidential and your name will not be associated with the data collected in this study. You will not be identified individually in any way in any written or communicated reports of this research.

BENEFITS

The ability to maintain balance during the dynamic movements involved in sport is critical to performance. Injury, especially repeated ankle sprains may compromise an athlete's ability to achieve his / her maximal potential. We know that an ankle injury especially those that are chronic, can result in mechanical and functional changes at the ankle joint and surrounding structures. Therefore, information that helps to identify the biomechanical changes as they relate to performance that may occur as a result of ankle sprains are of vital importance. The present study takes the known research findings about lateral ankle sprains and applies them to the performance aspect of dynamic balance. The outcomes will be important for clinical therapists working with injured athletes and will help to customize rehabilitation treatment protocols to specifically address any deficiencies found.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and anonymous; meaning that no one but the researchers (Dr. Stephen Perry and Jennifer Childs) will see your responses on the questionnaires. At the beginning of the study each participant will be assigned a code number. This code will allow us to match up all the data for each participant. Once the data is matched, the list identifying the participant's name with the code number will be destroyed and only the code number will be left. From that point on, all information will be anonymous. All of the electronic data collected will be stored on a password protected computer in a secure card access only biomechanics lab in the Athletic Complex. No identifying information will be present in the data, therefore ensuring complete anonymity of response. Only group data will be presented in subsequent summaries of the study, therefore, no one will be able to know your individual responses to the questions in this study.

COMPENSATION

Participants will not be compensated for this study.

CONTACT

If you have any questions at any time about the study or the procedures, or you experience adverse effects as a result of participating in this study, you may contact Dr Stephen Perry, Department of Kinesiology, Wilfrid Laurier University, Waterloo, ON N2L 3C5 at 519-884-1970 ext. 4215 or Jennifer

Childs through email at jchilds@wlu.ca or by phone at 519-884-1970 ext. 2178. This project has been reviewed and approved by the University Research Ethics Board (REB Approval number: 3308). If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Robert Basso, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-1970, extension 5225 or rbasso@wlu.ca

PARTICIPATION

Your participation in the study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty. If you withdraw from the study before data collection is completed every attempt will be made to remove your data from the study, and have it destroyed. You have the right to omit any question(s) or procedure(s) you choose.

FEEDBACK AND PUBLICATION

The results of this research may be used for presentations at conferences and in research journals. A written summary of this study will be provided to your athletic therapist and will be made available to the athletes. If you would like to receive a personal summary, you can indicate an email address at the bottom of the consent sheet and we will forward a preliminary and final summary of our findings to you.

CONSENT

I have read and understand the above information. I have received a copy of this form.

I agree to ______________________________________ (participant's name) to participate in the study.

Participant's signature____ Date _______________

Investigator's signature____ Date _______________

Summary of Findings

I would like to receive a summary of the preliminary findings of this study. I have provided the following email address for that purpose:

Name: _______________________________________

Email address: ________________________________

APPENDIX C: Exclusion Screening Questionnaire

VOLUNTEER EXCLUSION CRITERIA

NAME : ________________________________ DATE: _______________

PHONE NUMBER:_____________________

AGE: ____________ GENDER: □ MALE □ FEMALE

HAVE YOU EVER EXPERIENCED? CHECK YES OR NO AND SPECIFY.

6. VESTIBULAR CONDITION (ie. Vertigo): □ YES □ NO

7. BALANCE PROBLEMS / DIZZINESS: □ YES □ NO

8. NEUROLOGICAL IMPAIRMENT: □ YES □ NO

9. VISUAL IMPAIRMENT: □ YES □ NO

10. HEAD INJURY / CONCUSSION: □ YES □ NO
(CURRENTLY SYMPTOMATIC)

11. FRACTURE OF THE SPINE OR PELVIS: □ YES □ NO

12. LOWER EXTREMITY FRACTURES: □ YES □ NO

13. LOWER EXTREMITY SURGERIES: □ YES □ NO

DO YOU FEEL ANY INSTABILITY IN YOUR KNEE? □ YES □ NO

DO YOU FEEL ANY INSTABILITY IN YOUR HIP? □ YES □ NO

DO YOU HAVE ANY MEDICAL CONDITIONS THAT AFFECT THE USE OF YOUR ARMS AND/OR LEGS?

□ YES □ NO IF YES, PLEASE EXPLAIN:

ARE YOU TAKING MEDICATIONS (PRESCRIPTION OR OVER-THE-COUNTER) THAT AFFECT YOUR BALANCE?

□ YES □ NO

DO YOU HAVE AN ACUTE INJURY PRESENTLY THAT WILL AFFECT YOUR ABILITY TO JUMP?

□ YES □ NO

APPENDIX D: MEDICAL HISTORY QUESTIONNAIRE

VOLUNTEER INCLUSION CRITERIA

NAME : ________________________________ DATE: _______________

PHONE NUMBER:_____________________

AGE: _____________ GENDER: □ MALE □ FEMALE

HEIGHT: _______ CM WEIGHT: _______ KG

DOMINANT FOOT (IF KNOWN): □ LEFT □ RIGHT

VARSITY ATHLETE: □ YES □ NO

IF YES: WHICH SPORT: ____

YEARS OF PARTICIPATION AT VARSITY LEVEL: _______

ARE YOU PHYSICALLY ACTIVE:

HOW MANY TIMES PER WEEK?

FOR HOW LONG?

TYPE OF ACTIVITY?

PREVIOUS ANKLE SPRAINS: □ YES □ NO

HOW MANY & WHEN? RIGHT ANKLE:

LEFT ANKLE:

DID A MEDICAL DOCTOR ASSESS YOUR INJURY? □ YES □ NO

WERE YOU ABLE TO WALK NORMALLY AFTER SUSTAINING YOUR ANKLE SPRAIN?

□ YES □ NO

DID YOU USE CRUTCHES? □ YES □ NO FOR HOW LONG: _____

WERE YOU IMMOBILIZED AFTER YOUR INJURY (IE. CAST, WALKING BOOT)? □ YES □ NO

IF YES, FOR HOW LONG? _______

HAVE YOU EVER HAD A SURGICAL PROCEDURE ON YOUR ANKLE AS A RESULT OF AN ANKLE INJURY? □ YES □ NO

IF YES, PLEASE EXPLAIN:

HAVE YOU HAD ANY PREVIOUS TREATMENT? □ YES □ NO

IF YES, WHAT TREATMENTS HAVE YOU HAD & WHEN?

HAVE YOU HAD X-RAYS TAKEN OF YOUR ANKLE? □ YES □ NO WHEN: _______

IF YES, DO YOU HAVE THE RESULTS OF THE X-RAYS?

DO YOU WEAR AN ANKLE BRACE? □ YES □ NO

IF YES, WHICH ANKLE? □ R □ L □ BOTH

DO YOU HAVE YOUR ANKLE TAPED FOR ACTIVITY?

IF YES, WHICH ANKLE? □ R □ L □ BOTH

DO YOU WEAR ORTHOTICS? □ YES □ NO

ARE YOU CURRENTLY EXPERIENCING ANY RESIDUAL SYMPTOMS FROM YOUR ANKLE SPRAIN? PLEASE CHECK ALL THAT APPLY.

PAIN	□	WEAKNESS	□
SWELLING	□	INSTABILITY	□
LACK OF MOTION	□	INCREASED MOTION	□
GIVING WAY	□	TENDERNESS	□
DECREASED FUNCTION	□		

EXPLAIN:

CHANGE IN SENSATION (IE. TINGLING, NUMBNESS) □

OTHER, PLEASE EXPLAIN:

APPENDIX E: THE FOOT AND ANKLE DISABILITY INDEX

Subject Number: _____________ Date: ____________

Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark N/A.

1. **Standing**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

2. **Walking on even ground**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

3. **Walking on even ground without shoes**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

4. **Walking up hills**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

5. **Walking down hills**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

6. **Going up stairs**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

7. **Going down stairs**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

8. **Walking on uneven ground**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

9. **Stepping up and down curves**

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

10. Squatting

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

11. Sleeping

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

12. Coming up on your toes

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

13. Walking initially

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

14. Walking 5 minutes or less

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

15. Walking approximately 10 minutes

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

16. Walking 15 minutes or greater

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

17. Home responsibilities

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

18. Activities of daily living

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

19. Personal care

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

20. Light to moderate work (standing, walking)

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

21. Heavy work (push / pulling, climbing, carrying)

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

22. Recreational activities

4	3	2	1	0	N/A
No difficulty	Slight difficulty	Moderate difficulty	Extreme difficulty	unable to do	not applicable

23. General level of pain

4	3	2	1	0	N/A
No pain	Mild pain	Moderate pain	Severe pain	Unbearable	Not applicable

24. Pain at rest

4	3	2	1	0	N/A
No pain	Mild pain	Moderate pain	Severe pain	Unbearable	Not applicable

25. Pain during your normal activity

4	3	2	1	0	N/A
No pain	Mild pain	Moderate pain	Severe pain	Unbearable	Not applicable

26. Pain first thing in the morning

4	3	2	1	0	N/A
No pain	Mild pain	Moderate pain	Severe pain	Unbearable	Not applicable

APPENDIX F: THE FOOT AND ANKLE DISABILITY INDEX SPORT SCALE

Subject Number: _____________ Date: ____________

Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark N/A.

1. Running

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

2. Jumping

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

3. Landing

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

4. Squatting and stopping quickly

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

5. Cutting, lateral movements

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

6. Low-impact activities

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

7. Ability to perform activity with your normal technique

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

8. Ability to participate in your desired sport as long as you would like

4	3	2	1	0	N/A
No difficulty	Slight difficulty	moderate difficulty	extreme difficulty	unable to do	not applicable

APPENDIX G: PARTICIPANT RECORDING FORM

Date: _______________ Height:

Code: ______________ Weight:

Foot length ________ (cm)

Heel width ________ (cm)

Leg length (GT → lat mall) ________ (cm)

Starting distance from force plate:

Follow-up testing:

Date of injury:

Involved side:

Suspected degree of injury:

Date when able to weight bear:

Date of return to sport:

Baseline Testing:

TRIAL #	Condition	Leg	Eyes	Time	Notes	FP file	Opto file
1	2 leg quiet stance		open				
2	1 leg quiet stance		open				
3	1 leg quiet stance		open				
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							

14							
15							
16							
17							