# EFFECTS OF ACUTE LATERAL ANKLE SPRAINS ON POSTURAL CONTROL OF BIPEDAL STANCE

by

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# TABLE OF CONTENTS

## LIST OF TABLES

**Table** **Page**

## LIST OF FIGURES

# ABSTRACT

**Context**: Bilateral deficits of postural control during unipedal stance have been reported after an acute ankle sprain and CAI, but it is little evidence of postural control deficits on bipedal stance. **Objective:** To determine effects of acute lateral ankle sprain on postural control of the bipedal stance. **Design**: A case-control design. **Setting**: Laboratory. **Patients or Other Participants**: Ten patients with LAS (7 males and 3 females) and gender-matched 10 subjects without any history of ankle injuries participated in the study. **Intervention(s)**: Postural control was assessed with Sensory Organization Test (SOT). Subjects were asked to perform 3trials on each of the 6 SOT condition and each trial was lasted for 20 s. **Main Outcome:** Equilibrium scores for each trial were calculated and utilized to quantify bipedal postural control with higher equilibrium score indicating better postural control. **Results**: The injured group had significant lower equilibrium scores when compared with the uninjured group on the stable surface with eyes open (U=78, *p*=.035; SOT Condition 1) and with eyes closed conditions (U=.81, *p*=.019; SOT Condition 2). No significant group differences were found in other 4 SOT conditions (*p*>.05). **Conclusions**: The findings indicate that an acute LAS may negatively affect the ability of postural control during quiet bipedal stance. **Word Count:** 208

**Key Words:** Acute lateral ankle sprain, Bipedal stance, Postural control

# CHAPTER I

## Introduction

### Introduction

Lateral ankle sprains (LAS) are one of the most common acute injuries that occurs during physical activity.[1-4] The high incidence rate of LAS contributes to the public perception of it being an innocuous injury. However, LAS have been documented to result in varying degrees of consequences including impairments (ex: decreasing strength) , functional limitations, and even disability.[3] Chronic pain, swelling, muscle weakness, crepitus, ankle instability and/or recurrent LAS have been reported months to years after initial injuries, and up to one-sixth of time lost from sports are due to this injury.[5-8] In addition, 68-78% of patients with a history of ankle sprain reported the onset of ankle osteoarthritis.[9-10] It is not uncommon for primary care physicians and other health care providers such as physical therapists and athletic trainers to misdiagnose various ankle problems as simple ankle sprains[11], and thus it is critical to have a good system in evaluation of acute ankle sprain injury. Current literature suggests a thorough injury assessment is warranted to better capture all aspects of these injury consequences, leading to more effective treatment strategies.[5, 9, 12-13]

Postural control deficits are a prominent problem in patients with LAS and chronic ankle instability.[14-17] Postural control has been shown to have an inverse relationship with risk of LAS. That is, individuals with poor postural control tend to have a higher risk of injury and those with better postural control may have a lower risk of injury.[18-20] In addition, preventative training programs and rehabilitative balance programs for postural control have been shown to substantially decrease the risk of injury and improve self-reported motor function.[19, 21-22] Therefore, it is critical to thoroughly assess the postural control of patients with LAS in an effort to better understand the injury and enhance treatment outcomes

Postural control deficits in an unipedal stance have consistently been reported following an ankle sprain.[16-17, 23] A prospective study of total 28 individuals (11 males/17 females, age = 19.7 ± 1.4 years), who suffered acute, mild to moderate LAS, determined that unilateral acute ankle sprains impaired postural control in both the injured limbs and the uninjured limbs[24]. The findings of bilateral deficits in postural control after an acute LAS seem to be conclusive in a systematic review.[17] The bilateral postural control deficits following a unilateral ankle sprain indicate a central impairment in neuromuscular control referred to as a feed-forward mechanism. A feed-forward mechanism produces postural control deficits in the uninjured limb. However, Proprioceptive deficits in the injured ankle are considered a result of impairments in the feed-back mechanism.[23] Given the bilateral impairments following unilateral acute LAS, individuals with the injury may suffer deficits in postural control of the bipedal and the unipedal stance. To our best knowledge, there has been only one study that assessed postural control deficits on bipedal stance [25]and found that individuals with acute ankle sprains presented deficits in bipedal stance, but the findings were not statistically significant. However, bipedal deficits were measured in only quiet stance on a force plate in the previous study by Rose et al.[25] This current study added several measurements of bipedal postural control to understand and analyze the relative contributions of the somatosensory, visual and vestibular systems.

## Purpose

To fill the gap in the literature clarifying postural control impairments of the bipedal stance for patients with acute LAS, the purpose of the study was to determine effects of acute LAS on postural control of the bipedal stance. Since it is not uncommon to utilize a single leg stance balance assessment for evaluation and exercises for rehabilitation after an acute LAS, this study is important to be conducted to provide insights into both the rehabilitative balance training protocol and balance assessment.

## Significance of the Study

The outcomes of this study provides significant contributions to the field of sports medicine by 1) examining the effects of an acute LAS (within 3 days after the injury) on ability of postural control on bipedal stance, 2) providing the information of an underlying of mechanism of postural control deficits associated with an acute LAS. In the literature, bilateral deficits on postural control associated with an acute LAS have been reported[12-13]. This finding indicated that centrally mediated changes occur associated with a LAS[12-13, 20], and spinal-level motor control mechanism are altered as the cause of bilateral deficits in postural control[12-13, 20]. Alterations of motor control mechanisms at spinal-level may be viable and a plausible concern on the finding of bilateral deficits associated with an acute LAS, even though the exact mechanisms of these alterations remain unknown. Also, these bilateral postural control deficits were found on assessment with a single leg stance[13]. There are limited findings on individual's ability of postural control on bipedal stance following an acute LAS.[19] Also, there are few studies that strictly include subjects who sprained an ankle within the past three days like this study. This study help athletic trainers and other health care professional better understand the influences the "true" acute ankle sprain has on postural control.

**Research Question**

This study is designed to answer the following questions:

- Do individuals with an acute lateral ankle sprain have postural control deficits in bipedal stance, compared to individuals without the injury?
- In the case of presence of deficits in postural control in individuals with the injury, which setting of SOT will show postural control deficits?

**Hypothesis**

- We hypothesize that the acute ankle sprain group would present deficits in postural control, compared to the group without the injury
- We hypothesize that the acute ankle sprain group would exhibit decreased contribution of the somatosensory system to bipedal balance, compared to the group without the injury
- We hypothesize that deficits in postural control would be moderately correlated with alterations of somatosensory contribution to balance

**Assumptions**

- This study assumed participants are honest in all self-reports of pain, previous injury, medical history, current health, all of the assessments.
- This study assumed participants fully comply with restrictions prior to the study participation.
- This study assumed participants perform balance tasks in Neurocom with their best efforts.

**Delimitations**

- Participants are 18-55 years of age.
- Participants was confirmed grade I or II acute ankle sprains
- Participants were measured and evaluated within 3 days of injury.
- Participants do not have current lower extremity injuries within the past 6 weeks
- Participants do not have any history of lower extremity surgery
- Participants are free from any neurological conditions known to affect postural control assessment on NeuroCom

**Limitations**

- Balance testing of unipedal standing is NOT allowed on the NeuroCom
- The order of 6 balance tests on Sensory Organization Test cannot be randomized.

**Operational Definitions**

<u>Center of gravity (COG)</u>: A point of action of the total gravitational force. In general, an individual's COG may be located within or outside to the body, depending on the individual's posture

<u>Postural Control</u>: An ability to utilize sensorimotor system to maintain COG within the base of support

<u>COG sway angle</u>: An angle between a vertical line projecting upward from the center of the area of foot support and a second line projecting from the same point to the individual's COG

Ankle sprain: A condition that described as stretching or tearing of the collagen fibers of lateral ankle ligaments including anterior talofibular ligament (ATFL), calcaneofibular (CFL), posterior talofibular ligament (PTFL).

Chronic ankle instability: A condition of feeling of ankle joint instability occurs with recurrent episodes of lateral instability contributing to subsequent ankle injuries

Sway: Movements of the forceplate or the surroundings, or the both, referenced by individual's COG movement during the 20sec assessment of the Sensory Organization Test

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# CHAPTER II

## Literature Review

The purpose of the current literature review is to discuss the relevant literature surrounding 1) epidemiology and evaluation of lateral ankle sprain, 2) Consequences of a lateral ankle sprain focusing on postural control deficits, 3) mechanisms of postural control deficits following an ankle sprains, and 4) methods of postural control assessment

### Epidemiology of Lateral Ankle Sprain

Lateral ankle sprain is one of the most common acute injuries that occur during physical activity.[2-4] Recently, a large-scale study reported 628, 026.4 ankle sprains per year in the general population in the United States.[5] The reported incidence of ankle sprain in military and athletic groups is 27 times greater than the reported incidence in the general population.[5] The sprained ankle has been commonly described as stretching or tearing of the collagen fibers of lateral ankle ligaments including anterior talofibular ligament (ATFL), calcaneofibular (CFL), posterior talofibular ligament (PTFL), as a result of excessive and explosive plantarflexion and inversion while the tibia is externally rotated.[6, 41] The ATFL is most susceptible to ankle sprains, because it becomes taut when the foot and ankle are supinated. If the amount of supination is sufficient or if the ankle is near its neutral position, the CFL may be damaged. A study with 639 ankle sprain patients found that 448 patients injured the ATFL with and without injuries to other ligaments. The ATFL was the only lateral ligament involved in 90 cases, while both the ATFL and CFL were involved in 187 cases. 171 cases were involved with combination of the ATFL, CFL and PTFL. Only nine cases involving isolated PTFL were noted in this study.[41] A significant inversion force in an ankle dorsiflexed, or closed- packed position, is the required mechanism to stress PTFL. As you can see from the previous study[41], sprains of the PTFL rarely occur in isolation. Trauma to the PTFL is often associated with significant ligament disruption of the ATFL and CFL.[41]

**Evaluation of Ankle Sprains**

The differential diagnosis for any self-reported acute traumatic incident involving forced inversion includes, at a minimum, LAS, distal fibular fracture, fracture to the base of the fifth metatarsal, peroneal strain, impingement of the medial joint capsule, osteochondral fractures of the talus, and fractures of the medial malleolus can occur concurrently with LAS.[42] Patients with acute LAS will usually report local pain on the lateral aspect of the ankle, typically over the malleolus and sinus tarsi. Hearing or feeling a “pop” or any abnormal tearing sensation is also possible, but neither is an indicator of injury severity.[43]

Since the ATFL and PTFL are capsular structures, damage to these ligaments can produce rapid and diffuse swelling. Observation of the lateral aspect of the ankle typically reveals swelling and discoloration around the lateral joint capsule that may or may not spread to the dorsum of the foot and into the sinus tarsi area. Within 24-48 hours after the injury, discoloration can be observed.[44] Ankle edema can be classified visually as light, moderate and severe, and it is common that the health care providers, such as doctors, athletic trainers, or physical therapists, utilize this classification[1]. However, visual inspection of discoloration and edema is not recommended as the sole indicator to determine injury presence or severity due to the fact that interobserver agreement for the visual inspection of discoloration and edema is poor to fair.[44] Figure 8 girth measurement technique for edema, which has high reliability [Intraclass correlation coefficient (ICC) = 0.98], is recommended and is easy to use.[1] The figure 8 technique for the ankle is measured with the participant in a seated position while the knee is in full extension and the ankle is in a neutral position. The guideline for tape measure alignment and sequence, from a previous study is as follows: 1) Starting at the "zero" point, which is the middle point between the articular projection of the anterior tibial tendon and the lateral malleolus, 2) to the center of the foot along the medial longitudinal arch on the navicular bone, 3) to the lateral malleolus and calcaneal tendon, 4) to the medial malleolus, and 5) to the zero point of the tape measure.[1, 45]

Palpation often elicits pain along involved ligaments and particularly over the sinus tarsi area overlaying the ATFL.[44] The reliability of eliciting ATFL point tenderness has been determined as moderate, but clinicians should be aware of often diffuse presentation of pain upon initial examination, becoming more localized to the ATFL 5 days post-injury.[44] Palpation of the medial structures, especially the deltoid ligaments and medial malleolus, should be part of the initial examination in spite of the lateral nature of the injury. In severe LAS, the medial wall of the talus can strike the distal medial malleolus, resulting in a bone bruise and/or fracture.[41, 44] Severe LAS can also include impingement of the medial ligaments, medial joint capsule, and the structures passing beneath the medial malleolus, specifically, tibialis posterior.[44] Range of motion (ROM) is typically decreased in all planes due to pain and swelling; additionally, active plantar flexion/inversion and passive inversion elicits lateral pain over the lateral ligaments as the ATFL and CFL are stretched.[6, 44]

The Foot and Ankle Ability Measure (FAAM) can be utilized to quantify and assess physical function for participants with foot and ankle related impairments.[46] This self-reported outcome instrument is 29-items questionnaire divided into 2 subscales: activities of daily living (21 items) and FAAM sport scale (8 items). Each item is scored on a 5-point Likert scale (4 to 0) from 'no difficulty at all' to 'unable to do'. Item score totals, which range from 0 to 84 for the ADL subscale and 0 to 32 for the Sports subscale, are transformed to percentage scores. Higher scores represent higher levels of function for each subscale, with 100% representing no dysfunction.

**Consequences Following an Ankle Sprain**

Ankle sprains may be erroneously seen as mild injuries with no permanent disabilities, because of the high incidence.[20] A systematic review which included 31 prospective studies noted a rapid decrease in pain, and improvement in function in the first 2 weeks after injury.[47] However, 5 – 33% of patients continued to have pain at 1 year or longer follow-up.[47] A long-term outcome study demonstrated that 32% of the 7 years post-injury subjects complain of chronic pain, swelling or recurrent sprains.[7] Chronic complaints of pain, swelling, muscle weakness, crepitus, ankle instability and/or recurrent LAS have been reported months to years after initial injuries, and up to one-sixth of time lost from sports are due to this injury.[6-9] LAS has been documented to result in varying degrees of consequences including impairments and functional limitations, and even disability.[4]

After an initial injury to the lateral ankle, injury recurrence or chronic ankle instability (CAI) can occur. CAI is defined as recurrent episodes of lateral instability contributing to subsequent ankle injuries.[14] CAI is classified into two categories; functional instability and mechanical instability.[48] Functional ankle instability describes individuals who report instability but have normal joint motion, whereas mechanical ankle instability describes those with excessive joint motion.[48-49] Mechanical ankle instability includes laxity in both the talocrural joint and subtalar joint, which both contribute to symptoms of instability.[41, 48] On the other hand, it has been noted that functional ankle instability is caused by deficits in sensorimotor and/or neuromuscular functions.[24, 50] Mechanical and functional instability of the ankle joint can contribute to increased re-injury rate.[41] It is suggested that the recurrence rate of lateral ankle sprains after initial injury could be as high as approximately 75%[13]. In addition, it is reported that 68-78% of CAI patients has developed ankle osteoarthritis, which usually leads to long term suffering of the patient from symptoms.[10]

The sensorimotor functions, such as proprioception, postural control, reflex reactions, alpha motor neuron pool excitability and muscle strength, in individuals with ankle instability have been investigated.[16, 24, 51-52] A recent systematic review noted postural control deficits when standing with eyes closed on unstable surfaces, prolonged time to stabilize after a jump, and concentric inversion strength deficits in those with CAI.[51] In 1965, Freeman and colleagues demonstrated and described a consistent clinical presentation with sensorimotor deficits associated with lateral ankle sprains.[53] After the work of Freeman, postural control tasks have been focused on, not only in research and literature, but also in the clinical setting to prevent, assess, and rehabilitate patients with acute LAS or CAI. There is strong evidence supporting that postural control has an inverse relationship with risk of injury; where individuals with poor postural control have an increased risk of injury and those with better postural control have a lower risk of injury.[19-21] Also, preventative training programs for postural control, and rehabilitative balance programs have been shown to sustainably decrease the risk of injury and improve self-reported function.[20, 22-23] American Physical Therapy Association (APTA) has recommended incorporating balance or proprioception exercises following acute LAS on the clinical practice guidelines for ankle ligament sprain to prevent reoccurrence of the injury.[54]

A meta-analysis study[17] demonstrated that postural control deficits are present in people with a history of both acute LAS and CAI. This review included 25 studies, which found postural control deficits in the injured ankle groups, when compared to the control groups.[17] This study agrees with the impairment of postural control and how it relates to an increased risk of ankle injury but also demonstrated that there were bilateral postural control deficits following acute LAS.[17] Due to difficulties to meet the inclusion criteria for subjects with an acute ankle sprain, many studies have been conducted on individuals with CAI. In two recent systematic reviews and meta-analysis, 44 studies met inclusion criteria for the investigation of postural control deficits following lateral ankle trauma.[17-18] Among those 44 studies, there are only 12 studies including individuals with an acute ankle sprain. The finding of postural control deficits on both the injured leg and uninjured leg is interesting, although the sample size for the acute ankle sprain group was not as large as the CAI group. This finding may have a strong influence in prevention and rehabilitation, since health care providers commonly utilize the uninjured limb as a criterion of "normal" postural control among patients with acute LAS or CAI. Additionally, inappropriate conclusions will more likely be made if the uninjured limb is used as a reference. The wide range of variance of the inclusion criteria for the acute ankle sprain group is a limitation of these studies. Some tested their subjects on the 3$^{rd}$-10$^{th}$ day after the injury while other studies tested 30 days after the injury.

Significant deficits in static postural control existed on both the injured limb and uninjured limb for up to 7 days [25], while deficits in dynamic posture have also been shown following an acute ankle sprain using the Star Excursion Balance Test (SEBT).[55] As a single leg stance has been commonly utilized to assess or rehabilitate postural control, those 12 studies assessed postural control on a single leg stance. Only one study utilized a bipedal stance with conditions of eyes open and closed. This study found an interesting result that the ankle sprain group consistently demonstrated worse scores in the bipedal stance with both conditions of eyes open and closed over the 11 days of testing compared to the healthy control group, although this interesting difference was not significant.[26]

**Mechanisms of Postural Control Deficits Following Ankle Sprains**

Freeman and colleague proposed a theory called articular de-afferentation, which is based on a feedback-only model of proprioceptive and efferent motor control deficits.[53] This theory indicates that sensorimotor deficits following joint injuries are caused by damage to the afferent receptors within the injured ligaments and joint capsule at the joint.[53] Upon LAS, there is damage to the collagenous connective tissues such as ligament and joint capsule, but also to the sensory mechanoreceptors on the ligaments and joint capsule. It is believed that proprioceptive deficits occur due to the damage to sensory mechanoreceptors. This decrease in proprioceptive input may cause central nervous system dysfunction in accurate perception of where the ankle joint is in space, and consequently lead to an increased incidence of the ankle sprains, which is also known as CAI, due to the fact that there is inadequate peroneal musculature response to the ankle position.[52, 56-58]

Although this traditional theory has widely been used and cited for more than 30 years in literatures, there are some impediments that cannot be ignored, in order to fully accept it. There is consistent evidence showing absence of postural control deficits in individuals who experimentally induced proprioceptive deficits.[59-60] Two studies have aimed to anesthetize the lateral ligaments of the ankle or the entire foot and ankle, as to directly impair the function of the ligamentous and capsular Proprioception.[59-60] Deficits in passive joint position sense was found, but postural control in a single leg stance, active joint position sense or peroneal reaction time were not impaired.[59] Similarly, no postural control deficits were reported in a study in anesthetized lateral ligaments of the ankle.[60] The lack of actual change in postural control despite anesthetization of the lateral ankle ligaments is most likely attributed to the redundancy of sensory information available from other sensory receptors, such as articular, musculotendinous, and cutaneous receptors. These findings suggest that postural control deficits following an acute ankle sprain may be influenced by changes in neuromuscular control via alpha motorneuron pool excitability and/or the feed-forward role of the gamma motorneuron system.[58, 61] In addition, the finding of postural control deficits in both injured and uninjured limbs provides further evidence of changes in alpha motorneuron pool excitability in individuals with acute LAS.[17-18] This information indicates that motor control mechanisms are clearly altered at the spinal level.

The postural control system consists of the complex organization of three major sensory input systems, somatosensory, vision and vestibular; which are all integrated by the central nervous system (CNS) to generate a motor response.[28, 52, 57, 62-64] Optimal postural control prevents the body from falling to the ground while performing a variety of activities from quiet stance to complicated athletic tasks.[62] To maintain normal quiet stance and to safely achieve the majority of daily living activities, individuals rely primarily on proprioceptive inputs.[27] Even though convincing evidence of postural control deficits following either an acute LAS or CAI has been reported in literature, it has not been investigated yet whether changes in integration of those three sensory systems for postural control exists after acute LAS. Hence, it is critical to examine and understand that individuals with acute LAS may have a certain preferred strategy to maintain their postural control due to the effects of somatosensory deficits.

## Methods to Measure Postural Control

A variety of non-instrumented and instrumented measures of postural control have been reported in ankle instability studies over several decades. Instrumented force plate measurement is currently the gold standard of assessment for postural control abilities.[36]

### Instrument

*Force platform*

Force platform is a technical instrument that provides an indirect assessment of changes in postural sway by recording the ground-reaction forces projected from the body.[65] Since the early 1970s, force platforms have been utilized to obtain quantitative measures and analyses of postural control.[65] The center of pressure (COP) is calculated and obtained directly from a force platform. A variety of output data quantifying postural control is available from analysis of COP including mean sway amplitude, maximum sway amplitude, minimum sway amplitude, peak-to-peak amplitude, sway path, sway velocity, root-mean-square (RMS) amplitude, and RMS velocity.[65]

In numerous studies examining the postural control system, researchers and clinicians have mainly focused on the movements of two variables, COP and center of gravity (COG). The variable COG is analyzed in the evaluation of postural sway, but this variable cannot be directly acquired from a force platform. Postural sway specifically refers to changes in COG. COG is considered to be a passive variable that is guided by the postural control system, while the COP is the center of the distribution of the total force applied to the supporting surface. The COP is acquired when both feet are in contact with a single force platform; found between the right and left feet. It is dependent on how much weight each foot absorbs.

*COP parameters*

The maximal amplitude is a maximum absolute displacement of COP from its mean displacement from the center of the forceplate. The minimum amplitude, on the other hand, is a minimum displacement of COP from its average point.[65] A decrease in either the maximum or minimum amplitude indicates better postural control. However, they are not reliable variables [65] due to high variability found between trails and between subjects. For this reason, peak-to-peak amplitude, the difference between the maximum and minimum amplitudes, should not be utilized to analyze or examine postural control.[65]

Mean amplitude of COP, which represents an average value of all data points collected in a trail and is a more representative measure of postural control. A smaller value in mean COP amplitude indicates better postural control. Mean COP is used to assess postural equilibrium in the Anterior/ Posterior (A/P) and Medial/ Lateral (M/L) directions.[65] However, this measure is very sensitive. Small amounts of noise can cause an abnormal increase in COP for a moment, which can lead to misinterpretation of the outcome. Mean amplitude is defined as the average COP amplitude, which was utilized for a study and demonstrated to be reliable during a double-legged stance between trials (intraclass correlation coefficient = 0.70 – 0.90).[65] Since the value can be varied depending on the location of the feet or foot on the platform, it requires standardizing feet position and confirming feet position each trial. Displacement from the standardized feet position changes the mean amplitude and misrepresents a change in outcomes.

Total excursion (TE) of the COP is the total distance traveled by the COP over the course of the trail duration.[65] Since a large TE may simply suggest that the COP needs to make sizeable excursions or several small excursions to have a good postural control, the value of TE to analyze postural control would not be high. COP velocity is defined as the total distance traveled by the COP over time. This parameter is calculated by dividing TE by the trial duration. COP velocity has been demonstrated to be reliable between sessions in a double legged stance (R= 0.84).[66] An increase in COP velocity represents a decreased ability to control posture.[65]

Root-mean-square (RMS) amplitude is defined as standard deviation of the displacement of COP.[65] This variable measures the average absolute displacement around the mean COP. RMS velocity represents the distribution of COP displacements over time. A higher value for either of these variables represents an increased ability to control posture. It has been suggested that RMS amplitude (coefficient of variance = 31.95%) and velocity (coefficient of variance = 26.95 %) are reliable to analyze postural control.[67] RMS amplitude and velocity have been demonstrated to be sensitive to altered somatosensory system.[67]

Thus, a variety of COP parameters can be utilized to detect postural control deficits in patients with neurological disorders and musculoskeletal pathologies. Mean COP, RMS amplitude and RMS velocity are recommended because those variables are capable of detecting changes in the A/P and M/L directions, so that missing postural control deficits can be minimized.[65]

*Biodex Stability System (BSS)*

The Biodex Stability System (BSS) is a multi-axial device that provides objective measurements and records an individual's ability to stabilize the involved joint under dynamic stress. The BSS utilizes a circular platform that is free to move in the A/P and M/L axes simultaneously.[68] The BSS allows up to 20 degrees of foot platform tilt, which allows ankle joint mechanoreceptors to be stimulated maximally. The BSS measures the tilt about each axis during dynamic conditions and calculates a M/L stability index (MLSI), A/P stability index (APSI), and an overall stability index .[30] A study conducted found the BBS to be a reliable postural control assessment device across multiple test trials, which lasts for 20 seconds, in healthy college individuals.[69] At level 2 resistance (out of 8), the intraclass correlation coefficient for the OSI measures was R=0.60 for assessment of the dominant and the non-dominant leg. At level 8, the intraclass correlation coefficient was R=0.95 for assessment of the dominant leg, and R=0.78 for assessment of the non-dominant leg.[69]

*SMART EquiTest*

The SMART EquiTest is an instrument that provides objective information of postural control and has the capability of retraining the sensory and voluntary motor control in balance with visual biofeedback on an either stable or unstable support surface and in a stable or dynamic visual environment.[28] This assessment instrument utilizes a dynamic dual force plate and consists of two 22.89cm × 45.72cm footplates connected by a pin joint. The machine consists of a 3-sided booth, moveable dual force plates, a moveable monitor, and overhead attachment for a safety harness strap. It also has 4 corner transducers measure the vertical forces, whereas the center transducer measures the shear forces in the plane parallel to the floor. The machine has rotation capabilities and measures vertical forces exerted by the individual's feet and a moveable visual surround booth.[27-28] The SMART EquiTest includes the following standardized assessment protocols; Sensory Organization Test (SOT), Motor Control Test (MCT), Adaptation Test (ADT), Limits of Stability[70], Rhythmic Weight Shift (RWS), Weight Bearing Squat (WBS), and Unilateral Stance (US).[28] SOT, MCT and ADT consists of the core battery of tests recognized as computerized dynamic posturography, which is considered the highest standard available for diagnosing the functional impairments underlying postural control disorders.[28]

*Sensory Organization Test (SOT)*

The SOT protocol objectively identifies abnormalities in the patient's use of the three systems that contribute to postural control, somatosensory, visual and vestibular. Sensory Organization is the capability of an individual to effectively process individual sensory system input cues to maintain postural control. During the test, useful information delivered to the patient's eyes, feet and joints is effectively eliminated through calibrated "sway referencing" of the support surface and/or visual surround, which tilt to directly follow the patient's anteroposterior (A-P) body sway.[28] Therefore the more accurate the sensory cues to produce appropriate motor and postural response strategies, the better postural control are. The SOT systematically evaluates the ability of utilizing three sensory systems for postural control, objectively isolateing and quantifying the use of each sensory system and the adaptive responses of the central nervous system (CNS).[28] The SOT protocol consists of 6 sensory conditions: (Figure 2.1)

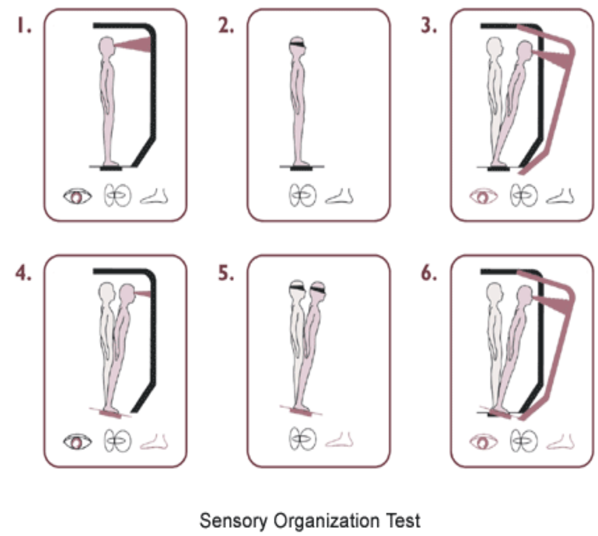


**Figure 2.1: 6 Conditions of SOT Test**

During this test, a safety harness is provided to the participant.[31] There are three different sizes, including small, medium and large, and an appropriate size is provided to each participant. After the appropriate safety harness is worn, the participant is instructed to position themselves in standard testing position: 1) aligning the medial malleolus to the center horizontal line, 2) aligning the calcaneous (lateral border of the foot) to the appropriate height line, and 3) participants may be allowed to splay to comfort with the rear foot position as you can see in Figure 2.2 The participant is familiarize with the SOT by being informed of the the six conditions (1-6): 1) Eyes open, fixed surface and visual surround, 2) Eyes closed, fixed surface, 3) Eyes open, fixed surface, sway-referenced visual surround, 4) Eyes open, sway-referenced surface, fixed visual surround, 5) Eye closed, sway-referenced surface, and 6) Eyes open, sway-referenced surface and sway-reference visual surround[28]. Sway-referenced surface involves the tilting of the support surface and/or visual surround to directly follow the participant's COG sway such that the orientation of the surface remains constant in relation to the COG angle. With this technique, the six different settings on SOT can challenge participant's capability of postural control by manipulating visual, somatosensory and vestibular inputs. While standing on bare feet on the force plates during those 6 settings, participants were instructed to maintain an upright posture while looking straight ahead with hands on their iliac crest.[31] Three trials of each condition were administered. A good test-retest reliability has been noted on this test[71]; investigation of whether the SOT is consistent in measuring average balance performance over the three trials were also conducted[71] Conditions 1 to 2 and 4 to 6 exhibited fair to good reliability (ICC: condition 1= 0.51, condition2 = 0.42, condition 3 = 0.26, condition 4 = 0.47, condition 5 = 0.68, condition 6 = 0.64). The SOT composite score demonstrated good reliability with an ICC of 0.66.[71]

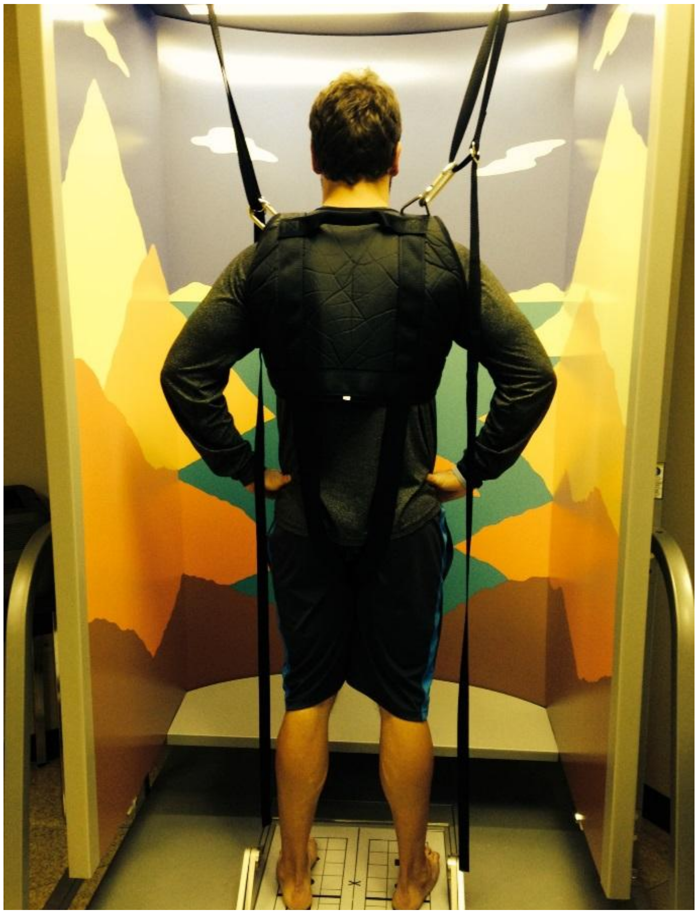

**Figure 2.2: Position of Subjects during SOT Test**

SOT provides a variety of outcomes; Equilibrium Score, Sensory Analysis, Strategy Analysis and COG alignment. Equilibrium score quantifies the center of gravity

(COG) sway or postural stability under each of the three trials of the six sensory conditions. Effective use of individual sensory inputs is determined from the overall pattern of scores on the six conditions. The composite equilibrium score, the weighted average of the scores of all sensory conditions, characterizes the overall level of performance.[28] Sensory analysis ratios are utilized in conjuction with the individual sensory sytems. This outcome emphasizes the uniqness of this instrment and test (Table 2.1). Strategy analysis quantifies the relative amount of movement about the ankles (ankle strategy) and about the hips (hip strategy) the patient used to maintain postual control during each trial. Normal, stable individuals move primarily about the ankle joints when the surface is stable and shift to hip movements as they become less stable. COG alignment reflects the patient's COG postion relative to the center of the base of support at the start of each trial of the SOT. Normal individuals maintain their COG near the center of the support base.

**Table2.1:** Sensory Analysis Ratio

| Sensory Analysis | | |
|---|---|---|
| **Ratio Name** | **Ratio Pair** | **Significance** |
| **SOM Somatosensory** | **Condition 2 / Condition 1** | **Question:** Does sway increase when visual cues are removed? **Low scores:** Patient makes poor use of somatosensory system cues for balance |
| **VIS Visual** | **Condition 2 / Condition 1** | **Question:** Does sway increase when somatosensory cues are inaccurate? **Low scores:** Patient makes poor use of visual system cues for balance control |
| **VEST Vestibular** | **Condition 2 / Condition 1** | **Question:** Does sway increase when visual cues are removed and somatosensory cues are inaccurate? **Low scores:** Patient makes poor use of |
| **PREF Visual Preference** | **Condition 3 +6 / Condition 2+5** | **Question:** Do inaccurate visual cues result in increased sway compared to no visual cues? **Low scores:** Patient relies on visual cues even when they are inaccurate (such as in moving |

The equilibrium scores are calculated using all conditions of SOT based on a subject's postural sway for each condition of SOT. The postural sway is calculated by determining the maximal and minimum AP sway angles. The AP sway ankle is the angle between a line projecting vertically from the center of foot support and a line from the center of foot support to the COG. An overall composite equilibrium score describes an individual's overall level of performance during all of the trials in the SOT. The composite score is the average of the following 14 scores: the condition 1 average score, the condition 2 average score, and the three equilibrium scores from each of the trials in conditions 3-6. A composite equilibrium score of 100 indicates no postural sway; therefore, a higher score represents better postural control. Numeric data provides the absolute values for each trial of each condition; this absolute value allows for an objective comparison to the normative value of a matched-age average and to the control group of this study.

Sensory analysis represents the potential contributions of visual, somatosensory and vestibular sensory systems to maintain postural control. Because each condition of the SOT targets specific sensory systems while maintaining postural control, the SOT allows measuring the respective contributions. For instance, we can assess individual's ability to utilize the somatosensory system to maintain postural control with calculation of the ratio of the equilibrium scores of condition 2 (eyes closed and fixed surface) and condition 1(eyes open and fixed surface). This ratio indicates the relative reduction in postural control when visual and vestibular inputs are simultaneously disrupted. In the same way, the ratios of condition 4 to condition 1 and condition 5 to condition 1 are calculated to analyze the vision and vestibular systems. These sensory ratios are useful to identify the contribution of each sensory system for postural control and sensory integration.

**Non-instrument**

*A single-leg stance*

A single leg balance test (SLB) described as early as 1965 is a traditionally simple and inexpensive assessment to identify balance deficits. A SLB on a firm surface to assess balance is relevant because it identifies balance impairments associated with functional ankle instability and it is the most frequent type of surface utilized to assess balance.[26, 72] The SLB test is defined as standing on one foot without shoes with the contralateral knee bent and not touching the weight bearing leg; the hips are level to the ground; the eyes open and fixed on a spot marked on the wall; and then the eyes are closed for 10 seconds. Then the participant reports any sense of imbalance and the investigator notes if the participant's legs touched each other, the feet moved on the floor, the foot touches down, or the arms moved from their start position.[72] Some studies demonstrated that the SLB test predicts susceptibility of ankle sprain injury.[19, 72] The SLB test was used in a prospective cohort study of high school and college athletes, and demonstrated a significant association between a positive SLB test and ankle sprain; a positive test indicating greater risk of ankle sprains.[72] A high relative risk in those athletes with a positive SLB test and a history of ankle sprains should be placed in a prevention program or device like ankle taping and bracing (relative risk = 7.18 (95%CI, 1.06 – 61.7).

There are some variables to examine during a single leg stance. One of the most reliable means to utilize a single leg balance test would be the foot-lift test. Test-retest reliability of the foot-lift test is fairly good (Pearson's r= 0.78; ICC = 0.73, 95% CI= 0.40 -0.89).[73] During the foot-list test, participants stand barefoot on one leg in a standardized position; the other foot touched the stance calf, arms by the side, and looking straight ahead. When participants feel steady, they close their eyes and maintain their balance without using their arms or other leg. If they lose their balance, they are instructed to keep their eyes closed while they attempt to regain their balance. The number of times a part of the foot was lifted during the 30 seconds is recorded. The ankle instability group lifted the foot more frequently than the control group in a SLB test.[73]

*BESS*

The Balance Error Scoring System (BESS) was initially established and developed as an easily administered cost-effective objective assessment tool used by clinicians for the evaluation of postural stability after concussion.[74] The BESS consists of 6 different conditions of postural task; 1) double leg stance on firm, 2) double leg st[75]ance on foam, 3) tandem stance on firm, 4) tandem stance on foam, 5) single leg stance on firm, and 6) single leg stance on foam. Through past studies[74, 76-78], BESS has been demonstrated to correlate well with other measures of postural control. A study demonstrated a high reliable coefficient on BESS (R=0.88).[74] Due to presence of a practice effect found in trial 1, it was eliminated from the analysis. This resulted in reliability coefficient for the criterion score of trials 2 and 3 of 0.84. Consistency of scores was gained between trails 2 and 3. This would suggest that the use of 1 trial may be appropriate for estimation of postural control. The BESS is a modified assessment designed to evaluate static postural control in concussed athletes.[74]

*SEBT*

The Star Excursion Balance Test (SEBT) is a well-known simple and non-instrumented test to measure dynamic aspects of postural control. It requires participants to maintain a single-leg stable stance and to reach for maximal distance with the other leg in 8 different directions.[79] When the stability of the supporting leg is compromised, the test is ended. Measures are normalized to the subject's leg length.[80-81] On the SEBT, individuals with an acute ankle sprain or CAI consistently perform worse than healthy individuals.[79]

The results of SEBT performance is how far a participant can reach without violating any of the stipulations, such as touching the ground heavily, come to rest at the touch-down point, making contact with the ground with the reaching foot to maintain balance, lifting or shifting any part of the foot of the stance limb, and the trial is not considered complete. The reach distance values are utilized as an index of dynamic postural-control. These measurements can be compared between injured and uninjured limbs or pre- and post-intervention to assess deficits or improvements in dynamic postural-control. Many studies demonstrated that either acute ankle sprain or CAI is associated with a decreased level of dynamic postural control with SEBT. Akbari and colleagues compared the injured and uninjured sides of participants with unilateral ankle instability and reported that the performance of the injured side was worse than that of the uninjured side ($p = 0.03$).[55] It was unclear which directions were utilized in this study and how much time had passed since individuals had sustained the ankle injuries. A study reported decreased performance of the CAI group on their injured sides in the anterior ($p = 0.03$), medial ($p=0.02$), and posterior ($p=0.01$) directions.[82] Similarly, Hertel and colleague reported group-by-side interaction that demonstrated diminished reaching distances on the injured sides of participants with CAI for the anteromedial ($p=0.005$), medial ($p< 0.001$), and posteromedial ($p=0.03$) directions.[83] In addition, another study confirmed the deficits in task performance in participants with CAI at baseline before implementation of a rehabilitation protocol, with injured limbs performing worse dynamic balance than the uninjured limbs for the posteromedial ($p=0.047$), posterolateral ($p=0.007$), and lateral ($p=0.03$) directions.[15] Lastly, Nakagawa and Hoffman demonstrated better total score performance in healthy control individuals than the CAI group ($p=0.01$).[84] On the other hand, another study reported no differences between participants with and without CAI utilizing the anteromedial, medial, and posteromedial directions.[85]

The SEBT became a widely utilized dynamic postural control test for clinical and research testing purposes. Through a couple of decades of research findings in validity for the SEBT, it should be considered a highly representative non-instrumented dynamic postural control test. Since the SEBT can be performed quickly and reliably, it also can be utilized in the pre-participation physical examination to identify those at greater risk of injury. Moreover, since strength, flexibility, neuromuscular control, core stability, ROM, balance and proprioception are all necessary to complete tasks in the SEBT, this makes for an excellent test for pre-participation physicals and clinical examinations because one faulty component in any of those systems will indicate a positive test.[79]

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# CHAPTER III

## Methods

### Research Design

This thesis project is a laboratory study with a case-control design. The independent variable, group assignment, included two levels: LAS group and non-injured group. The primary outcome variables were the Neurocom Smart EquiTest equilibrium scores from balance performance on a series of bipedal stances for 20 seconds.

### Subjects

Ten subjects with LAS and ten subjects without any history of ankle sprains were recruited from a University community and participated in the study. The uninjured subjects were matched by gender, age, height, and mass (Table 1). Subjects between the ages of 18-55 were assigned to either the LAS or non-injured group based on presence of an acute injury to lateral ligaments that occurred within the past 72 hours. The exclusion criteria for the LAS group were: 1) LAS older than 72 hours, 2) any acute ankle injuries other than LAS, and 3) any history of neuropathies, diabetes, and balance disorder. The exclusion criteria for the non-injured group were: 1) a history of ankle injury to either limb, 2) a history of lower extremity injures within the past 6 months, 3) any limitations of current ankle function, and 4) any history of neuropathies, diabetes, and balance disorders. A certified athletic trainer, who has at least 1-2 years of clinical experience as an ATC, performed all ankle evaluations to maintain consistency in the evaluation process to determine the diagnosis and LAS injury severity with a standardized evaluation form. The study protocol was approved by the Institutional Review Board and written informed consent was obtained from all of the participants before any study procedures began. Figure 1 is described for the mehod.

**Instrumentation**

We utilized the SMART EquiTest (NeuroCom International Inc., Clackamas, OR) with a three-sided visual surround booth, movable dual force plates as support surface, a movable monitor, and an overhead attachment for a safety harness strap [1-2]. In addition, Neurocom Balance Master ® software 8.5 version (NeuroCom International Inc., Clackamas, OR) was used for the Sensory Organization Test (SOT) to assess bipedal balance.

**Postural Control Assessment**

We employed a previously reported method of postural control testing with the SOT on a SMART EquiTest.[3] The SOT quantifies not only balance performance during a bipedal stance, but also provides the information of the contribution of visual, vestibular and somatosensory systems to balance. The test selectively interferes with the function of a specific sensory system by producing inaccurate sensory information. For example, the visual system can be challenged with the visual surround that moves as the participant sways in the anterior-posterior direction during testing. This testing condition is referred to as sway-referenced visual surround. Similarly, a sway-referenced surface indicates a testing condition in which the forceplates move as the participant sways to interrupt the somatosensory feedback during the bipedal stance.[2, 4] The SOT consists of 6 different testing conditions for bipedal stance: 1) Eyes open, fixed surface and visual surround 2) Eyes closed, fixed surface , 3) Eyes open, fixed surface, sway-referenced visual surround, 4) Eyes open, fixed visual surround, sway-referenced surface, , 5) Eye closed, fixed visual surround, sway-referenced surface, and 6) Eyes open, sway-referenced surface and sway-referenced visual surround.[2, 5] Participants were asked to quietly stand on bare feet for 20 seconds in each condition.

A safety harness was provided to the participants. They were instructed to align the medial malleoli to the center horizontal line on the force plate and stand with a comfortable stance with feet shoulder width apart[2] The participants were also instructed to stand on bare feet with hands on their iliac crest, look straight ahead, and maintain an upright posture.[6] The postural control assessment began once the participants were fully informed of all testing procedures of the SOT. Three trials of each condition were recorded in the standardized order of the condition 1 through 6.

**Data Processing**

Balance performance in each condition of SOT was quantified with an equilibrium score, which quantifies the amount of postural sway in the anterior-posterior direction in degree of angle. The score is calculated using the equation 1 as a percent score of a range of postural sway from the maximum possible sway angle of 12.5 degrees.[2]

$$12.5 - (\text{maximal anterior sway angle} + \text{maximal posterior sway angle}) / 12.5 * 100$$

[Equation 1]

A lower postural angle produces higher equilibrium score, and indicates better postural control with 100 being the highest attainable value. The average of 3 scores for each condition was used for statistical analysis.

**Statistical Analysis**

A Mann-Whitney U test was used to determine a group difference in each condition of SOT as Shapiro-Wilk's tests ($p$<.05) and visual inspection of the data histograms showed that the SOT data were not normally distributed. An effect size for group differences was calculated with $r$, which interpreted as a small effect if >.10, medium if >.30, and large if >.50.[7] Alpha levels were set a *priori* at $p \leq 0.05$. All statistical analyses were performed using SPSS 20.0 statistical software (SPSS Incorporated, Chicago, IL, USA).

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## CHAPTER IV

## Manuscript

### Introduction

Lateral ankle sprains (LAS) are one of the most common acute injuries that occurs during physical activity.[2-5] The high incidence rate of LAS contributes to the public perception of it being an innocuous injury. However, LAS have been documented to result in varying degrees of consequences including impairments (ex: decreasing strength) , functional limitations, and even disability.[4] Chronic pain, swelling, muscle weakness, crepitus, ankle instability and/or recurrent LAS have been reported months to years after initial injuries, and up to one-sixth of time lost from sports are due to this injury.[6-9] In addition, 68-78% of patients with a history of ankle sprain reported the onset of ankle osteoarthritis.[10-11] It is not uncommon for primary care physicians and other health care providers such as physical therapists and athletic trainers to misdiagnose various ankle problems as simple ankle sprains[12], and thus it is critical to have a good system in evaluation of acute ankle sprain injury. Current literature suggests a thorough injury assessment is warranted to better capture all aspects of these injury consequences, leading to more effective treatment strategies.[6, 10, 13-14]

Postural control deficits are a prominent problem in patients with LAS and chronic ankle instability.[15-18] Postural control has been shown to have an inverse relationship with risk of LAS. That is, individuals with poor postural control tend to have a higher risk of injury and those with better postural control may have a lower risk of injury.[19-21] In addition, preventative training programs and rehabilitative balance programs for postural control have been shown to substantially decrease the risk of injury and improve self-reported motor function.[20, 22-23] Therefore, it is critical to thoroughly assess the postural control of patients with LAS in an effort to better understand the injury and enhance treatment outcomes

Postural control deficits in an unipedal stance have consistently been reported following an ankle sprain.[17-18, 24] A prospective study of total 28 individuals (11 males/17 females, age = 19.7 ± 1.4 years), who suffered acute, mild to moderate LAS, determined that unilateral acute ankle sprains impaired postural control in both the injured limbs and the uninjured limbs[25]. The findings of bilateral deficits in postural control after an acute LAS seem to be conclusive in a systematic review.[18] The bilateral postural control deficits following a unilateral ankle sprain indicate a central impairment in neuromuscular control referred to as a feed-forward mechanism. A feed-forward mechanism produces postural control deficits in the uninjured limb. However, Proprioceptive deficits in the injured ankle are considered a result of impairments in the feed-back mechanism.[24] Given the bilateral impairments following unilateral acute LAS, individuals with the injury may suffer deficits in postural control of the bipedal and the unipedal stance. To our best knowledge, there has been only one study that assessed postural control deficits on bipedal stance [26]and found that individuals with acute ankle sprains presented deficits in bipedal stance, but the findings were not statistically significant. However, bipedal deficits were measured in only quiet stance on a force plate in the previous study by Rose et al.[26] This current study added several measurements of bipedal postural control to understand and analyze the relative contributions of the somatosensory, visual and vestibular systems.

To fill the gap in the literature clarifying postural control impairments of the bipedal stance for patients with acute LAS, the purpose of the study was to determine effects of acute LAS on postural control of the bipedal stance. Since it is not uncommon to utilize a single leg stance balance assessment for evaluation and exercises for rehabilitation after an acute LAS, this study is important to be conducted to provide insights into both the rehabilitative balance training protocol and balance assessment. We hypothesized that postural control of individuals with acute LAS during quiet bipedal standing would be disrupted when compared with that of individuals without any history of ankle sprains.

**Methods**

We performed a laboratory study with a case-control design. The independent variable, group assignment, included two levels: LAS group and non-injured group. The primary outcome variables were the Neurocom Smart EquiTest equilibrium scores from balance performance on a series of bipedal stances for 20 seconds.

*Subject*

Ten subjects with LAS and ten subjects without any history of ankle sprains were recruited from a University community and participated in the study. The uninjured subjects were matched by gender, age, height, and mass (Table 1).

Subjects between the ages of 18-55 were assigned to either the LAS or non-injured group based on presence of an acute injury to lateral ligaments that occurred within the past 72 hours. The exclusion criteria for the LAS group were: 1) LAS older than 72 hours, 2) any acute ankle injuries other than LAS, and 3) any history of neuropathies, diabetes, and balance disorder. The exclusion criteria for the non-injured group were: 1) a history of ankle injury to either limb, 2) a history of lower extremity injures within the past 6 months, 3) any limitations of current ankle function, and 4) any history of neuropathies, diabetes, and balance disorders.

**Table 4.1.** Subject Demographics (Means and Standard Deviations)

| | Group | |
|---|---|---|
| Variable | Injured | Uninjured |
| Subject | 10 | 10 |
| Sex | 3 females, 7 males | 3 females, 7 males |
| Age (yrs) | 23.5 ± 6.3 | 22.6 ± 1.8 |
| Height (cm) | 177.1 ± 7.7 | 178.8 ± 10.9 |
| Mass (kg) | 78.1 ± 9.8 | 75.7 ± 14.0 |
| Injury grade | 7 grade I, 3 grade II | N/A |
| Injured limb | 5 right, 5 left | N/A |

A certified athletic trainer, who has at least 1-2 years of clinical experience as an ATC, performed all ankle evaluations to maintain consistency in the evaluation process to determine the diagnosis and LAS injury severity with a standardized evaluation form. The study protocol was approved by the Institutional Review Board and written informed consent was obtained from all of the participants before any study procedures began. Figure 4.1 is described for the method.

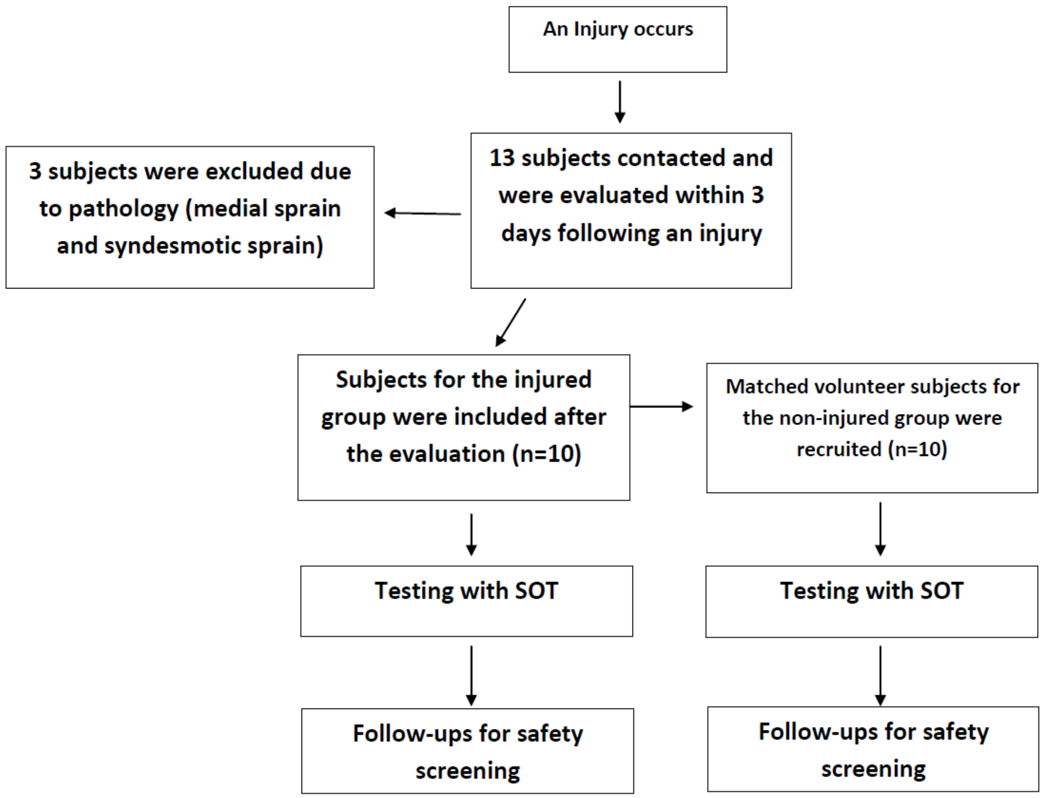


**Figure 4.1:** Subject Recruitment and Flow of the Method

*Instrumentation*

We utilized the SMART EquiTest (NeuroCom International Inc., Clackamas, OR) with a three-sided visual surround booth, movable dual force plates as support surface, a movable monitor, and an overhead attachment for a safety harness strap [27-28]. In addition, Neurocom Balance Master ® software 8.5 version (NeuroCom International Inc., Clackamas, OR) was used for the Sensory Organization Test (SOT) to assess bipedal balance.

*Postural control assessment*

We employed a previously reported method of postural control testing with the SOT on a SMART EquiTest.[29] The SOT quantifies not only balance performance during a bipedal stance, but also provides the information of the contribution of visual, vestibular and somatosensory systems to balance. The test selectively interferes with the function of a specific sensory system by producing inaccurate sensory information. For example, the visual system can be challenged with the visual surround that moves as the participant sways in the anterior-posterior direction during testing. This testing condition is referred to as sway-referenced visual surround. Similarly, a sway-referenced surface indicates a testing condition in which the forceplates move as the participant sways to interrupt the somatosensory feedback during the bipedal stance.[8, 28] The SOT consists of 6 different testing conditions for bipedal stance: 1) Eyes open, fixed surface and visual surround 2) Eyes closed, fixed surface , 3) Eyes open, fixed surface, sway-referenced visual surround, 4) Eyes open, fixed visual surround, sway-referenced surface, , 5) Eye closed, fixed visual surround, sway-referenced surface, and 6) Eyes open, sway-referenced surface and sway-referenced visual surround.[28, 30] Participants were asked to quietly stand on bare feet for 20 seconds in each condition.

A safety harness was provided to the participants. They were instructed to align the medial malleoli to the center horizontal line on the force plate and stand with a comfortable stance with feet shoulder width apart[28] The participants were also instructed to stand on bare feet with hands on their iliac crest, look straight ahead, and maintain an upright posture.[31] The postural control assessment began once the participants were fully informed of all testing procedures of the SOT. Three trials of each condition were recorded in the standardized order of the condition 1 through 6.

*Data processing*

Balance performance in each condition of SOT was quantified with an equilibrium score, which quantifies the amount of postural sway in the anterior-posterior direction in degree of angle. The score is calculated using the equation 1 as a percent score of a range of postural sway from the maximum possible sway angle of 12.5 degrees.[28]

12.5- (maximal anterior sway angle + maximal posterior sway angle) /12.5 *100

[Equation 1]

A lower postural angle produces higher equilibrium score, and indicates better postural control with 100 being the highest attainable value. The average of 3 scores for each condition was used for statistical analysis.

*Statistical Analysis*

A Mann-Whitney U test was used to determine a group difference in each condition of SOT as Shapiro-Wilk's tests ($p<.05$) and visual inspection of the data histograms showed that the SOT data were not normally distributed. An effect size for group differences was calculated with *r*, which interpreted as a small effect if >.10, medium if >.30, and large if >.50.[32] Alpha levels were set a *priori* at $p \leq 0.05$. All statistical analyses were performed using SPSS 20.0 statistical software (SPSS Incorporated, Chicago, IL, USA).

## Results

Thirteen subjects with acute LAS were identified as candidates for this study. Three subjects were recruited but excluded from the analysis because they were injured in medial and syndesmotic ligaments. Therefore, 10 injured subjects participated in this study. The injured group consisted of 3 patients with grade I sprains and 7 with grade II sprains.

It was found that subjects with acute LAS demonstrated significant lower equilibrium scores than those in the non-injured group on SOT condition 1 (U=78, $p$=.035) and condition 2(U=.81, $p$=.019). The Mann-Whitney U test did not reveal significant group difference on the other 4 SOT conditions ($p$>.05). The magnitudes of the group differences found in conditions 1 and 2 were medium ($r$=.48 for both conditions). Descriptive data for the 6 conditions of SOT are presented in Table 2.

**Table 4.2.** Outcomes of Sensory Organization Tests (Median and Range of Scores)
Note.*indicates significant performance difference

| Variable | Group | |
|---|---|---|
| | Injured | Uninjured |
| Condition 1* | 95.0 (91.3- 96.3) | 96.2 (94.7 – 97.3) |
| Condition 2* | 91.7 (69.3 - 95.7) | 95.0 (91.0 – 96.0) |
| Condition 3 | 93.3 (81.0 – 95.0 ) | 94.0 (91.3 – 97.0) |
| Condition 4 | 85.8 (56.0 – 93.3) | 88.7 (50.0 – 94.3) |
| Condition 5 | 59.8 (42.0 – 80.3) | 72.7(40.0 – 85.7) |
| Condition 6 | 73.7 (34.7 -80.0) | 74.5 (46.7 – 87.3) |

## Discussion

Our hypothesis that postural control in quiet bipedal stance would be disrupted in individuals with a unilateral acute LAS when compared to individuals without any history of ankle sprains was confirmed as there were significant differences between the groups in equilibrium scores in the SOT condition 1, eyes open and stable surface, and 2, eyes closed and stable surface. The effect sizes of the group difference ($r$ =.48) in both conditions 1 and 2 are categorized as medium. The close to large effect sizes were in agreement with the statistically significant findings indicating that the true LAS effect on bipedal postural control in the population might be large. No significant group differences were found between the two groups in the SOT conditions 3 – 6.

Our primary finding was that postural control impairments during quiet bipedal stance occurred after unilateral acute LAS. This finding is in agreement with the results of the Rose et al[26] study that the injured group demonstrates consistent poor postural control in quiet bipedal stance throughout two weeks of the testing, both eyes open and closed, in comparison to the non-injured group, but the result failed to reach statistical significance. Rose et al [26] was the only study that utilized a double leg stance for postural control assessment after an acute ankle sprain. They originally investigated the effects of therapeutic intervention on postural control over the two weeks following the ankle injury. The participants were tested on days 3, 7 and 14 following the injury. The postural stability of both patients with an acute ankle sprain and uninjured subjects were measured in two and one legged stance, with eyes open or closed, on a static platform. A similar pattern of the result in bipedal postural control from the Rose et al has been reported in this study.[26] Furthermore, the result in the present study of poor postural control during quiet bipedal stance with eyes open and closed was statistically significant.

The underlying mechanism for the postural control deficit of the injured subjects on quiet bipedal stance could be a combination of deficits in both central and peripheral system.  The central impairments in sensorimotor system may explain postural control deficits on the uninjured limb in addition to proprioceptive deficits causing postural control deficits in the injured limb.  Proprioception is thought to be most important in the feed-back control of slow movements of a limb, such as static balance tasks.[33]  During balance tasks, proprioception effects at a subconscious level to maintain postural control via spinal reflexes. It is suggested that that humans can use proprioception to make reflexive postural modifications in response to small changes in the joint position of a limb without being aware of the changes.[34]  Also, greater errors in the perception of the joint position in ankle inversion of the injured limb have been demonstrated in individuals with acute ankle sprains.[35]  With conclusive evidence of postural control deficits in the injured limb after acute ankle sprains in a systematic review,[36] it is logical to state that proprioceptive deficits occurs after a ankle joint injury, and in turn affects postural control in the injured limb.  This mechanism may explain the result of this study in the SOT conditions 1 and 2.  The injured group demonstrated much lower equilibrium scores than the non-injured group because the subjects heavily relied on somatosensory system for postural control on a fixed surface (condition 1 and 2).

Because these postural control deficits occurred during bipedal stance after acute LAS, its influence on the uninjured limb cannot be ignored.  Central impairments in the sensorimotor system can be used as the mechanism for the postural control deficits according to the previous results of bilateral deficits in postural control during unipedal stance following an acute ankle sprain or in subjects with CAI.[17-18, 24]  The central impairments in postural control has been demonstrated and concluded in the studies investigated effects of an acute ankle sprains or CAI in postural control deficits during a single leg stance. This is also called the feed-forward mechanism of postural control deficits.[17-18, 24] The feed-forward mechanism of postural control deficits represents changes in the gamma motoneuron system or the influence of adaptations in the alpha motoneuron pool excitability after an injury. There is another mechanism of postural control deficits, which is called the feed backward mechanism. The feed backward mechanism of postural control deficits suggests that proprioceptive deficits are from joint deafferentation following ankle ligament injury. In 2008, Hertel [24] proposed a contemporary theory that encompasses both the feedback and feed-forward mechanisms of postural control deficits related to ankle sprains.[24] The contemporary theory has been supported with the findings of bilateral unipedal stance postural control deficits on single leg stance after unilateral LAS or CAI.[17-18, 25-26] The result of the present study supports the contemporary theory in postural control deficits. That is, the uninjured limb does not have abnormal afferent inputs and subconsciously compensate for proprioceptive deficits in the injured limb to maintain postural control. The central impairments, which cause motor control deficits in the uninjured limb, may have some negative impacts on the postural control deficits in bipedal stance. Our study was the first to investigate and focus on the effects of an acute LAS on postural control during bipedal stance. The finding of postural control deficits in quiet bipedal stance may be clinically important because the injured patients are functionally less stable at the acute injury stage than the uninjured individuals.

Conditions 3-6 create a challenging environment to either visual, somatosensory or both sensory systems to isolate a specific sensory system and stress the adaptive responses of the CNS. The possible explanation of the findings that no group differences in SOT conditions 3-6 could be the modifications that occurred in the central nervous system (CNS) which overrode the effects of proprioceptive impairments in injured individuals. Postural control requires the accurate integration of somatosensory, vestibular, and visual sensory inputs and motor response to control muscles in the trunk and lower extremities in order to maintain appropriate postural control. During the SOT, useful information delivered to the participant's eyes, feet, and joints was interfered with body sway of the support surface and/or visual surrounding. The overall findings of this study indicates the central mechanism that is responsible for integrating the three sensory systems, and it plays a more important role on postural control of bipedal stance than a sensory system causing proprioceptive deficits. In other words, alterations in the central sensorimotor system may or may be useful as a strategy of postural control for individuals with an acute ankle sprain. For example, improvements in postural stability have been reported after three weeks of oculo-motor exercises and gaze stability training.[37]

To clinically interpret the results of this study, the postural control deficits are present in quiet bipedal stance either with eyes opened or closed at least within three days following an acute LAS. Our study strictly and carefully selected the subjects. None of the injured subjects failed to stand on both legs and perform all 6 conditions of SOT including the 7 subjects with a grade II sprain. The fact that majority of our subjects had a grade II sprain may enlarge the postural control deficits. That probably explains the significant group differences in SOT conditions 1 and 2. A few studies[25-26, 38] examined the postural control within 3-5 days after the injury which were in line with our findings.

The importance of our finding has some positive implications. It may be beneficial to implement the bipedal stance exercises for patients with an acute LAS during a postural control assessment as well as designing the early phase rehabilitation training program. Exercises in bipedal stance can minimize the risk of falling or aggravation of the injury from rehabilitative balance exercises, reduce patient's fear of falling, and helps initiate balance exercises in the earlier phase of rehabilitation. Postural control exercises following acute ankle sprains have clearly been demonstrated to reduce the risk of recurrent ankle sprains.[20, 39-40] It is plausible that earlier initiation of balance exercises may result in earlier improvements in postural control, and help preventing recurrent ankle sprains. In addition, this result indicates that having athletes to return to full activity within 72 hrs following an acute LAS may be dangerous given the significant deficits of postural control during bipedal stance. Furthermore, postural control on bipedal stance can be safer and beneficial as a therapeutic exercise before balance exercises on a single leg.

**Limitations**

A limitation of this study is the sample size. The lack of statistical significance may be due to the large variability between the subjects. Furthermore, the single leg stance was not assessed because the EquiTest SOT could only be used for bipedal stance. Although the bilateral deficits of postural control have been reported in some systematic reviews, assessment on single leg stance in addition to bipedal stance can be beneficial for further studies to understand the mechanism of postural control deficits in individuals with an acute ankle ligamentous injury. It is also possible that there may be a training effect of the testing procedure itself, which can be a limitation. It would have been preferred to randomize the order of the 6 testing conditions for minimizing the effects. The order of testing, however, was set out in the computer software of EquiTest and was not possible to change. Therefore, our findings can only be generalized to patients with similar age, gender, and injury.

**Conclusion**

The findings of this study significantly contributed to the literature by providing researchers and practitioners with recommendation of using bipedal stance exercises in assessment and rehabilitative trainings to enhance injured patients' postural control. Further research is needed to determine the length of postural control deficits on bipedal stance following an acute LAS and analysis in correlation with postural control on single leg stance of the injured and uninjured leg to postural control on bipedal stance.

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# APPENDIX SECTION

## Appendix A

## Additional Methods

**Table A1: Consent Form**

**Texas State University Consent Form – IRB #2013I2272**

### Consent of an Adult to Be in a Research Study

*In this form "you" means a person 18 years of age or older who is being asked to volunteer to participate in this study. In this form "we" means the researchers and staff involved in running this study at Texas State University.*

**Principal Investigator:** Kyung Min Kim, PhD, ATC, LAT
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512-245-4373

**What is the purpose of this form?**
This form will help you decide if you want to be in the research study. You need to be informed about the study, before you can decide if you want to be in it. You do not have to be in the study if you do not want to. You should have all your questions answered before you give your permission or consent to be in the study.

Please read this form carefully. If you want to be in the study, you will need to sign this form. You will get a copy of this signed form.

**Why is this research being done?**
The purpose of this study is to understand how an acute lateral ankle sprain affects activity of the nerves providing a motor control for lower leg muscles. You are being asked to participate in this study because you have recently sprained your ankle or you have never had an ankle injury before.

**How long will this study take?**
Your participation in this study will require one visit to Biomechanics/Sports Medicine Laboratory at Texas State University. It would take approximately 1.5 to 2 hours to complete the study.

**What will happen if you are in the study?**
If you agree to participate, you will sign this consent form before any study procedures take place. You will be screened for your current health status to determine whether you qualify for participating in the study. The screening involves filling out health questionnaires. You may choose not to answer any questions for any reason

In addition, if you sprained your ankle, a licensed health care professional will perform an evaluation of your injury for determining accurate diagnosis.

Once you are found to be eligible, you will be prepared for lower leg reflex and balance tests. The reflex testing will be performed before the balance test because the reflex measures could be affected by the balance task.

**Reflex Testing**: this testing provides an estimate of how well the nerves in the lower leg are functioning. The following procedures will be performed in the order;

1. You will be instructed to lie on your stomach on a padded table with your feet and lower leg elevated.
2. You will have sticky electrodes placed on your lower legs. These electrodes are called Electromyography (EMG) electrodes to record electrical (reflexive) activity of the lower leg muscles.
3. The sites of the EMG electrodes in your lower legs (calf, shin, and a side of the knee) will be shaved, and cleaned with alcohol for clean recording.
4. An electrode that provides a very-quick stimulus will be placed and taped behind your knee.
5. The intensity and number of stimulus will vary with individuals due to variability in the nervous system.
6. The stimulus feels similar to a shock of static electricity like when you are walking across a carpet and then touch a doorknob, except the voltage is much lower.
7. Reflex measurements will be taken on both of your legs.

**Balance Testing**; this testing provides information on how well you maintain an upright posture for 10 seconds in different balance conditions. The following procedures will be performed in the order;

1. You will be positioned on a force plate looking like a squared metal plate used to measure your balance
2. You will be asked to stand on both feet with eyes open and closed for 10 seconds, and on one foot with eye open and closed for 10 seconds (done separately in each foot)
   ***We will stay close enough to you when performing the single-leg stance with eye closed in order to prevent potential falling on the floor***
3. If you touches down with the opposite limb, makes contact with the stance limb, or is unable to maintain standing posture for 10 seconds, the trial would be terminated and repeated.
4. Three successful trials of each balance condition will be measured.

## What are the risks of being in this study?

There are a few minor risks or possible discomforts associated with this study. There is a small chance that you would lose balance during the test and fall. You may also experience some mild levels of pain with the balance activity and mild transient discomfort due to electrical stimulus, but we will take every precaution to minimize the risks and discomforts by making sure that pain/discomfort levels is minimal prior to participating in the study. If at any time you are uncomfortable with participating in the study you may withdraw from the study with no fear of repercussions.

You may have side effects that we do not expect or know to watch for now. Call us if you have any symptoms or problems that you feel are related to the study.

If you are pregnant now, or get pregnant during the study, please tell us. Being in this study might hurt your unborn baby, so you will not be able to join or stay in the study.

## What if you are hurt in this study?

Please be advised that medical treatment is available upon the event of physical injury resulting from the study. Medical treatment will be limited to first aid and ice. In the event that you sustain an injury needing medical treatment beyond that of first aid and ice, you will need to seek appropriate medical attention. Texas State University-San Marcos students may choose to go to the Student Health Center free of charge. Please call 512-245-2161 to schedule an appointment or speak to a health care provider at the Student Health Center. We will report any adverse events per institutional policy. In the event that you believe you have suffered injury not apparent immediately after testing, please contact the IRB chairperson Dr. Jon Lasser at 512-245-3413, who will review the matter with you and identify any other resources that may be available to you.

Texas State University Consent Form – IRB #2013I2272

## Will you be compensated/helped for being in this study?

You will get paid $50 if you complete the study in the experiment group consisting of those with acute lateral ankle sprains and $25 if you do in the healthy control group. You will not get paid at all if you decide not to complete the study.

In addition to the compensation for your time being in the study, your participation would contribute to expanding the body of knowledge to understand consequences of an acute ankle injury, which may provide evidence useful in the rehabilitation of the ankle injuries.

## Who funds the study?

The study is funded by Texas State University through Research Enhance Program.

## Who will see your information?

Your participation in this study is confidential. Only the investigators will have access to your personal identifiers and to any information that may be linked with your identity. All information that you complete will have an identification number rather than your name to ensure your confidentiality. All data will be stored in a locked cabinet in the Biomechanics/Sports Medicine Lab for seven years. In the event of this study being published, none of your personal identifying information will be disclosed.

## If you want to know about the results before the study is done:

We will tell you, during the study, of any results that are important to your health. That information is important for you to know, because it may help you decide whether you want to continue being in this study. We cannot tell you any other information until the results have been studied. At that time you can ask for more information.

## Please contact the researchers listed below if you want to:

- Obtain more information about the study
- Ask a question about the study procedures or treatments
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

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## Voluntary Participation:

Your participation in this study is completely voluntary. You may withdraw from this study at any time without any negative consequences from anyone associated with the study

## What if you have a concern about a study?

This project [insert IRB Reference Number] was approved by the Texas State IRB on [insert IRB approval date]. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Becky Northcut, Director, Research Integrity & Compliance (512-245-2314 - bnorthcut@txstate.edu).

## What does your signature mean?

Before you sign this form, please ask questions about any part of this study that is not clear to you. Your signature below means that you understand the information given to you about the study and in this form. If you sign the form it means that you agree to join the study.

## Consent from adult

| ______________________ | ______________________ | ________ |
|---|---|---|
| PARTICIANT (PRINT NAME) | PARTICIAPNT (SIGNATURE) | DATE |

To be completed by participant if 18 years of age or older

## Person Obtaining Consent

By signing below you confirm that you have fully explained this study to the potential subject, allowed them time to read the consent or have the consent read to them, and have answered all their questions.

| ______________________ | ______________________ | ________ |
|---|---|---|
| PERSON OBTAINING CONSENT (PRINT NAME) | PERSON OBTAINING CONSENT (SIGNATURE) | DATE |

## Biomechanics/Sports Medicine Lab

**Health Questionnaire: General**

**Subject ID:_______________IRB# ______________**

| HEIGHT | WEIGHT | SEX | AGE | DATE OF BIRTH |
|---|---|---|---|---|
| | | | | / / |

What is your dominant hand? Right ☐ Left ☐

Which leg would you use to kick a ball? Right ☐ Left ☐

Which leg would you use to jump from? Right ☐ Left ☐

***Please check below if you have or have had any of the following:***

**General Medical**

☐ Allergies (latex, heat, cold, electricity, medications, etc)
☐ Cancer
☐ Biomedical Devices (implants, pacemaker)
☐ Currently pregnant or nursing
☐ Recent illness (upper respiratory infection, cold, infections)
☐ Diabetes
☐ Asthma
☐ Surgery
☐ Other: ______________________

***Please explain any checked items***: ________________________________________

______________________________________________________________________

***Please provide date of last physical exam:*** ___________________________________

**Neurological**

☐ Epilepsy/seizures
☐ Anxiety disorders
☐ ADHD
☐ Diabetic Neuropathy
☐ Concussion OR Traumatic Brain Injury
☐ Cerebral Palsy
☐ Balance Disorder
☐ Vertigo
☐ Parkinson's Disease
☐ Multiple Sclerosis
☐ Other _______________

***Please explain any checked items***: ________________________________________

______________________________________________________________________

**Cardiovascular**

☐ Stroke
☐ High Blood Pressure
☐ Heart Attack
☐ Shortness of Breath
☐ Sickle Cell Trait
☐ Heart Murmur
☐ Heart Disease (Coronary Heart Disease, Arteriosclerosis)
☐ Thrombosis or Embolism
☐ Marfan's Syndrome
☐ Cardiac Arrythmia (Irregular Heart Beat)
☐ Other: _______________

**Figure A1: Health Questionnaire: General**

## Biomechanics/Sports Medicine Lab

**Health Questionnaire: General**

***Please explain any checked items***: ______________________________________________

______________________________________________

**General Orthopedic**

- ☐ Rheumatoid Arthritis
- ☐ Osteoarthritis
- ☐ Osteoporosis/Osteopenia
- ☐ Previous Fracture
- ☐ Surgery
- ☐ Gout
- ☐ Assistive Devices (crutches, braces)
- ☐ Other: ________________

***Please explain any checked items***: ______________________________________________

______________________________________________

**Other**

Have you taken any prescription or over the counter medications within the last 24 hours?

***Yes*** ☐ ***No*** ☐

***If yes, please list***: ______________________________________________

______________________________________________

Have you consumed any of the following stimulants or depressants in the last 12 hours?

- ☐ Caffeine
- ☐ Tobacco
- ☐ Alcohol
- ☐ Other__________________

***If yes, please explain***:

______________________________________________

______________________________________________

Do you exercise regularly? ***Yes*** ☐ ***No*** ☐

***If yes, how often, what type and for how long?*** ______________________________

______________________________________________

Are you currently on an athletic team? ***Yes*** ☐ ***No*** ☐

***If yes, at what level?*** ______________________________________________

***If yes, for what sport?*** ______________________________________________

**Figure A1 (continue): Health Questionnaire: General**

**Table A2: Subject Screening Form**

IRB #:

Subject ID# ________________. DATE:

__________.

## □ Acute Ankle Sprain Group

**Inclusion Criteria:**

YES

- □ Subjects who has a lateral ankle sprain (tested within 3 days after the injury)
- □ Subjects between the ages of 18-55

**Exclusion Criteria:**

NO

- □ Subjects who have incurred an acute lateral ankle sprain older than 3 days (72 hours)
- □ Subjects that have been diagnosed with or have evidence of ankle injuries other than lateral ankle sprains (ex. ankle fracture, high and medial ankle sprains)
- □ Subjects that have been diagnosed with neurological injury
- □ Subjects who have a history of lower extremity injury within the past 6 months

## ☐ Healthy Group

**Inclusion Criteria:**

YES

- ☐ Subjects who has a history of no lower extremity injury within the past 6 months
- ☐ Subjects between the ages of 18-55

**Exclusion Criteria:**

NO

- ☐ Subjects that have been diagnosed with neurological injury
- ☐ Subjects who have history of lower extremity surgery
- ☐ Subjects who have low back pain or hip pathology/pain that may affect balance
- ☐ Subjects who have a history of lower extremity injury within the past 6 months
- ☐ Subjects that have been diagnosed with neurological injury

This subject was **INCLUDED** / **EXCLUDED** in this study

**Standardized Ankle Injury Evaluation Procedures and Categorization of Findings**

**History**

Age______ Gender: O Male O Female Height_____ Weight_____

Elapsed time from injury to evaluation: ____hours

Injured ankle: O Right O Left
Dominant foot: O Right O Left

Mechanism of injury:
O jump landing O cutting/pivoting O uneven surface O external blow

Sport:

| | | | |
|---|---|---|---|
| ___ Basketball | ___ Soccer | ___ Volleyball | ___ Swimming |
| ___ Baseball | ___ Hockey | ___ Golf | |
| ___ Football | ___ Lacrosse | ___ Gymnastics | |
| ___ Softball | ___ Tennis | ___ Wrestling | |

Shoe:

| | | |
|---|---|---|
| O Low-Top Sneaker | O Low-Top Cleat | O Sandals |
| O High-Top Sneaker | O High-Top Cleat | O Barefoot |
| O Running Shoe | O Dress Shoe | |

Type of surface:

| | | |
|---|---|---|
| O grass | O concrete | O rubber track |
| O artificial turf | O gym floor | |

**Inspection (Swelling)**

Degree:
0: no perceptible swelling
1: mild swelling; highly localized loss of normal surface concavity
2: moderate swelling; soft tissue distention confined to ankle and hindfoot
3: severe swelling; diffuse soft tissue distension that includes dorsum of forefoot

Location:

| | | | |
|---|---|---|---|
| O Periphery of lateral malleolus | ___1 | ___2 | ___3 |
| O Periphery of medial malleolus | ___1 | ___2 | ___3 |
| O Tibiofibular syndesmosis | ___1 | ___2 | ___3 |

**Palpation (Tenderness)**

Degree:
0: no tenderness apparent
1: mild discomfort; no demonstration of apprehensive response
2: moderate discomfort; vocal response and/or observation of grimacing facial expression
3: intense discomfort/pain; reflexive withdrawal, vocal response, and/or facial grimace

Anatomic Structures:

| | | | |
|---|---|---|---|
| O Ant. Talofibular Ligament (ATFL) | ___1 | ___2 | ___3 |
| O Calcaneofibular Ligament (CFL) | ___1 | ___2 | ___3 |
| O Inferior Peroneal Retinaculum (IPR) | ___1 | ___2 | ___3 |
| O Calcaneocuboid Ligament (CCL) | ___1 | ___2 | ___3 |
| O Sinus Tarsi | ___1 | ___2 | ___3 |
| O Tibiofibular Syndesmosis (TFS) | ___1 | ___2 | ___3 |
| O Deltoid Ligament (DL) | ___1 | ___2 | ___3 |
| O Posterior Tibialis Tendon (PTT) | ___1 | ___2 | ___3 |

**Figure A2: Standard Ankle Evaluation Form**

**ROM – Dorsiflexion** 0: normal (equal to uninvolved extremity)
1: minor restriction (able to dorsiflex beyond neutral position; 90 degrees)
2: moderate restriction (unable to dorsiflex beyond neutral position)
3: severe restriction (unable to achieve neutral position)

**Special Tests (Laxity and/or Pain Provocation)**

Laxity: -1: hypomobile (locked joint)
0: no perceptible abnormal displacement
1: minor degree of abnormal displacement apparent
2: moderate degree of abnormal displacement apparent with firm end point
3: extreme degree of abnormal displacement apparent with empty end feel

Pain: 0: no discomfort elicited by forced passive motion
1: mild discomfort elicited by forced passive motion
2: moderate pain induced by forced passive motion
3: intense pain induced by forced passive motion

Tests:
O Anterior Drawer:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3
O Talar Tilt:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3
O Squeeze Test:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3
O External Rotation (Kleiger's) Test:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3
O Fibular Translation Test:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3
O Medial Subtalar Glide Test:
Laxity: ___-1 ___0 ___1 ___2 ___3 Pain: ___0 ___1 ___2 ___3

**Functional Capability Rating (with ankle support provided)**

O Incapable of bearing weight (reliant on crutches for ambulation; swing-through crutch gait)
O Capable of bearing partial weight (walk-through crutch gait or cane assistance)
O Capable of bearing full weight without assistance; some degree of gait asymmetry apparent
O Normal walking gait demonstrated (no perceptible limp or other compensatory gait asymmetry)
O Capable of unilateral vertical hopping on involved extremity without pain or apprehension
O Capable of unilateral horizontal hopping on involved extremity without pain or apprehension
O Capable of performing sport-specific movement patterns without pain or apprehension
O Capable of unrestricted participation in sport-specific practice drills and controlled scrimmage
O Capable of unrestricted participation in competitive events
O Full functional capabilities (no performance decrement apparent)

**Acute Phase Management**

Compression:
O Intermittent
O Continuous _____Focal _____Uniform Circumferential
Support:
O Tape
O Brace _____Stirrup _____Lace-Up _____Walker Boot
Supplemental Therapeutic Procedures:
O Electrical Stimulation
O Joint Mobilization _____Active ROM _____Passive ROM _____Manual Therapy

**Figure A2 (continue):Standard Ankle Evaluation Form**


Instructions:
The patient should be comfortably positioned supine with the ankle off the edge of the table. The tape measure should start distal to the lateral malleolus and cross medially over the dorsum of the foot, to fall just distal to the navicular tuberosity. Then it should wrap around the sole of the foot, under the medial arch towards the proximal aspect of the head of the 5th metatarsal. From here, the tape measure is drawn across the dorsum of the foot and the anterior tibialis tendon to the distal aspect of the medial malleolus. Finally, this is wrapped around the Achilles tendon back to the lateral malleolus where the measurement started. The measurement is taken in centimeters. Again, this should be done on both ankles in order to assess a limb difference.

**Figure A3: Figure-8 Maneuver of Measuring Ankle Effusion**

Participant ID number:______ Limb side: R L Date:______________

Rate the amount of ankle pain you are experiencing **right now**.

No pain ________________________________________ Worst pain imaginable

Rate the severity of your worst ankle pain **in the past 24 hours**

No pain ________________________________________ Worst pain imaginable

Rate the amount of ankle pain you are experiencing **during the Anterior Drawer test**

No pain ________________________________________ Worst pain imaginable

Rate the amount of ankle pain you are experiencing **during the Talar Tilt test**

No pain ________________________________________ Worst pain imaginable

**Figure A4: Visual Analog Scale (VAS)**

Please answer **every question** with one response that most closely describes to your condition within the past week.
If the activity in question is limited by something other than your foot or ankle mark not applicable (N/A).

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

**Figure A5: Foot and Ankle Ability Measure Form (FAAM)**

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

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

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

□□□.0 %

**Figure A5 (continue): Foot and Ankle Ability Measure Form (FAAM)**

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

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

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

☐☐☐.0 %

Overall, how would you rate your current level of function?

☐ Normal ☐ Nearly normal ☐ Abnormal ☐ Severely abnormal

**Figure A5 (continue): Foot and Ankle Ability Measure Form (FAAM)**

## Disability in the Physically Active Scale©

**Instructions:** Please answer **each statement** with one response by shading the circle that most closely describes your problem(s) within the past **24 hours.** Each problem has possible descriptors under each. Not all descriptors may apply to you but are given as common examples.

**KEY**

**1** - no problem
**2** - I have the problem(s), but it does not affect me
**3** - The problem(s) slightly affects me
**4** - The problem(s) moderately affects me
**5** - The problem(s) severely affects me

| | No problem<br>**1** | Does not affect<br>**2** | Slight<br>**3** | Moderate<br>**4** | Severe<br>**5** |
|---|---|---|---|---|---|
| **Pain** – *"Do I have **pain**?"* | O | O | O | O | O |
| **Motion** - *"Do I have impaired **motion**?"*<br>**Ex.** decreased range/ease of motion, flexibility, and/or increased stiffness | O | O | O | O | O |
| **Muscular Functioning** - *"Do I have impaired **muscle function**?"*<br>**Ex.** decreased strength, power, endurance, and/or increased fatigue | O | O | O | O | O |
| **Stability** - *"Do I have impaired **stability**?"*<br>**Ex**. the injured area feels loose, gives out, or gives way | O | O | O | O | O |
| **Changing Directions** – *"Do I have difficulty with **changing directions** in activity?"*<br>**Ex.** twisting, turning, starting/stopping, cutting, pivoting | O | O | O | O | O |
| **Daily Actions** – *"Do I have difficulty with **daily actions** that I would normally do?"*<br>**Ex**. walking, squatting, getting up, lifting, carrying, bending over, reaching, and going up/down stairs | O | O | O | O | O |
| **Maintaining Positions** – *"Do I have difficulty **maintaining the same position** for a long period of time?"*<br>**Ex.** standing, sitting, keeping the arm overhead, or sleeping | O | O | O | O | O |
| **Skill Performance** – *"Do I have difficulties with **performing skills** that are required for physical activity?"* | | | | | |
| 1.) **Ex**. running, jumping, kicking, throwing, & catching | O | O | O | O | O |
| 2.) **Ex.** coordination, agility, precision & balance | O | O | O | O | O |
| **Overall Fitness** - *"Do I have difficulty maintaining my **fitness** level?"*<br>**Ex**. conditioning, weight lifting & cardiovascular endurance | O | O | O | O | O |
| **Participation in Activities** – *"Do I have difficulty with **participating in activities**?"* | | | | | |
| 1.) **Ex**. participating in leisure activities, hobbies, and games | O | O | O | O | O |
| 2.) **Ex.** participating in my sport(s) of preference | O | O | O | O | O |
| **Well Being** – *"Do I have difficulties with the following…?"* | | | | | |
| 1.) Increased uncertainty, stress, pressure, and/or anxiety | O | O | O | O | O |
| 2.) Altered relationships with team, friends, and/or colleagues | O | O | O | O | O |
| 3.) Decreased overall energy | O | O | O | O | O |
| 4.) Changes in my mood and/or increased frustration | O | O | O | O | O |

**Figure A6: Disability in the Physical Active Scale (DPA)**

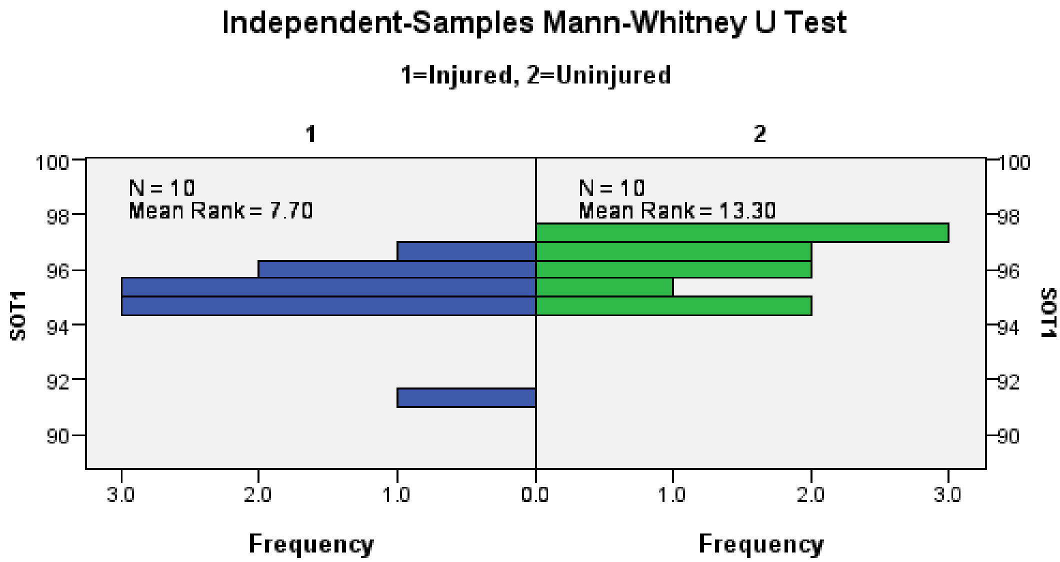
**Table A3: Procedures for EquiTest**

In the Neurocom Room

1. Turn on the computer & EquiTest
2. To have a subject wear an appropriate size of safety vest (S, M, L)
3. To create a new file for the subject
4. To click "continue" after complete the new file (Operator/referral would be under "Sho Arai Thesis")
5. To select both SOT and MCT under "Balance (SA)" assessment suite
6. To have the subject stand on the neurcom plate (Make sure that the subject is standing on the plate with bear feet
7. Testing Position
    a. Align the medial malleolus to the center horizontal line
    b. Align the calcaneus (lateral border of the foot) to the appropriate height line
    c. With the rear foot positioned as above, you may allow the subject to splay to comfort
8. Strap the subject to the EquipTest machine with the appropriate tension for the safety
9. Start SOT testing
    a. Instructions:
        i. Setting 1: Eyes opened / fixed surface
        ii. Setting 2: Eyes closed / fixed surface
        iii. Setting 3: Eyes opened / surroundings may be moved
        iv. Setting 4: Eyes opened / Platform may be moved
        v. Setting 5: Eyes closed / Platform may be moved
        vi. Setting 6: Eyes opened / surroundings & platform may be moved
10. Start MCT testing
    a. Instructions:
        i. Instruct the subject to remain as still as possible during the testing
        ii. 3 consecutive trial for each (backward/forward translation)
            1. Small
            2. Medium
            3. Large
11. Print out the data
12. Shut down the computer
13. Turn off the Neurocom machine

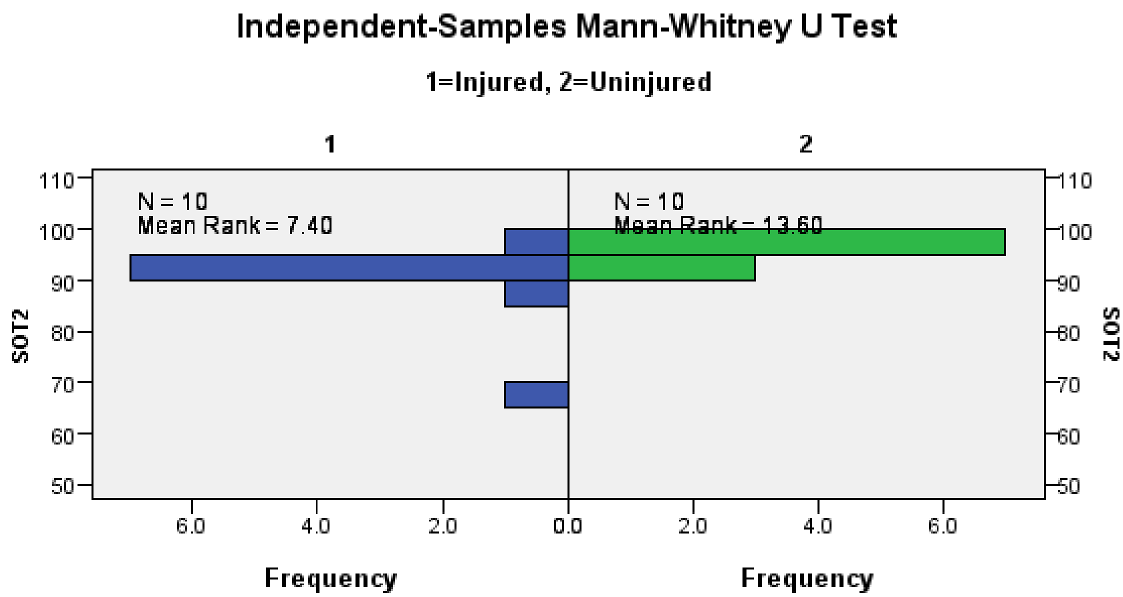
Appendix B

Additional Results



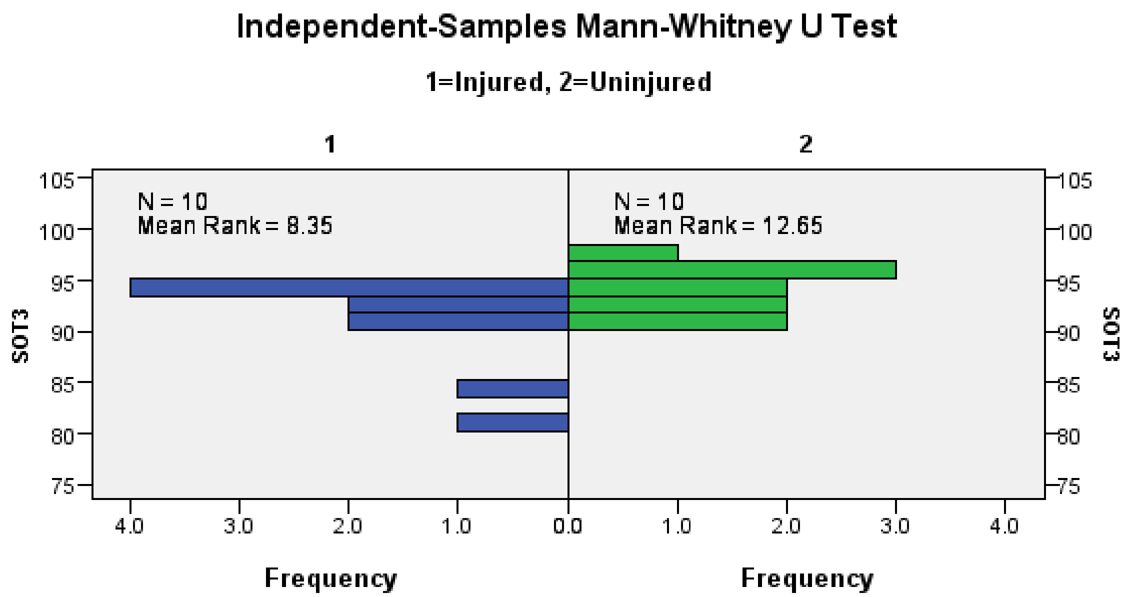

| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 78.000 |
| **Wilcoxon W** | 133.000 |
| **Test Statistic** | 78.000 |
| **Standard Error** | 13.149 |
| **Standardized Test Statistic** | 2.129 |
| **Asymptotic Sig. (2-sided test)** | .033 |
| **Exact Sig. (2-sided test)** | .035 |

**Figure B1: SOT condition 1**



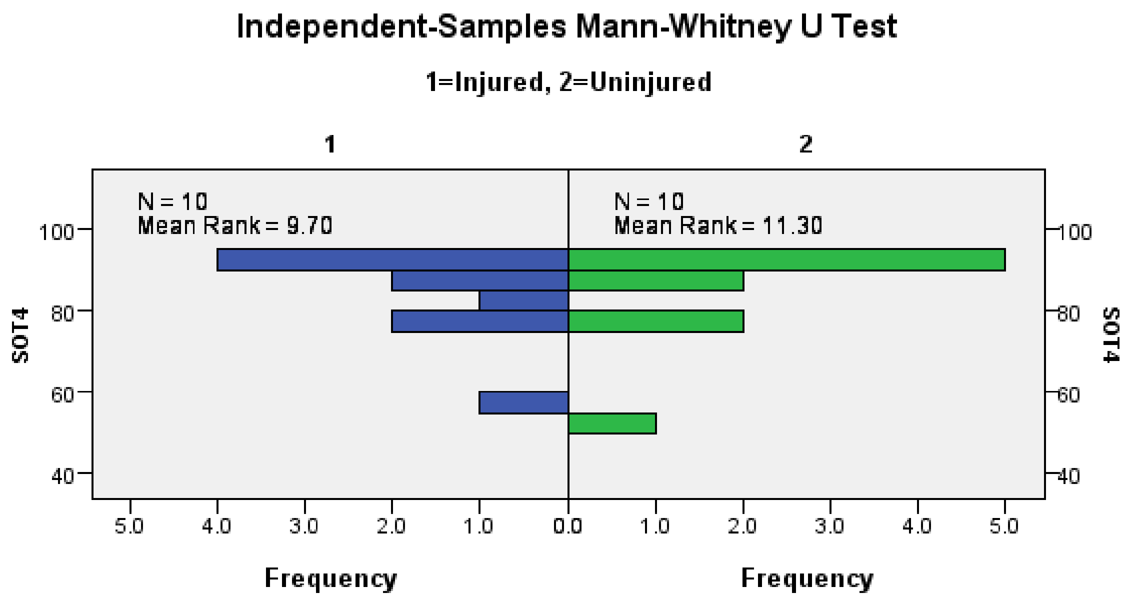

| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 81.000 |
| **Wilcoxon W** | 136.000 |
| **Test Statistic** | 81.000 |
| **Standard Error** | 13.144 |
| **Standardized Test Statistic** | 2.359 |
| **Asymptotic Sig. (2-sided test)** | .018 |
| **Exact Sig. (2-sided test)** | .019 |

**Figure B2: SOT condition 2**



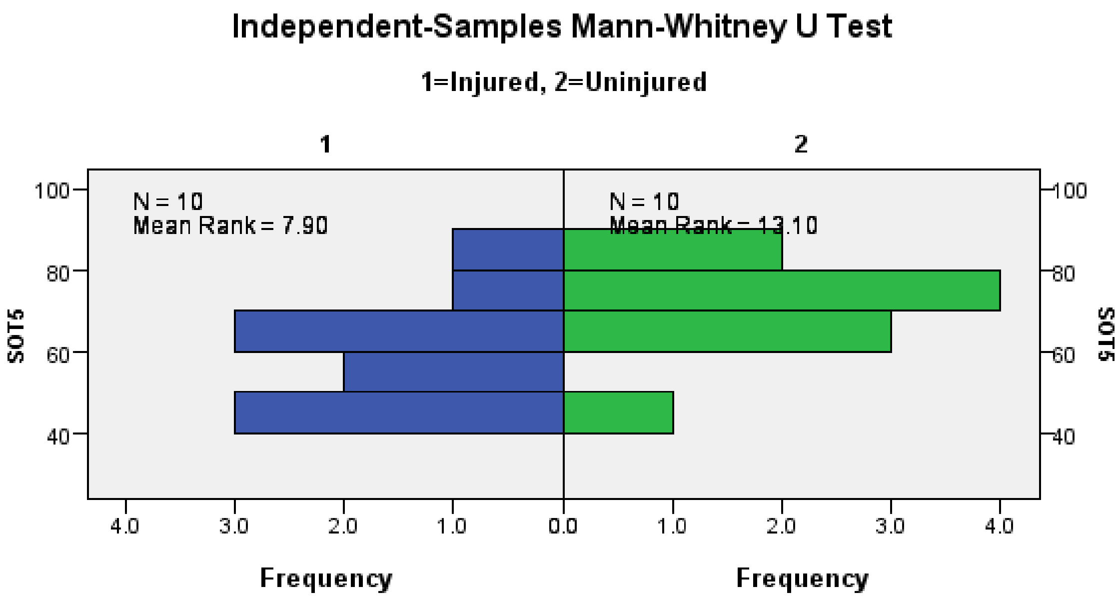

| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 71.500 |
| **Wilcoxon W** | 126.500 |
| **Test Statistic** | 71.500 |
| **Standard Error** | 13.179 |
| **Standardized Test Statistic** | 1.631 |
| **Asymptotic Sig. (2-sided test)** | .103 |
| **Exact Sig. (2-sided test)** | .105 |

**Figure B3: SOT condition 3**




| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 58.000 |
| **Wilcoxon W** | 113.000 |
| **Test Statistic** | 58.000 |
| **Standard Error** | 13.229 |
| **Standardized Test Statistic** | .605 |
| **Asymptotic Sig. (2-sided test)** | .545 |
| **Exact Sig. (2-sided test)** | .579 |

**Figure B4: SOT condition 4**

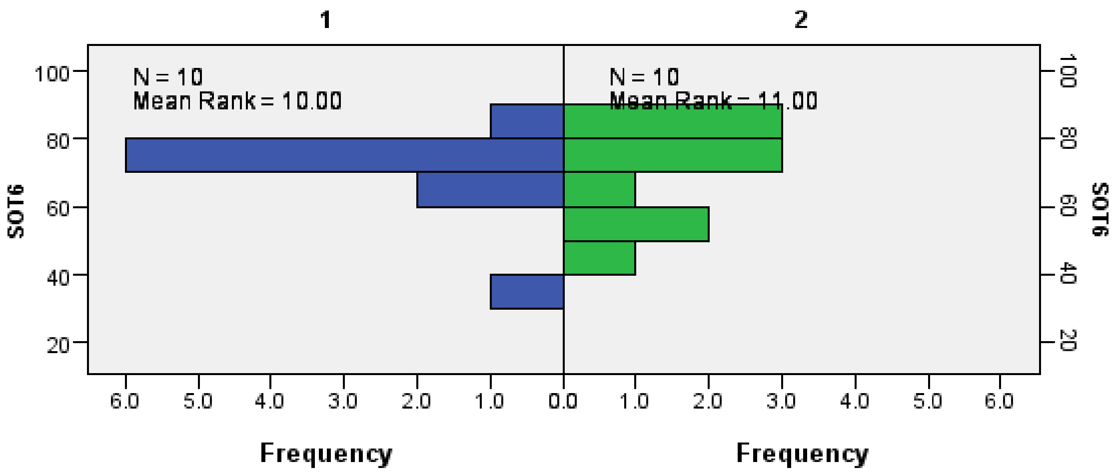



| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 76.000 |
| **Wilcoxon W** | 131.000 |
| **Test Statistic** | 76.000 |
| **Standard Error** | 13.224 |
| **Standardized Test Statistic** | 1.966 |
| **Asymptotic Sig. (2-sided test)** | .049 |
| **Exact Sig. (2-sided test)** | .052 |

**Figure B5: SOT condition 5**

**Independent-Samples Mann-Whitney U Test**

**1=Injured, 2=Uninjured**




| | |
|---|---|
| **Total N** | 20 |
| **Mann-Whitney U** | 55.000 |
| **Wilcoxon W** | 110.000 |
| **Test Statistic** | 55.000 |
| **Standard Error** | 13.224 |
| **Standardized Test Statistic** | .378 |
| **Asymptotic Sig. (2-sided test)** | .705 |
| **Exact Sig. (2-sided test)** | .739 |

**Figure B6: SOT condition 6**

## Appendix C

## Recommendations for Future Research

- To prevent the high variability between and within the groups and increase power of the study, larger sample size will be beneficial.
- To analyze the correlation of postural control between the bipedal and unipedal postural control, it is beneficial to include unipedal stance assessment in addition to the bipedal stance
- To evaluate the length of postural control deficits during bipedal stance following an acute LAS, it is beneficial to assess multiple days.
- An intervention study is beneficial to conduct to determine and compare the effects of a standard single leg stance balance exercise and bipedal stance balance exercise with challenging central sensorimotor system, such as gaze stabilization exercise.