A Thesis

entitled

An Examination of Contributing Factors to Star Excursion Balance Test in Individuals with and without Chronic Ankle Instability

by

Sara E. Carey, ATC

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Masters of Science Degree in Exercise Science

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An Abstract of

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Objective: The purposes of this study were to determine if differences exist in sagittal plane strength at the ankle and knee, static and dynamic postural control, ankle dorsiflexion range of motion (DFROM), and ankle laxity between individuals with and without chronic ankle instability (CAI) as well as to determine which factors contribute the most to Star Excursion Balance Test (SEBT) performance in the CAI and healthy control groups. Design: A case-control study. Setting: Research laboratory. Participants: Twenty healthy control participants (M=6, F=14, 20.5±1.3 yrs, 70.63±15.9 kg, 167.52±11.1 cm.) and eighteen CAI participants (M=10, F=8, 20.2±2.2 yrs, 75.66±14.7 kg, 171.45±9.7 cm.) volunteered for this study. Interventions: Dynamic postural control was assessed with the three directions of the SEBT. After four practice trials, participants performed four testing trials. Concentric strength of the sagittal plane movers of the ankle and the knee was assessed on an isokinetic dynamometer. Static postural control was assessed during a single-leg static balance on a force plate under eyes-closed (EC) conditions. Center of pressure (COP) displacements were recorded in the anteroposterior (AP) and mediolateral (ML) directions during 3, 15-second trials. Ankle DFROM was assessed using the weight-bearing lunge test (WBLT). Ankle joint laxity was evaluated using the
instrumented ankle arthometer in the AP and Inversion-Eversion (IE) directions. **Main Outcome Measures:** Dynamic postural control was represented as the average of the three reach distances (cm) normalized by leg length (cm) and represented as a percentage score (MAXD). Static balance was calculated as the center of pressure velocity (COPV, m/s²) and time-to-boundary (TTB). Ankle dorsiflexion from the WBLT is represented by the distance away from the wall (cm) the foot can slide and still allow the knee to touch the wall while performing closed-chain dorsiflexion. Ankle dorsiflexion and plantar flexion, and knee flexion and extension strength was normalized to body mass and represented as average peak torque (Nm/kg) from five trials. AP and IE ankle laxity were quantified in millimeters and degrees, respectively. **Statistical Analysis:** Independent t-tests were used to compare each dependent variable between the CAI and control groups. A Cohen’s $d$ effect size along with 95% confidence intervals (CI) was calculated for each comparison between groups. A backward regression analysis was performed to determine which dependent variables influence the SEBT performance of both groups. Significance was set a priori at $p<0.05$. **Results:** Significant differences were observed in static postural control measures between the groups in the static postural control ($p < 0.05$). All other variables were not statistically significant ($p > 0.05$). The regression model showed that ankle plantar flexion and WBLT predicted SEBT performance in the CAI group whereas knee strength and static postural control predicted SEBT performance in the control group. **Conclusion:** Participants with CAI had decreased postural control compared to the healthy controls, indicating that the presence of CAI may be associated with altered sensorimotor control. Ankle dorsiflexion and plantar flexor strength were significant predictors of SEBT performance in the CAI group, while knee strength and static balance
were the major contributors to the SEBT performance. When deficits in dynamic postural control is detected using the SEBT, our data suggests the need to address ankle DFROM and plantar flexor strength for individuals with CAI as well as knee strength and static balance for those without any lower extremity injury in order to improve their dynamic function.
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List of Abbreviations

% MAXD.................................Normalized Percentage of the Reach Distance

CAI........................................Chronic Ankle Instability
CKC........................................Closed Kinetic Chain
COP .....................................Center of Pressure

DF........................................... Dorsiflexion

ES......................................... Effect Size

FAAM......................................Foot and Ankle Ability Measure

PL......................................... Posteriorlateral
PM......................................... Posteriormedial

ROM....................................... Range of Motion

SEBT...................................... Star Excursion Balance Test

TTB......................................... Time to Boundary

WB......................................... Weight Bearing
WBLT...................................... Weight Bearing Lunge Test
Chapter 1

Introduction

Lateral ankle sprains are one of the most common injuries in the physically active population.\textsuperscript{1-4} In the 2005-2006 academic years, there were 4,350 sports injuries reported in high school athletes in the United States.\textsuperscript{5} Of these injuries, 52.8\% were lower extremity injuries, and an ankle sprain was the most common injury in the lower extremity.\textsuperscript{5} Lateral ankle sprains result in time loss from sports participation\textsuperscript{5,6}, cause long-term disability such as recurrent ankle sprains and ankle osteoarthritis\textsuperscript{3,4,7,8} and have a major impact on health care costs and resources.\textsuperscript{9} Therefore, lateral ankle sprains are a critical issue in public health, especially the physically active.

Yeung et al.\textsuperscript{4} reported that 73\% of athletes with an initial ankle sprain had repeated ankle sprains and 59\% of those had significant residual disability and symptoms with functional and mechanical impairments. The condition associated with recurrent ankle sprains is commonly known as chronic ankle instability (CAI).\textsuperscript{7} Functional and mechanical impairments associated with CAI have been related to the development of post-traumatic osteoarthritis.\textsuperscript{8} Therefore, there is a need to develop effective intervention and prevention programs for decreasing the prevalence of CAI and the associated long-term complications.
Important steps in decreasing the prevalence of CAI are identifying modifiable risk factors and the development of intervention strategies to target these risk factors. The leading risk factor and predictor for recurrent ankle sprains is a previous history of an ankle sprain.\textsuperscript{10} Additionally, altered arthrokinematics and neuromuscular control have been previously observed following an ankle sprain, manifesting as restricted ankle dorsiflexion (DF) range of motion (ROM),\textsuperscript{11} increased ankle laxity,\textsuperscript{12,13} decreased strength in the proximal and distal segment,\textsuperscript{12,14} and poor postural control\textsuperscript{12,15-18}. There does not appear to be a single factor that accounts for clinical deficits associated with recurrent ankle sprain and a multi-factorial approach for determination of risk factors and intervention has been suggested.\textsuperscript{12,15} Therefore, it is important to identify which factors are associated with the existence and risk of ankle pathology, and then determine which are modifiable with clinical intervention.

Specifically, previous studies\textsuperscript{14,19,20} found reductions in torque production of the ankle plantarflexors and evertors as well as knee flexors and extensors in individuals with CAI. Furthermore, Friel et al.\textsuperscript{21} observed hip abductor weakness in those with CAI. However, McHugh et al.\textsuperscript{22} reported that hip weakness did not predict ankle sprains in high school athletes. Together, these findings suggest that strength deficits may develop in the entire lower extremity following an initial ankle sprain rather than exist prior to initial ankle sprain.

Another factor related to CAI is static postural control. Static postural control requires the individual to maintain the base of support for a given amount of time. Measurements of static postural control include time to boundary (TTB) and center of
pressure (COP). Hertel et al.\textsuperscript{23} found decreased TTB in CAI participants compared to healthy participants. Pope et al.\textsuperscript{24} evaluated COP in CAI and healthy participants and observed that the CAI group had a more anterior and lateral displacement of their COP than the healthy group.\textsuperscript{24} These findings showed that alterations in static postural control are likely associated with CAI.

Mechanical impairments have been observed in CAI population, including ankle joint laxity and restricted DF-ROM. Hubbard et al.\textsuperscript{25} found increased laxity in functional unstable ankles compared to uninjured ankles. Increased ankle laxity can cause a change in the support of the ankle joint and altered healing of the ligament.\textsuperscript{26} Restricted DF during running has also been observed in individuals with CAI.\textsuperscript{27} Deficiencies in strength, static postural control, ankle stability and DF-ROM following an ankle sprain can be considered modifiable factors that increase the risk for recurrent ankle sprains, and should be addressed to develop a more effective intervention program in patients with CAI.

The star excursion balance test (SEBT) has been developed as a simple and inexpensive injury screening test to identify individuals more at risk for an ankle sprain.\textsuperscript{28-31} The SEBT assesses dynamic postural control which has shown to better correlate to functional activities than static.\textsuperscript{15} The SEBT requires an individual to maintain the base of support while reaching to a maximum distance with the free leg.\textsuperscript{32} The SEBT is sensitive to detect risks for a lower extremity ankle injury\textsuperscript{30} and deficiencies in dynamic postural control stability in individuals with ankle pathology.\textsuperscript{17,33} Gribble et al.\textsuperscript{34} reported that individuals with CAI demonstrated diminished dynamic postural
control during the SEBT coupled with decreased knee and hip flexion angles compared to the control group.

Previous prospective research\textsuperscript{28-31} has shown that athletes with poor performance of the SEBT were more likely to have an ankle injury during a competitive season. Based on our preliminary research,\textsuperscript{28-30} a cut off score has been established to identify athletes who may be at a greater risk for an ankle sprain. Athletes, who have scored under a 67\% of their leg length in the anterior reach direction of the SEBT, will be five times more likely to suffer an ankle injury.\textsuperscript{28-30}

The SEBT suggests to requirement of a combination of strength, balance, range of motion, and coordination/neuromuscular control. However, previous studies have not determined which of these factors, individually or in combination, influences the SEBT the most. These factors represent deficits associated with ankle injuries that are addressed and modified through rehabilitation. While the SEBT has potential for use as an injury screening tool to predict a lateral ankle sprain as well as to identify disability associated with CAI, it is not known what a clinician should focus on if poor performance on the SEBT is detected in order to reduce the deficits in dynamic postural control and the risk for subsequent ankle sprain.

1.1 Statement of Problem

While clinical practice and research focus on ankle sprains, they remain common injuries in the physically active population. A deficit in dynamic postural control performance on the SEBT has been observed in individuals with CAI. However, the SEBT does not specify which factors (such as deficiencies in strength, static balance,
ROM, and ankle laxity) are associated with diminished dynamic postural control in individuals with CAI.

1.2 Statement of Purpose

The purpose of this study was (1) to compare SEBT performance, strength, ankle joint laxity, ankle DF ROM, and static balance between individuals with and without CAI and (2) to determine which of these variables greatest contribute to SEBT performance in those with and without CAI.

1.3 Research Hypothesis

H1: Participants with CAI would have decreased knee and ankle strength compared to those in the control group.

H2: CAI participants would produce lower SEBT reach distances compared to those in the control group.

H3: Participants with CAI would have increased laxity measurements compared to the control participants.

H4: CAI participants would have decreased static postural control, identified by decreased time to boundary measures and increased COP measurements compared to the control group.

H5: CAI participants would have decreased DF ROM compared to the control group.

H6: Knee extension strength, ankle plantar flexion strength and ankle laxity would be the greatest predictors of SEBT performance in the CAI group.
H7: Static postural control and DF ROM would be the greatest predictors of SEBT performance in the control group.

1.4 Significance of study

It has been established that individuals with CAI have decreased performance on the SEBT test, and that a poor score on the SEBT is associated with an increased risk for an ankle sprain. However, it is unknown which of the factors that are suggested to influence the SEBT performance are the most predictive of the performance. Therefore, identifying the contributing factors to the SEBT performance may have clinical benefits for the development of more effective intervention and prevention programs for ankle sprains by targeting these factors. Our findings will provide researchers and clinicians insight into the deficits in dynamic stability in individuals that are identified as having CAI and those that are identified as having an increased risk for an ankle sprain. Our findings will also provide direction as to what factors should be the focus to reduce the risk of an ankle sprain when identifying poor performance on the SEBT. By linking modifiable risk-factors to the SEBT, this tool may become more useful to implement in pre-participation exams and aid in the early detection of potential injury. If we can determine what factors contribute the most to decreased SEBT performance, we can use them to target prevention programs, possibly reducing the risk for ankle sprain in individuals scoring below the SEBT cut-off score and improving residual disability and symptoms after an ankle sprain. In the long-term, this knowledge could reduce long-term consequences like osteoarthritis and help to decrease associated healthcare costs.

1.5 Assumptions
We assumed all participants would be honest in their responses to the health questionnaire, the Foot and Ankle Ability Measure (FAAM), the FAAM sport, and the AII (Ankle Instability Instrument). We also assume all participants give their best effort in all tasks.

1.6 Operating Definition

**Ankle Sprain:** Damage to the ligaments and surrounding structure of the ankle involving excessive joint motion.

**Balance:** The state of keeping the center of gravity/mass over the base of support and the resultant force is zero.\(^{35}\)

**CAI (Chronic Ankle Instability):** Residual symptoms including “recurrent sprain, episodes of ankle joint “giving way,” pain, swelling, and decreased function.”\(^{36}\)

**CKC (Closed Kinetic Chain):** a condition in which a force to one segment causes motion at all connected segments (i.e. kinetic chain).\(^{37}\)

**COP (Center of Pressure):** The point at which an equivalent single force causes the same effect on a rigid body as a distributed force.\(^{38}\)

**Center of Pressure Velocity =COPV:** The average value of the instantaneous resultant velocity in a given direction during a given time period.\(^{39}\)

**DF = Dorsiflexion**

**ROM = Range of Motion**
Sensorimotor control: A system incorporating all the afferent, efferent, and central integration and processing centers involved in maintaining functional joint stability.\(^{40}\)

SEBT (Star Excursion Balance Test): a clinical test of dynamic postural control that involves unilateral stance while attempting maximal reach with the opposite leg in 8 different directions.\(^{41}\)

TTB (Time to Boundary): TTB is a measure of the time it would take for the COP to reach the boundary of the base of support if the COP was to continue at the same velocity.\(^{23}\)

Torque: The turning effect of a force about the longitudinal axis of a body.\(^{38}\)

WBLT (Weight Bearing Lunge Test): A test where participants keep their test heel firmly planted on the floor while they flexed their knee to the wall to test dorsiflexion range of motion.\(^{42}\)

Postural Control: the act of maintaining, achieving or restoring a state of balance during any posture or activity.\(^{35}\)

Static Postural Control: The ability or inability to maintain stability above a narrow base of support in single-limb stance.\(^{16}\)

Dynamic Postural Control: Attempting to maintain a base of support while completing a movement.\(^{17}\)

FAAM =Foot and Ankle Ability Measure
Chapter 2

Literature Review

2.1 Purpose of literature review

The purpose of this literature review is to discuss ankle sprain prevalence, risk factors for an acute traumatic ankle sprain, and contributing factors leading to CAI. Understanding what factors increase the risk for a traumatic ankle sprain and contribute to an increase in “giving way” and instability may lead to the development of more effective prevention and intervention strategies for a traumatic ankle sprain and CAI.

2.2 Ankle Anatomy

The ankle is a complex joint containing four main bones: the tibia, fibula, talus and calcaneus, which are stabilized by a number of static and dynamic restraints. The static restraints include ligamentous structures, joint capsule, cartilage, bony geometry within the articulation, and friction between the cartilage surfaces. The three main ligaments provide statistic stability to the lateral aspect of the ankle and rearfoot complex, including the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL). The lateral ligamentous complex helps to protect the ankle against excessive supination forces. On the medial side, the deltoid ligaments
help to prevent ankle eversion. The dynamic stabilization against and ankle sprain mechanism is provided by both extrinsic and intrinsic muscles, such as the anterior tibialis, gastroc-soleus complex, tibialis posterior, flexor digitorum longus, and flexor hallucis longus, and the peroneal muscles. These muscles help to keep the ankle stable during dynamic tasks. One example is by controlling rearfoot supination, which is commonly associated with lateral ankle sprains.⁷

### 2.3 Lateral Ankle Sprain Prevalence

The most common mechanism of injury for an ankle sprain is ankle inversion.⁷,⁴³,⁴⁴ In some cases, there have also been reports of inversion with internal rotation and plantar flexion contributing to the injury.⁴⁵ However, both Mok et al⁴³ and Kristanlund et al⁴⁴ concluded, based on their findings, that plantar flexion is not required for an ankle sprain.

Ankle sprains are one of the most common lower extremity injury in the physically active population.¹,²,⁴⁶ In a study of lower extremity injuries in high school athletes, Fernandez et al.⁵ reported high school athletes sustain over 2 million injuries annually, and over 53% of these injuries occur in the lower extremity (LE). Of these injuries 40.3% were ankle injuries.⁵ Borowski et al.⁴⁷ also found that high school basketball players most commonly suffered from their ankle/foot injuries (39.7%) and 44% of these injuries were ligamentous sprains.

The prevalence of an ankle sprain is consistently high in other athletic populations. The NCAA recorded injury data over 16 years for 15 different sports and reported that over 50% of injuries were to the lower extremity.¹ Ankle sprains accounted
for 15% of all total injuries, approximately 27,000.\textsuperscript{1} Yeung et al.\textsuperscript{4} reported on lost participation time from an ankle sprains in the Hong Kong National teams, showing that 72% of those who sustained an ankle injury had to sit out four weeks or more of participation their activity.\textsuperscript{4} Kofotolis et al.\textsuperscript{48} found in a group of amateur soccer players that lateral ankle sprain sprains averaged 6.5 days lost. Both of these studies showed that ankle sprains can lead to loss of participation time.

Ankle sprains not only cause time loss from participation, but with that many injuries they have increased health care costs. Ankle sprains treatment can end up costing the patient a lot of money. In 2003 the US Consumer Products Safety Commission estimated that treatment of ankle sprains was $70 million dollars for just high school soccer and basketball players.\textsuperscript{49} They also estimate $1.1 billion indirect costs from ankle sprains too.\textsuperscript{49} This cost could be from ER visits along with diagnostic testing to rule out fracture and full ligament tears. Therefore, a lateral ankle sprain could be considered as a significant public health concern.

\textbf{2.4 Chronic ankle instability}

With ankle sprains being such a common injury, there is a greater possibility that those who have already suffered one sprain may suffer another one. It has been reported that over 40% of individuals who suffered from an initial ankle sprain experienced recurrent ankle sprains with residual symptoms, such as “giving-way”, instability, pain, and functional impairments.\textsuperscript{3,4} The recurrent ankle sprain with residual symptoms has been referred to as CAI.\textsuperscript{36} Chronic ankle instability can lead to developing long term complications, such as post-traumatic osteoarthritis.\textsuperscript{8} It was reported that 182 patients
suffered posttraumatic ankle osteoarthritis following an ankle sprain, with 30 of those with CAI.\textsuperscript{8}

2.4.1 Pathomechanics of CAI

Hertel\textsuperscript{7} classified CAI into the two subgroups: mechanical and functional insufficiencies. Mechanical insufficiencies can include pathological laxity, arthrokinematic impairments, synovial and degenerative changes within the body.\textsuperscript{7,12} An overstretch injury to the lateral ligamentous complex in the ankle may lead to ankle joint laxity. Increases in ligament laxity can make the ankle mechanically unstable at both the talocrural and subtalar joints.\textsuperscript{7} Hubbard et al.\textsuperscript{25} examined ankle laxity in CAI patients and they found increased anterior displacement in the injured limb compared to the non-injured limb. They also found overall greater anterior/posterior displacement in the functionally unstable ankle compared to the uninjured ankle.\textsuperscript{25} The increased mechanical laxity of the ankle joint complex following initial ankle sprain could put the ankle in vulnerable positions and prevents the ankle from reaching its closed-pack-position during dynamic tasks, contributing to increased ankle sprains.\textsuperscript{7} Diminished dorsiflexion prevents the ankle from reaching its closed-pack-position by holding the ankle in a hyper-supinated position. Increased laxity in the ATFL may also lead to increased anterior displacement of the talus.\textsuperscript{7} This increase in anterior displacement of the talus could decrease the availability of ankle dorsiflexion range of motion (DF-ROM).

The positional fault of the distal fibula and talus may be one of factors that contributes to mechanical instability.\textsuperscript{7} If the fibula sits more anteriorly, the ATFL will have more slack and when the ankle moves into inversion there will be more inversion
before it becomes taut.\textsuperscript{7} This increase in motion can lead to ankle sprain and recurrent instability. The anterior displacement of the fibula can also lead to decreased DF-ROM, or hypomobility, and then further alterations to compensate for that lack of motion.\textsuperscript{7} With the fibula more anteriorly positioned, the tibiofibular joint is not anatomically correct. This slight motion will change the joint axis and not allow the talus to move through the mortise, subsequently restricting dorsiflexion. Hubbard et al.\textsuperscript{50} found increased anterior position of the fibula in those with CAI compared to both the uninjured ankle and the matched control ankle. These participants did, however, regain full DF-ROM similar to the control group. Denegar et al.\textsuperscript{51} observed that CAI participants demonstrated a decreased posterior talar guide or increased anterior displacement of the fibula and restoration of ankle DF-ROM. Both Hubbard et al.\textsuperscript{50} and Denegar et al.\textsuperscript{51} showed displacements of the talus or fibula following ankle injury, but neither were sure if the positional fault was present before the injury. Limited ankle DF-ROM may be caused by a lack of gastrocnemius and soleus flexibility or arthrokinematics restrictions.\textsuperscript{51} Restoration of DF-ROM without proper arthrokinematics at the ankle joint may be attributed to gastrocnemius and soleus flexibility. However, Drewes et al.\textsuperscript{11} reported decreased ankle DF during jogging in individuals with CAI.

These alterations in ankle stability and arthrokinematics following an ankle sprain may lead to chronic inflammation in the joint, because of improper healing mechanisms. The inflammation can cause increased pain due to impingement of synovial tissue.\textsuperscript{7} Another issue is degenerative changes following repeated ankle instability. Lee et al.\textsuperscript{52} arthroscopically looked at changes after being diagnosed with CAI. Their results showed
all individuals had some degree of synovitis, while others lesions seen were talar chondral defects and talar OCD. Their observations show degenerative changes over time in those with CAI.

Functional insufficiencies include impaired sensorimotor, neuromuscular control, strength, and overall postural control. Ankle proprioception and joint receptors help in the body’s awareness of ankle positions. Ankle proprioception is important because when the ankle moves the brain needs to be able to detect where the ankle is positioned. Following an ankle sprain, the mechanoreceptors of the ankle ligaments are damaged, leading to decreased proprioception. These receptors turn a movement into afferent or proprioceptive information to send to the brain. If the ability to detect joint position is lost, the ankle could be put into more compromising positions that could lead to injury. It can also lead to altered movement to compensate to maintain function. Glencross and Thornton tested the ability to replicate plantar flexion joint position. Their results showed greater error in the injured ankle compared to the uninjured ankle. This shows that the alteration is associated with the injury. Altered joint position sense of the knee can also be a factor in CAI. Tsiganos et al. observed altered joint position sense of the knee in individuals with CAI. Also they found that there was a difference in the non-injured leg as well, indicating that CAI may be associated with central mediated alterations.

Another functional factor is the neuromuscular control of the ankle and lower extremity. When asked to complete a functional task it is important that the muscles are ready to contract and in a timely manner. In healthy individuals, there is not only
activation after landing, but pre-activation, of the motor neurons prior to gait or a jump task. In CAI individuals, pre-activation is still present, but it does not activate as in healthy individuals. That is an example of a feedforward response, while there have also been deficits in feedback response of the injured ankle. Palmieri-Smith et al. found decreased activation of the peroneals following an inversion perturbation in the CAI ankle compared to their healthy ankle. Following an inversion perturbation of the ankle, the peroneals should activate to pull the ankle into eversion. Their results show a change in activation following the injury altering the feedback response. In a similar study by Beckman and Buchanan, they also introduced an ankle inversion perturbation and looked at peroneal activation as well as gluteal activation. In the ankle pathological group, they found increased latency in gluteal activation on both the right and left side when that respective side was tested. These results also show an alteration in feedback response.

Alterations in NMC, following an injury, not only affect the ankle, but the more proximal joints as well. In a study by Gribble and Robinson, they had both CAI and control participants complete a jump landing task and then evaluated the differences in the landing pattern. The researchers found that the CAI group, regardless of the side (injured or non-injured), had decreased knee flexion angles compared to the control group. This alteration in landing pattern may suggest that the injury causes a centrally mediated change that presents as decreased knee flexion since it showed in both legs of the CAI group. The alteration in knee function during landing could contribute to continuing instability or CAI.
Altered muscle activation during a functional task will show that there is a change in the activation pattern. Hopkins et al.\textsuperscript{58} recorded muscle EMG patterns of the peroneus longus and tibialis anterior during walking on a treadmill. Their pathological group showed increased activation of the muscles.\textsuperscript{58} The tibialis anterior was more active during 15-30\% and 40-70\% of stance and the peroneal longus had higher activation at heel contact and toe off.\textsuperscript{58} This shows that the eversion muscles (peroneal longus) are more active at the beginning and end of the stance phase. This may be as a protective mechanism to make sure that the foot remains neutral or does not invert. The researchers also found that the timing of activation was different than their matched controls.\textsuperscript{58} Compared to the control group, the injured group had increased invertor activation and decreased evertor activation during the stance phase.\textsuperscript{58} They believe that this can lead to ankle instability.\textsuperscript{58} This provides evidence that CAI causes altered activation patterns of normal gait. If gait or running patterns change then the individual may be at an increased for further injury. A change in activation patterns has also been shown in the hip musculature by Bullock-Saxton et al.\textsuperscript{59}. During a prone hip extension task, they showed decreased hip muscle activation and delayed hip activation in the injury group. This shows that the injury not only causes alterations at the injured joints, but at the proximal joints too.

An alteration in sensorimotor control can lead to impaired postural control.\textsuperscript{60} McKeon reported that poor postural control increases a risk for an ankle sprain and is observed following an ankle sprain.\textsuperscript{16} Functional impairments of the ankle can lead to using a “hip strategy” instead of an “ankle strategy,” which is the most efficient way of
activation.\textsuperscript{60} “Hip strategy” involves using the hip musculature to maintain control at the ankle.\textsuperscript{60} After injury, the ankle muscles and other structures need to maintain ankle posture and keep the ankle out of vulnerable positions, the hip muscles activate to help maintain postural control.

In several studies,\textsuperscript{61-64} balance training has been shown to decrease the risk for further injury especially in CAI. The studies show after at least 6 weeks of balance training, not only did dynamic balance increase,\textsuperscript{62,64} but the number of injuries decreased.\textsuperscript{63} These results are short term outcomes and need to be assessed over several years to examine the effects of the balance training over time. Postural control also requires strength, which also should be assessed to see if a deficit in strength is contributing to the postural control deficits. The effects of this program may only be temporary and not effective in the long run unless repeated annually. These short term improvements show promise that the consequences of CAI can be diminished.

Altered postural control has been observed in both static and dynamic measures. Hertel and Olmsted\textsuperscript{23} found deficits in time to boundary measurements between CAI and healthy individuals. In five of the six analysis performed, the CAI group had significantly lower TTB scores than the healthy group.\textsuperscript{23} They did not see as big of differences in COP data between the groups.\textsuperscript{23} The Lower TTB measures are indicative of not being able to control their leg while balancing on a single limb. Pope et al.\textsuperscript{24} discovered that the CAI group, with their eyes open, had a more anteriorly and laterally centered COP. They also found more anterior-posterior changes in COP when the CAI group had their eyes closed.
These results indicate that CAI individuals have more movement in a static balance situation than healthy individuals.

COP deficits have been detected in dynamic tasks. Hopkins et al. reviewed plantar pressure of a control and pathological group while walking. Their results showed more laterally placed pressure of those in the pathological group. The researchers theorized this was related to the alteration in muscle activation patterns that they found during the walking task.

The star excursion test is often used to detect differences in dynamic balance between healthy and CAI groups. Olmsted et al. showed decreased reach distance in individuals with CAI compared to those without CAI. Gribble et al. also observed that CAI patients exhibited decreased reach distances in the anterior, medial and posterior directions compared to individuals without CAI. Together, these findings indicate that altered dynamic postural control may be associated with CAI. Olmsted et al. also found that the reach distance was decreased on the injured side compared to their uninjured leg, indicating that the central mediated alterations are associated with CAI.

Strength deficits in the lower extremity have been shown in individuals with CAI in previous studies. Willems et al. found ankle evertor and invertor weakness in individuals with the CAI compared to those without CAI. In contrast, Kaminski et al. conducted a review of strength related literature and found that there is no real agreement on where strength losses occur following an ankle sprain. Even though there does not seem to be a consensus as to where the strength loss lies, most research seems to point to
the loss of inversion strength.\textsuperscript{66-68} This seems to be because of a stretch to the peroneal muscles and/or damage to the mechanoreceptors in the ankle.\textsuperscript{66}

There has also been limited research on sagittal plane strength deficits. Gribble and Robinson\textsuperscript{14} examined sagittal plane strength in those with CAI and found that ankle plantar flexion strength was decreased compared to the control and their uninjured leg. Similarly, Fox et al.\textsuperscript{69} saw that plantar flexion torque was decreased in the injured group compared to the control. These studies show that ankle sprains can cause alterations in force production of the muscles of the ankle.

Ankle strength should not be the only focus when it comes to strength loss following an ankle injury. The ankle is the most distal joint involved in a series of motions to keep the lower extremity stable. Following an injury both ankle (only plantar flexion) and knee strength in the sagittal plane deficits were found in those with CAI.\textsuperscript{14} In this same study, they found no hip strength deficits in the sagittal plane.\textsuperscript{14} Friel et al.\textsuperscript{21} found not only a decrease in ankle plantar flexion in the involved leg, but also a decrease in hip abductor strength. Several studies state that hip strength is needed to maintain balance.\textsuperscript{12,21} A weakness in hip strength could lead to alterations at the knee and ankle. The hip abductors help to keep the hip and knee abducted so there is less pronation at the foot.

All of these factors, mechanical and functional, contribute to ankle instability. Because the factors are all intertwined it seems they do not happen in single form. Therefore, a combination of the mechanical and functional factors most likely will lead to ankle instability.\textsuperscript{12} In a study by Hubbard et al.\textsuperscript{12} examining factors contributing to CAI,
deficiencies in balance, joint stability, and sagittal force production about the ankle were the best discriminates between individuals with and without CAI, indicating that instability is a multifactorial complication.

2.5 Risk Factors

2.5.1 Risk for ankle sprain

There are numerous risk factors that will place individuals at a greater chance for injury. Wang et al.\textsuperscript{70} found that increased postural sway predicted the risk for ankle injury; however, they reported that isokinetic ankle strength and ankle dorsiflexion measures were not risk factors for ankle injury. Willems et al.\textsuperscript{71} showed that female physical education students with poor dynamic postural control, increased dorsiflexion strength, increased extension range of motion (ROM) of the first phalanx in the foot, and diminished joint positioning sense in ankle inversion were at risk for ankle sprains. Willems et al.\textsuperscript{71} also identified risk factors for an ankle sprain in male physical education students, including decreased dorsiflexion ROM (DF-ROM) and strength, increased extension ROM in the first phalanx in the foot, and increased balance test scores. de Noronha, et al.\textsuperscript{72} systematically reviewed literature that showed measures of voluntary strength, proprioception, ROM, or postural sway may increase a risk for lateral ankle sprain.

2.5.2 Risk Factors for CAI

There are several factors that can put individuals at an increased risk for an ankle sprain or repeated ankle sprains. The largest contributing risk factor to CAI is previous history of an ankle sprain.\textsuperscript{10,20} After injury there are changes that occur to the lower
extremity and the whole body in general. Hubbard et al.\textsuperscript{26} discuss pathological laxity and hypomobility of the joint as risk factors for further injury. One theory is that there is damage to the mechanoreceptors which will in turn alter the neural pathways to the brain.\textsuperscript{19} McKay et al.\textsuperscript{73} studied ankle injuries in basketball players and discovered three risk factors for ankle injury: (1) History of ankle injury, (2) Shoe with air cells in the heel, and (3) Not stretching prior to activity. There results reaffirm that a history of ankle sprain is the biggest risk factor. Despite knowing these factors, an ankle sprain can happen to anyone.

Overall, a loss of strength in the lower extremity could lead to an increase in ankle injury. The muscles of the ankle, knee, and hip need to function properly and in the correct order to decrease the risk of injury. Kaminski et al.\textsuperscript{66} concluded that those lacking muscle co-contraction may be at a higher risk for injury, because of their inability to dissipate the force of impact. Baumhauer et al.\textsuperscript{74} saw an imbalance between the evertor and invertor muscles to be a risk factor for suffering another sprain. Gribble and Robinson\textsuperscript{14} saw decreases in force production following injury. Decreased strength has been linked to poor postural control, as it is a combination of factors. In a correlation study by Hubbard et al.,\textsuperscript{75} they found in the CAI group, as the number of missed balance trials increased as the strength measures decreased. Balance, static and dynamic, involves lower extremity strength in some capacity and a decrease in strength can lead to this alteration. Hip strength deficits have been determined following an injury, but are not present prior to an ankle sprain.\textsuperscript{59} Because the deficit was not seen until after injury it means that the loss of hip strength increases the risk of injury.
Risk factors differ from study to study, especially on the level of how the factors contribute to risk. Hubbard et al.\textsuperscript{12} examined all possible contributing factors and compared them to a matched control group and to the uninvolved ankle. When comparing the CAI group to the control group the four most predictive factors of the CAI group were increased inversion laxity, increased anterior laxity, more missed balance trials, and a decrease in plantar flexion to dorsiflexion peak torque.\textsuperscript{12} The researchers found different results when comparing within the CAI individual. The CAI limb showed decreased dynamic balance, decreased plantar flexion peak torque, and increased inversion laxity compared to the uninjured limb.\textsuperscript{12}

2.6 Injury Prediction

As stated earlier, balance or postural control is affected by an ankle sprain. After an ankle sprain, clinical balance tests, such as the SEBT and BESS, have been used to identify postural control deficits following ankle sprains. Both tasks involve maintaining a base of support for a certain amount of time. However, static balance has been shown not to correlate well with functional tasks as dynamic balance does.\textsuperscript{15} Injuries are going to occur during a functional task or motion. By assessing the individual’s dynamic balance, the results are more applicable to an actual practice or game situation.

Dynamic postural control is more realistic and more applicable to a real dynamic event or injury. Dynamic postural control is attempting to maintain a base of support while completing a dynamic task.\textsuperscript{33} The Star Excursion Balance Test (SEBT) is an easy and relatively inexpensive way to assess dynamic postural control. The SEBT involves a star pattern of eight tape lines on the floor. The participant being tested then stands in the
middle of the star. While maintaining their base of support, they complete a reach as far as they can in the different directions. Gribble and Hertel found that results were more comparable when normalized using the individual's leg length. These values can be compared because the % is unique to the individual. Based on Hertel’s recommendations, the number of reach distances has been narrowed from eight to three directions: Anterior, Posterior-medial, and Posterior-lateral. These three measures can be done without redundancy in results.

It has been demonstrated that the SEBT may have predictive capability of the lower extremity injury. Plisky et al. reported that high school athlete with poor performance on the SEBT are 2.5 times more likely to sustain a lower extremity injury. de Noronha et al. also showed that previous history of a sprain and the poor SEBT performance in the PL direction were strongly predictive of an ankle sprain. In preliminary data from our laboratory, among football and basketball athletes, those who reached under 67% (reach distance/leg length) on the anterior reach, were determined to be approximately 5 times more likely to suffer an ankle sprain.

2.6.1 Potential contributing factors to the SEBT performance

Although investigations have yet to determine what factors are exactly contributing to the SEBT, the SEBT performance may be associated with strength, balance, and range of motion. In 2011, Hoch et al. examined the association between SEBT performance and the Weight Bearing Lunge Test (WBLT). They showed that the anterior reach distance was correlated with the WBLT, indicating that the availability of closed-kinetic-chain ankle DF influenced the anterior reach distance of the SEBT.
Robinson and Gribble\textsuperscript{41} examined that knee and hip kinematics were altered in those with CAI when performing the SEBT. This finding could indicate that these alterations could be associated with the SEBT performance in individuals with CAI.

2.7 Summary of Lit Review

In conclusion, several factors associated with CAI have been identified in previous literature, including ligament laxity, decreased strength in the lower extremity, restricted ankle DF-ROM, altered sensorimotor control, and diminished static and dynamic postural control. Previous prospective studies have also identified potential risk factors that make an individual more likely to sprain their ankle or suffer from repeated ankle sprains. The SEBT is a useful clinical tool that has shown sensitivity to predict lower extremity injuries and identify altered dynamic postural control in individuals with ankle pathology. However, there is little research that has investigated associations between characteristics associated with CAI and the SEBT performance. Identifying what factors contribute the most to SEBT performance in control and CAI groups may provide insight into the development of prevention and intervention strategies for an ankle sprain.
Chapter 3

Methods

3.1 Experimental Design

This study was conducted as a case control design to compare performance on the SEBT, ankle and knee strength, static postural control, ankle laxity, and ankle ROM in the CAI group with those variables in the control group. The factors contributing to the variance in SEBT performance were evaluated for each group.

3.2 Participants

We recruited 38 physically active participants from the University community for this study. Participants were grouped into CAI or control. Participants in the CAI group had a previous history of at least one significant ankle sprain that caused pain, swelling, and temporary loss of function; but no significant injury to the ankle in the previous three months as well as a history of at least two episodes of feeling unstable or “giving way” in the past 6 months. The participant demographics (sex, age, mass, and height) appear in Table 3.1.
Table 3.1: Participant Demographics (Mean ± Standard Deviation (SD))

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
<th>Age (years)</th>
<th>BW (kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI (n=18)</td>
<td>10</td>
<td>8</td>
<td>20.2±2.2</td>
<td>75.66±14.7</td>
<td>171.45±9.7</td>
</tr>
<tr>
<td>Control (n=20)</td>
<td>6</td>
<td>14</td>
<td>20.5±1.3</td>
<td>70.63±15.9</td>
<td>167.52±11.1</td>
</tr>
</tbody>
</table>

For both groups, all participants had no (1) history of any surgery or fracture in the lower extremity, (2) no balance or vestibular dysfunction, (3) no history of low back pain in the previous 12 months, and (4) no history of concussion in the previous 12 months. To determine additional inclusion criteria, participants completed two ankle questionnaires: 1) the Foot and Ankle Ability Measure (FAAM) with the FAAM sport subscale (FAAM-S) and 2) the Ankle Instability Instrument (AII). CAI participants scored < 90% on the FAAM and < 80% on the FAAM sport, and answered yes to at least four questions on the AII in addition to having had an ankle sprain. Those in the control group scored 100% on both the FAAM and FAAM sport and answered no to all questions in the AII. Prior to enrollment in the study, the participants read and signed an informed consent form approved by the University Institutional Review Board (IRB).

### 3.3 Instrumentation

An Isokinetic Dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to measure ankle and knee peak torque in the sagittal plane. A non-conductive force plate (model 4060NC; Bertec Inc, Columbus, OH) integrated with MotionMonitor software 8.0 (Innovative Sports Training, Inc., Chicago, IL) was used to analyze center of pressure velocity (COPV) and time to boundary (TTB). A portable ankle arthrometer (Blue Bay Medical Inc, Navarre, FL), was used to assess ankle joint laxity.
3.4  Testing Procedures

Participants reported to the Athletic Training Research Laboratory at the University of Toledo for one testing session. The height, mass, and leg length of each participant was recorded prior to data collection and used for normalization of the dependent variables. The leg length measurement was taken using a tape measure starting at the ASIS to the distal portion of the medial malleolus.53 Participants performed the SEBT, a static balance task, and strength, laxity, and ROM measurements. The order of the tests was randomized for each participant. Also, the examiners were blinded as to the group of the participant. All data collection was performed using the limb of the CAI participants with the lowest FAAM and highest AII scores. For the control group, a random limb was used for data collection.

3.5  Data Collection and Processing

3.5.1  Star Excursion Balance Test (SEBT)

Dynamic postural control was assessed using the SEBT. Participants performed the SEBT in the anterior, posteriormedial (PM), and posteriorlateral (PL) directions. These three directions have shown the strongest association with CAI53 and have been used in ankle injury prediction in recent work by the faculty advisor.28,29

Participants stood barefoot in the middle of the three tape lines. When testing in the anterior direction (Figure 3-1-A), the toes of the stance leg lined up at the starting line (center of the grid). For the posteriormedial (PM) and posteriorlateral (PL) directions (Figure 3-1-B and C), the heel of the stance leg is placed at the starting line (center of the grid). While maintaining the base of support on the stance limb, participants performed a
reach as far as they could with the opposite limb, made a tap with the most distal part of their foot on the line, and then returned to the starting position. The spot where their foot touched the line was recorded. The participants were given four practice trials in each of the three directions on each leg to minimize the learning effect.\textsuperscript{81} Three testing trials were performed in each of the three directions.\textsuperscript{30,81} The trials were repeated if (1) the participant does not keep their hands on their hips, (2) they lose their balance, (3) their heel is lifted from the floor, or (4) their foot is moved from the starting position. The number of failed trials was also recorded. The reach distance of the SEBT was averaged from the three trials in each direction and then normalized by dividing the reaching distance by the leg length and multiplied by 100, denoted as \% MAXD.\textsuperscript{17,33,76} Additionally, a composite score of the SEBT was calculated as the average of the three normalized reaching scores. The order of reach direction was randomized.

Figure 3-1-A: SEBT Anterior Reach
Figure 3-1-B: SEBT Posteromedial Reach

Figure 3-1-C: SEBT Posterolateral Reach
3.5.2 Static Postural Control

To assess static postural control, participants performed a single leg balance task (Figure 3-2). Participants stood barefoot in single leg stance on the middle of the force plate. They were asked to keep their hands on their hips while keeping their foot flat on the force plate. The non-stance leg was held at 45 degrees of knee flexion and 30 degrees of hip flexion. Participants were allowed three practice trials and then asked to perform three testing trials with their eyes closed. Participants were instructed to stand for 15 seconds while COP data was collected. Trials were discarded and repeated if (1) the non-testing limb touches down, (2) contact is made with the stance limb, (3) participants hop or take a step with the stance limb, and/or (4) they fail to keep their hands on their hips.

Figure 3-2: Static Postural Control
The COP data was collected at a sampling rate of 50 Hz for 15 seconds. All COP data was filtered by the Motion-Monitor software with a low pass, fourth order Butterworth filter set at a cutoff frequency of 10 Hz. The TTB (sec) in the anteroposterior (AP) and mediolateral (ML) directions was calculated and processed with a custom MATLAB file (Mathworks, Inc., Natick, MA) using the method previously described. To calculate the TTB, the testing foot was placed in a rectangle denoted on the force plate to allow for separation of the AP and ML components of COP and so that the dimensions of the foot in the X and Y direction are known. The following TTB variables are reported: (1) the TTB absolute minimum, (2) mean of the TTB minima, and (3) standard deviation (SD) of TTB minima.

3.5.3 Strength

Ankle plantar flexion and dorsiflexion isokinetic force production was assessed by placing participants in a seated position (Figure 3-3-A), with the ankle in 10° of plantar flexion. The knee was placed in a slightly flexed position, approximately 10°, to minimize hamstring action. Large straps were applied across the pelvis and the trunk to minimize knee and hip movement. The torso was stabilized and they were asked to keep their arms across their chest during the test procedure. For knee isokinetic strength testing (Figure 3-3-B), the participant remained in a seated position but more upright with the hip and knee flexed at 90°. Their torso, thigh, and shank were stabilized using hook-and-loop straps. The mechanical axis of the dynamometer was visually aligned with the rotational axis of the knee, a transverse axis through the femoral condyles.
The participants were given three warm-up trials to become familiar with the procedure. After the warm-up trials, the participant performed five maximum-effort repetitions continuously in both directions. Isokinetic strength was tested at 60°·s⁻¹ using a concentric/concentric procedure. Verbal encouragement was provided to help ensure
maximal effort on all trials. They were given two minutes of rest between each limb. Average peak torque was recorded for each direction at each joint and then normalized using body mass measurements (N·m⁻¹·kg⁻¹). The testing order of joints was randomized.

3.5.4 Laxity

To examine ankle laxity and stability, the participant laid on the treatment table in the supine position with only their testing foot not touching the table (Figure 3-4). A bolster was placed under the lower leg and then the leg was secured to the table using two Velcro straps. One strap was secured around the distal-thigh and another strap was secured just superior to the malleoli of the ankle being tested. The testing foot was then placed in the ankle arthrometer. It was secured to the foot using clamps around the heel and midfoot. A tibial pad was be placed 5 cm above the malleoli and secured to the lower leg. The test used 0° of plantar flexion as a reference/starting point.²⁵

![Figure 3-4: Ankle Laxity](image)

The total anterior/posterior (AP) displacement and inversion/eversion (IE) motions was measured using the method previously described.¹³,²⁵,⁷⁵,⁹¹ AP displacement
was recorded first followed by IE motion according to the manufacturer’s guidelines. To record total AP displacement, the ankle was loaded with 125 N of anterior and posterior force. Anterior loading was applied first from the neutral position, followed by posterior loading. The total AP displacement was measured in millimeters. For IE, the ankle was loaded to 4000 N/mm of inversion and eversion torque. Inversion load was applied first from the neutral position, followed by eversion loading. Total IE motion (degrees of motion) of the foot was recorded and defined as IE laxity. During each trial, participants were instructed to relax and avoid contracting their calf muscles. Three trials were recorded for each displacement direction.

3.5.5 Range of Motion

Participants performed three trials of the weight bearing lunge test (WBLT) (Figure 3-5) to measure closed kinetic chain dorsiflexion (CKC-DF) range of motion (ROM) by the knee-to-wall principle. A measuring tape was located on the floor, and participants placed their heel firmly on the floor and flexed their knee to the wall. Participants positioned their great toe 2 cm from the wall to begin the measurement, and progressed in 1 cm increments until they are unable to keep their heel on the ground or touch the wall with the knee. After participants failed a lunge attempt, foot placement was adjusted in smaller increments to achieve the maximum distance from the wall. The distance from their great toe to the wall (cm) was measured at reaching maximum dorsiflexion to the closest 0.1 cm. Maximum CKC-DF was defined as the furthest distance participants are able to maintain foot contact and touch their knee to the wall.
Participants were given three practice trials and one testing trial on the testing limb in which they keep their stance heel on the ground while their knee is flexed to the wall.

![Weight Bearing Lunge Test](image)

Figure 3-5: Weight Bearing Lunge Test

### 3.6 Statistical Analysis

The FAAM, FAAM-S, AII were compared between the CAI and control groups using independent t-tests.

The dependent variables include %MAXD in the anterior, PM, and PL directions of the SEBT, composite score of the SEBT, the sagittal-plane peak torques at the knee and ankle joints (dorsiflexion, plantar flexion, knee flexion and knee extension), the total AP displacement, the IE laxity, CKC-DF, COPV in the AP and ML directions, as well as the three TTB measures. For all dependent variables, means and standard deviations were calculated from the test trials and used for statistical analysis.

Independent t-tests were performed to compare each dependent variable between the CAI and control groups. Cohen’s d effect sizes using the pooled standard deviations were calculated, along with 95% confidence interval (CI) to determine the magnitude of
difference in dependent variables between groups. The strength of effect sizes was interpreted as weak (d < .04), moderate (.40 ≤ d < .80), and strong (d ≥ .80).  

A backward linear regression analysis was conducted to determine which modifiable factors best predict SEBT performance, separately for each participant group. The predictor variables include knee and ankle peak torques in the sagittal plane, the total AP displacement, the total IE laxity, CKC-DF, the mean of TTB minima. All predictor variables were entered into the backward regression analysis, and the variable which was the least predictor of the SEBT performance was removed and another analysis was performed. This process was repeated until the variables that accounted for the most variance in the SEBT performance were identified separately in each group. A separate regression model was created for each of the four separate SEBT measures. The level of significance was set a priori at p < 0.05 using SPSS 19.0 (SPSS, Inc. Chicago, IL.) for all statistical analysis.
Chapter 4

Results

There were statistically significant differences in the FAAM, FAAM sport, and AII between the CAI and control group, verifying the presence of the targeted pathology (Table 4.1).

Table 4.1: Ankle Injury Questionaries’

<table>
<thead>
<tr>
<th></th>
<th>CAI (n=18)</th>
<th>Control (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAAM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>89.08±6.54</td>
<td>100</td>
</tr>
<tr>
<td>t</td>
<td>7.47</td>
<td></td>
</tr>
<tr>
<td>p*</td>
<td>p&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>FAAM Sport</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>77.76±10.5</td>
<td>100</td>
</tr>
<tr>
<td>t</td>
<td>-9.48</td>
<td></td>
</tr>
<tr>
<td>p*</td>
<td>p&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>AII</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>5.6±0.98</td>
<td>0</td>
</tr>
<tr>
<td>t</td>
<td>25.68</td>
<td></td>
</tr>
<tr>
<td>p*</td>
<td>p&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

* Significance was set a priori at p<0.05

4.1 Comparison of the CAI and Control Groups

4.1.1 Sensorimotor Outcome Measures

4.1.1.1 Dynamic Postural Control: Star Excursion Balance Test
There was no statistically significant difference between the CAI and control groups in the anterior \( (t_{36}=0.009, p=0.993) \), PM \( (t_{36}=-0.244, p=0.808) \), and PL reach directions \( (t_{29.9}=-0.340, p=0.736) \), as well as composite score of the SEBT \( (t_{36}=-0.513, p=0.611) \) (Table 4.2). Effect sizes were small for all SEBT measures, with 95% CIs that crossed zero (Table 4.2).

**Table 4.2: Star Excursion Balance Test Variables for Chronic Ankle Instability (CAI) and control groups.**

<table>
<thead>
<tr>
<th></th>
<th>Mean ±SD</th>
<th>t</th>
<th>p #</th>
<th>Effect Size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAI</strong></td>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior (%)*</td>
<td>63.99±8.09</td>
<td>63.97±5.93</td>
<td>0.009</td>
<td>0.993</td>
</tr>
<tr>
<td>Posterior-Medial (%)*</td>
<td>75.76±13.93</td>
<td>76.73±10.21</td>
<td>-0.244</td>
<td>0.808</td>
</tr>
<tr>
<td>Posterior-Lateral (%)*</td>
<td>66.74±15.03</td>
<td>68.18±10.45</td>
<td>-0.340</td>
<td>0.736</td>
</tr>
<tr>
<td>Composite (%)*</td>
<td>68.77±11.25</td>
<td>70.36±7.66</td>
<td>-0.513</td>
<td>0.611</td>
</tr>
</tbody>
</table>

*Reach distance (cm) normalized to participant leg length (%MAXD). #Significance was set a priori at \( p<0.05 \)

**4.1.1.2 Static Postural Control**

There were statistical significant differences in the COPV-AP \( (t_{36}=2.931, p=0.006) \) and COPV-ML \( (t_{36}=2.988, p=0.005) \) between the CAI and control groups (Table 4.3). Effect sizes were strong for all COPV measures, with 95% CIs that did not cross zero (Table 4.3.) For the TTB measures, there were statistically significant differences the TTB absolute minima \( (t_{36}=-2.309, p=0.027) \), the mean of TTB minima \( (t_{32.7}=-2.991, p=0.005) \), and the SD of TTB minima \( (t_{32.8}=-2.665, p=0.012) \) in the AP direction between the CAI and control group (Table 4.3). Effect sizes were small for all
TTB measures in the AP direction with 95% CIs crossing zero (Table 4.3). However, there was no statistically significant difference in the TTB measures in the ML direction between the CAI and control groups (Table 4.3). Effect sizes were small for all TTB measures in the ML direction, with 95% CIs that crossed zero (Table 4.3). There was also no statistically significant difference between the number of eyes closed failed trials between the CAI and control groups ($t_{35}=1.340$, $p=0.189$) (Table 4.3). Effect sizes were moderate for all SEBT measures, with 95% CIs that crossed zero (Table 4.3).

Table 4.3: COPV (cm/s) and TTB measures (s) in an eyes closed condition evaluating Static Postural control.

<table>
<thead>
<tr>
<th></th>
<th>Mean ±SD</th>
<th>t</th>
<th>p *</th>
<th>Effect Size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPV-AP</td>
<td>1.63±0.363</td>
<td>2.931</td>
<td>0.006</td>
<td>0.95 (0.26,1.60)</td>
</tr>
<tr>
<td>COPV-ML</td>
<td>1.41±0.282</td>
<td>2.988</td>
<td>0.005</td>
<td>0.97 (0.28,1.62)</td>
</tr>
<tr>
<td>TTB Min ML</td>
<td>0.619±0.224</td>
<td>-1.036</td>
<td>0.307</td>
<td>0.34 (-0.31,0.97)</td>
</tr>
<tr>
<td>TTB Min AP</td>
<td>1.64±0.418</td>
<td>-2.309</td>
<td>0.027</td>
<td>0.75 (0.08,1.39)</td>
</tr>
<tr>
<td>TTB Mean ML</td>
<td>2.93±1.54</td>
<td>-1.356</td>
<td>0.184</td>
<td>0.44 (-0.21,1.08)</td>
</tr>
<tr>
<td>TTB Mean AP</td>
<td>6.31±2.03</td>
<td>-2.991</td>
<td>0.005</td>
<td>0.95 (0.26,1.60)</td>
</tr>
<tr>
<td>TTB SD ML</td>
<td>2.74±2.09</td>
<td>-1.119</td>
<td>0.271</td>
<td>0.36 (-0.29,1.00)</td>
</tr>
<tr>
<td>TTB SD AP</td>
<td>4.36±1.83</td>
<td>-2.665</td>
<td>0.012</td>
<td>0.85 (0.17,0.72)</td>
</tr>
<tr>
<td>Failed Trials</td>
<td>4.58±4.03</td>
<td>1.340</td>
<td>0.189</td>
<td>0.44 (-0.21,1.08)</td>
</tr>
</tbody>
</table>

* Significance was set a priori at $p<0.05$. AP = Anterior/Posterior; ML = Medial/Lateral; Min = Minimum; SD = Standard Deviation

4.1.1.3 Strength

There was no statistically significant group-difference in the ankle sagittal-plane force production (plantar flexion: $t_{36}=1.618$, $p=0.114$; dorsiflexion: $t_{36}=1.131$, 0.266; Table 4.4). The effect sizes were moderate for ankle plantar flexion strength and small for ankle dorsiflexion strength, with the wide range of 95% CIs around the effect sizes (Table 4.4).
For knee sagittal-plane torque production measures, there was no statistically significant differences in knee flexion ($t_{33.4}=0.604, p=0.550$) and knee extension ($t_{36}=0.030, p=0.976$) between the CAI and control groups (Table 4.4). The effect sizes were small for sagittal-plane force production in the knee, with 95% CIs that crossed zero (Table 4.4).

**Table 4.4: Ankle and knee average peak torque (N·m$^{-1}$·kg$^{-1}$) in the sagittal plane for the CAI and control groups.**

<table>
<thead>
<tr>
<th></th>
<th>Mean±SD</th>
<th>t</th>
<th>p *</th>
<th>Effect Size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle Plantar Flexion</td>
<td>0.4257±0.173</td>
<td>0.3410±0.149</td>
<td>1.618</td>
<td>0.114</td>
</tr>
<tr>
<td>Ankle Dorsiflexion</td>
<td>0.2088±0.041</td>
<td>0.1880±0.068</td>
<td>1.131</td>
<td>0.266</td>
</tr>
<tr>
<td>Flexion</td>
<td>0.8836±0.178</td>
<td>0.8395±0.267</td>
<td>0.604</td>
<td>0.550</td>
</tr>
<tr>
<td>Extension</td>
<td>1.44±0.426</td>
<td>1.43±0.404</td>
<td>0.030</td>
<td>0.976</td>
</tr>
</tbody>
</table>

* Significance was set a priori at $p<0.05$

4.1.2 Mechanical Joint Integrity Outcome Measures

There was no statistically significant differences in the WBLT between the CAI and control group ($t_{36}=0.856, p=0.398$) (Table 4.5). The effect size was small for the WBLT and 95% CI that crossed zero ($d = 0.28$ 95% CIs: -0.37, 0.91) (Table 4.5).

For the total AP displacement ($t_{36}=-0.931, p=0.358$) and total IE laxity ($t_{35.8}=-1.66, p=0.106$) there was no statistically significant difference between the CAI and control groups (Table 4.5). Effect sizes were small for total AP displacement and moderate for total IE laxity measures, with 95% CIs that crossed zero (Table 4.5).
Table 4.5: Mechanical joint integrity assessed using the Weight Bearing Lung Test (WBLT) and Instrumented Ankle Joint Laxity for the Chronic Ankle Instability (CAI) and control groups.

<table>
<thead>
<tr>
<th></th>
<th>Mean±SD</th>
<th>t</th>
<th>p *</th>
<th>Effect Size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAI</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBLT-DF-ROM (cm)</td>
<td>10.32±4.14</td>
<td>9.27±3.35</td>
<td>0.856</td>
<td>0.398</td>
</tr>
<tr>
<td>Total AP Displacement (mm)</td>
<td>13.3±4.65</td>
<td>14.6±4.58</td>
<td>-0.931</td>
<td>0.358</td>
</tr>
<tr>
<td>Total IE Laxity</td>
<td>33.88±9.98</td>
<td>39.36±10.29</td>
<td>-1.66</td>
<td>0.106</td>
</tr>
</tbody>
</table>

* Significance was set a priori at p<0.05. AP= Anterior/Posterior; I-E = Inversion/Eversion

4.2 Backward Regression

4.2.1 Anterior Reach of the Star Excursion Balance Test

When examining the regression models performed for the CAI group, the WBLT remained in the final model and significantly predicted 34.3% of the variance in anterior reach of the SEBT ($R^2=0.343$; p=0.013; Table 4.6). The combination of the WBLT, plantar flexion strength, and total IE laxity explained approximately 56% of the variance in anterior reach of the SEBT ($R^2=0.559$, p = 0.012). Ankle plantar flexion strength and total IE laxity accounted for 11.9% and 9.7%, respectively, in the variability in %MAXD. The WBLT is the strongest predictor of the variance in the SEBT performance in the anterior direction.

When examining the regression models performed for the control group, knee flexion and extension strength remained in the final model and accounted for 26.2% of the variance in normalized anterior reach distance ($R^2=0.262$; p=0.075; Table 4.6). The
combination of COPV-AP, total AP laxity, knee flexion extension strength predicted 37% of the variance in %MAXD ($R^2=0.371$; $p=0.117$; Table 4.6). The variance of COPV-AP and total AP laxity accounted only for 4.1% and 6.8%, respectively. Therefore, knee flexion and extension strength contributed the most to normalized anterior reach distance in the control group.

Table 4.6: Backward Regression of predictors of variance in the CAI and control groups for the anterior reach.

<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>$R^2$</th>
<th>$p^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>1 Total IE laxity, Plantar flexion strength, WBLT</td>
<td>0.559</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>2 Plantar flexion strength, WBLT</td>
<td>0.462</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>3 WBLT</td>
<td>0.343</td>
<td>0.013</td>
</tr>
<tr>
<td>Control</td>
<td>COPV-AP, total AP laxity, Knee Flexion and Knee Extension strength</td>
<td>0.371</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>2 Total AP laxity, Knee Flexion and Knee Extension strength</td>
<td>0.33</td>
<td>0.086</td>
</tr>
<tr>
<td></td>
<td>3 Knee Flexion and Knee Extension strength</td>
<td>0.262</td>
<td>0.075</td>
</tr>
</tbody>
</table>

*Significance was set a priori at $p<0.05$

4.2.2 Posteromedial Reach of the Star Excursion Balance Test

The strongest predictors of the variance in SEBT performance in the PM direction were the WBLT and plantar flexion strength in the CAI group. The variance in plantar flexion strength and WBLT accounted for 48.4% of the variance in %MAXD ($R^2=0.484$; $p=0.01$; Table 4.7). In combination with the WBLT and plantar flexion strength, mean of TTB minima in the AP direction (mean TTB-AP) and COPV-AP explained an additional 5.1% and 5.3%, respectively, of the variance in %MAXD in the PM direction.

The variances in knee flexion strength, total IE laxity, COPV-AP, and mean TTB-AP remained in the final regression model performed for the control group and accounted
for 52.4% of the variance in SEBT performance in the PM ($R^2=0.524; p=0.044$; Table 4.7).

**Table 4.7: Backward Regression of predictors of variance in the CAI and control groups for the posteromedial reach.**

<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>$R^2$</th>
<th>$p^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>1 COPV-AP, TTB-AP, Plantar flexion strength, WBLT</td>
<td>0.588</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>2 TTB-AP, Plantar flexion strength, WBLT</td>
<td>0.535</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>3 Plantar flexion strength, WBLT</td>
<td>0.484</td>
<td>0.01</td>
</tr>
<tr>
<td>Control</td>
<td>1 Knee Extension and Knee Flexion strength, total IE laxity, COPV-AP, TTB-AP</td>
<td>0.599</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>2 Knee Flexion strength, total IE laxity, COPV-AP, TTB-AP</td>
<td>0.524</td>
<td>0.044</td>
</tr>
</tbody>
</table>

*Significance was set a priori at $p<0.05$. TTB-AP = mean of time to boundary minima in the anterior-posterior direction.

4.2.3 **Posterolateral Reach of the Star Excursion Balance Test**

In the CAI group, the combination of total IE laxity, COPV-AP, ankle plantar flexion strength, WBLT significantly predicted 59% of the variance in SEBT performance in the PL direction ($R^2=0.590; p=0.022$; Table 4.8). While COPV-AP and total IE laxity predicted only 5.7% and 6.8%, respectively, of the variance of %MAXD, the combination of plantar flexion strength and WBLT accounted for 46.5% of the variance in %MAXD in the PL direction ($R^2=0.465; p=0.013$; Table 4.8). The strongest predictor of the SEBT performance in the PL direction were the combination of plantar flexion strength and WBLT.

In the control group, ankle plantar flexion strength was the strongest predictor of the SEBT performance in the PL direction (Table 4.8) and explained approximately 15% of the variance in %MAXD ($R^2=0.149; p=0.092$; Table 4.8). In combination with plantar
flexion strength, the variance in static postural control measures (mean TTB-AP, COPV-ML, and COPV) explained additional 15.8% of the variance in %MAXD ($R^2=0.307$; $p=0.221$).

### Table 4.8: Backward Regression of predictors of variance in the CAI and control groups for the posterolateral reach.

<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>$R^2$</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>Total IE laxity, COPV-AP, Plantar flexion strength, WBLT</td>
<td>0.59</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>COPV-AP, Plantar flexion strength, WBLT</td>
<td>0.522</td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td>Plantar flexion strength, WBLT</td>
<td>0.465</td>
<td>0.013</td>
</tr>
<tr>
<td>Control</td>
<td>COPV-AP, COPV-ML, TTB-AP, Plantar flexion strength</td>
<td>0.307</td>
<td>0.211</td>
</tr>
<tr>
<td></td>
<td>COPV-ML, TTB-AP, Plantar flexion strength</td>
<td>0.289</td>
<td>0.132</td>
</tr>
<tr>
<td></td>
<td>TTB-AP, Plantar flexion strength</td>
<td>0.209</td>
<td>0.136</td>
</tr>
<tr>
<td></td>
<td>Plantar flexion strength</td>
<td>0.149</td>
<td>0.092</td>
</tr>
</tbody>
</table>

*Significance was set a priori at $p<0.05$. TTB-AP = mean of time to boundary minima in the anterior-posterior direction.

#### 4.2.4 Composite Score the Star Excursion Balance Test

When examining the regression model performed for the CAI group, the combination of plantar flexion strength and WBLT were the strongest predictors of the SEBT composite score and significantly predicted 53.9% of the variance in the composite score ($R^2=0.539$; $p=0.004$; Table 4.9). In combination with plantar flexion strength and WBLT, the variance in total IE and COPV-AP explained an additional 5.5% of the variance in the composite score ($R^2=0.594$; $p=0.02$; Table 4.9).

In the control group, knee flexion strength was the strongest predictor of the SEBT composite score and accounted for 17.5% of the variance in the composite score ($R^2=0.175$; $p=0.066$; Table 4.9). However, adding static postural control measures
(COPV-AP and mean TTB-AP and-ML) increased the predictive value by 24% 
(R²=0.415; p=0.074).

Table 4.9: Backward Regression of predictors of variance in the CAI and control 
groups for the composite score.

<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>R²</th>
<th>p *</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>COPV-AP, total IE laxity, Plantar flexion strength, WBLT</td>
<td>0.594</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>Total IE laxity, Plantar flexion strength, WBLT</td>
<td>0.571</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>Plantar flexion strength, WBLT</td>
<td>0.539</td>
<td>0.004</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>TTB-ML, COPV-AP, TTB-AP, Knee Flexion strength</td>
<td>0.415</td>
<td>0.074</td>
</tr>
<tr>
<td>2</td>
<td>COPV-AP, TTB-AP, Knee Flexion strength</td>
<td>0.359</td>
<td>0.062</td>
</tr>
<tr>
<td>3</td>
<td>TTB-AP, Knee Flexion strength</td>
<td>0.246</td>
<td>0.091</td>
</tr>
<tr>
<td>4</td>
<td>Knee Flexion strength</td>
<td>0.175</td>
<td>0.066</td>
</tr>
</tbody>
</table>

*Significance was set a priori at p<0.05. TTB-AP = mean of time to boundary 
minima in the anterior-posterior direction. TTB-ML = mean of time to boundary 
minima in the medial-lateral direction.
Chapter 5

Discussion

The primary purpose of this study was to compare SEBT performance, strength, ankle joint laxity, ankle DF ROM, static postural control, and the SEBT performance between participants with and without CAI. The main findings of our study were that participants with CAI exhibited significantly increased COPV measures and decreased TTB measures compared to controls, indicating that a deficit in static postural control is present in those with CAI. However, no between-group differences existed in mechanical variables. It is apparent that the presence of CAI is more associated with altered sensorimotor function participants with CAI. Additionally, the regression model for CAI showed the strongest predictors of SEBT performance were WBLT and ankle plantar flexion strength. This finding revealed that the weight-bearing DF-ROM and/or plantar flexion strength may need to be addressed for therapeutic intervention if global functional deficits measured by the SEBT are detected in patients with CAI.

5.1 Discussion of Main Outcome Measures

Measures of static postural control have frequently been used to assess sensorimotor function in patients with CAI. Individuals with static postural
control deficits are likely to have faster COP excursion velocities than those who do not have static postural control deficits. Our data shows that the CAI group had increased COPV measures compared to the control group, indicating that the presence of CAI was associated with decreased static postural control, which is consistent with previous findings. As COPV increases, it becomes more difficult for the body to adequately correct the excursions and keep the COP within the base of support. Postural control requires the integration of somatosensory, visual, and vestibular afferent information and appropriate efferent responses to control the trunk and extremity muscles in an effort to maintain balance. Our findings suggest that the presence of CAI may alter the sensorimotor function, affecting the body’s ability to generate new patterns of movement to correct posture and steady their foot during the task. Perhaps an initial acute lateral ankle sprain caused damage to the mechanoreceptors and proprioceptors, leading to a decreased awareness of body position. With less awareness of body position, individuals with CAI are less able to detect somatosensory information. Therefore, participants with CAI, especially under the eyes closed condition, may have altered integration of somatosensory and visual afferent information and have difficulties maintaining balance during single limb stance.

We also found that participants with CAI demonstrated decreased TTB measures in the AP direction compared to the control group. Participants with CAI had less time to respond due to faster COP excursion and/or position close to the boundary of stability. Our findings are consistent with previous investigations that have reported lower TTB values in the CAI group compared to the control group. Taken together, our
findings of static postural control alterations suggest that a static postural control deficit is apparently present in participants with CAI. However, no differences were found in the TTB measures in the ML directions between the CAI and control groups. McKeon and Hertel\textsuperscript{88} suggested that the boundaries used in the calculation of TTB measures in the ML directions may underestimate the actual time it would take the COP to reach the medial or lateral boundaries of the foot. We used the same TTB model as they previously used.\textsuperscript{88} It is possible that the TTB model used in the current study may have lower sensitivity to detect differences in TTB measures in the ML direction.

It has been suggested that altered sensorimotor function associated with CAI may decrease dynamic postural control and force production at the lower extremity joints.\textsuperscript{53} However, we did not find significant differences in SEBT performance as well as knee and ankle sagittal plane force production between the CAI and control groups. These findings contradict previous findings that showed deficits in SEBT performance as well as knee and ankle strength in participants with CAI.\textsuperscript{12,14,15,17,65,69} The primary reason that we found no differences in the SEBT performance and strength of knee and ankle musculatures could be the inclusion criteria for the CAI group. The inclusion criteria used in the current study stated that a participant must have a history of at least one acute lateral ankle sprain in their lifetime and the repeated episodes of giving-way. These criteria include a wide spectrum of participants. While some participants may have only had one significant sprain, but have repeated episodes of giving way, some participants suffer many episodes of giving way and recurrent ankle sprains. We also used the FAAM and FAAM sports to differentiate the level of functional deficits in the identified
participants with CAI. The average FAAM (89.08±6.54) and FAAM sports (77.76±10.5) scores had relative large variability. A wide range of disability levels among participants with CAI may have been a confounding factor in these measures. Furthermore, we did not set activity level as inclusion criteria, SEBT performance could be less in the lower activity group. Therefore, the variability in activity and disability level could have influenced our SEBT and strength results. Sefton et al.\textsuperscript{15} were one of only a few groups that reported no differences in SEBT performance between participants with and without CAI. The authors stated similar concerns of how to select the participants with CAI.\textsuperscript{15} It has been suggested that a more homogenous grouping of the participants may consistently produce significant differences in sensorimotor variables between CAI and healthy groups.\textsuperscript{97} Future investigation should compare more homogenous subgroups of CAI to healthy controls, as well as examine if the SEBT and strength can be used to differentiate between different levels of CAI disability.

Although we are unaware whether all participants with CAI had completed a rehabilitation program following an initial ankle sprain, another potential explanation for lack of differences in knee and ankle strength observed in this study is that participants with CAI may restore normal strength following ankle sprains. Rehabilitation following a lateral ankle sprain traditionally focuses on restoring strength in the lower extremity\textsuperscript{62-64}; however, it is possible that other sensorimotor factors such as decreased muscle activation and corticospinal excitability may contribute to the presence of CAI.\textsuperscript{58,59} Recent investigations have proposed that inhibition of multiple neural pathways may lead to impaired neuromuscular control during static postural control in participants with
CAI.\textsuperscript{40,96} Therefore, future work should investigate the neurologic origins of CAI disability.

Our regression analysis may also explain the lack of differences in SEBT performance between the CAI and control groups. In our regression models, the WBLT, ankle plantar flexion strength, and total IE laxity strongly contributed to the SEBT performance. This finding suggests that deficits in the weight-bearing DF-ROM, ankle plantar flexion strength, and ankle joint stability associated with CAI may be responsible for poor SEBT performance. However, we did not observe differences in all of these three variables between the CAI and control groups. The only group differences were observed in the static balance measures, which did not contribute to the SEBT performance. Therefore, it is possible that we did not observe dynamic postural control deficits in participants with CAI because of lack of between-group differences in these factors that strongly predicted SEBT performance.

We observed no differences in total AP or IE laxity measurements between the CAI and control groups. These findings are opposite of the results of Hubbard et al\textsuperscript{25} who found increased laxity in those with CAI. One potential explanation is that an individual in either group could have generalized laxity. If healthy controls have generalized joint laxity, the laxity measures are more likely to produce similar results with CAI participants. Our findings are consistent with work by Hiller et al.\textsuperscript{97} that suggests that mechanical insufficiencies may not be a factor that strongly differentiates patients with and without CAI.
Furthermore, mechanical ankle laxity and restricted arthrokinematics could coexist in individuals with a history of an ankle sprain. It has been hypothesized that restricted arthrokinematics such as posterior talar glide may be associated with a positional fault, specifically anterior displacement of the talus, following lateral ankle sprains due to the disruption of the ligaments restraining anterior translation of the talus. Restricted arthrokinematics could lead to hypomobility of the ankle joint. If the talus and/or fibula is more anterior positioned, the amount of anterior displacement of the ankle could be smaller, and the amount of posterior translation might be restricted because the talus is stuck anteriorly.

We hypothesized that the CAI group would have decreased DF-ROM compared to the control group; however, we did not observe difference in the WBLT between the CAI and control groups. The lack of differences in ankle DF-ROM and laxity indicates that mechanical insufficiencies may not be present in participants with CAI. This study did not support previous observation that participants with CAI exhibit decreased DF-ROM with the WBLT. Factors such as the tightness of the gastrocnemius-soleus complex and restricted posterior talar glide decrease the weight-bearing DF-ROM following ankle sprains. Although arthrokinematic restrictions may still be present, ankle DF-ROM may be restored following lateral ankle sprains. Denegar et al. noted that restored ankle DF could be achieved by increasing flexibility of the gastrocnemius-soleus complex. Youdas et al. implemented a stretching program to increase the flexibility of the gastrocnemius-soleus complex following acute ankle sprain and found that DF-ROM was restored after two weeks post injury. All cases of ankle DF-ROM restrictions do not
arise from the same factors, possibly explaining the conflicting results of the WBLT in CAI population. Some participants had the lack of flexibility of the gastrocnemius-soleus and arthrokinematic restrictions, possibly resulting in the weight-bearing DF-ROM restriction. Some participants restored DF-ROM because they have only arthrokinematic restrictions. Therefore, a clinician should consider what factors limit ankle dorsiflexion following an ankle sprain.

The SEBT represents an effective and efficient tool to assess dynamic function, but it does not indicate what specific clinical impairments contributing to the SEBT performance need to be addressed for clinical interventions if an individual presents with global dysfunction on the SEBT. A recent investigation has demonstrated that anterior reach of the SEBT may be associated with the amount of the weight-bearing DF-ROM and sagittal plane kinematics at knee and hip in participants with CAI. Their work is important as it provides the first step toward understanding what modifiable factors make the greatest contribution to the SEBT in individuals with CAI. However, 78% of the variance in the SEBT performance in the anterior direction remained unexplained. The variance that was unexplained by the weight-bearing DF-ROM in their study may be a result of strength, static balance, and joint stability that are contributing to the SEBT performance. In the current study, the WBLT was the strongest contributor that explained approximately 34% of the variance in the anterior reach of the SEBT alone, supporting previous observation. Our preliminary data found that adding plantar flexion strength and total IE laxity to the WBLT increased the predictive value by approximately 22%. Furthermore, the combination of the WBLT and ankle plantar flexion strength was most
predictive of the other SEBT measures. These findings suggest that ankle plantar flexion strength and/or weight-bearing DF-ROM may represent modifiable areas for targeted intervention to improve a deficit in dynamic postural control in CAI patients.

During the SEBT, the sensorimotor system utilizes numerous options within the involved degrees of freedom to maintain balance and complete the task. We believe that participants with CAI seek to freeze the motion at the ankle in order to accomplish the SEBT; therefore, mechanical and functional factors at the ankle such as ankle strength and weight-bearing DF-ROM played a significant role in explaining why individuals with ankle pathology exhibit poor SEBT performance. However, previous investigation has observed that participants with CAI utilized more of “proximal strategies” and exhibited alterations in kinematics at the knee and hip during the SEBT. This may be explained by that local clinical impairments at the ankle require those with CAI to develop more proximal strategies to achieve maximal reaches. If one of the options within the degrees of freedom is not available because of the presence of CAI, other movement solutions may be utilized. We did not examine how hip strength contributions can affect SEBT performance in the CAI and control groups. Hip muscular dysfunctions have been observed in patients with CAI. Previous work reported that the sagittal plane hip kinematics provided an important contribution to SEBT performance. Future work should consider hip strength measures to determine the clinically modifiable impairments which may influence the SEBT.

In contrast to the prediction model of the CAI group, different predictors of the SEBT performance were identified in the control group compared to the model in the
CAI group. In the control group, knee strength and static balance contributed more to variances in SEBT performance. This indicates that altered knee strength and static balance may be responsible for shorter reach distance of the SEBT in the control group. These findings may help develop effective prevention strategies for individuals identified as at risk for potential ankle injury. Previous work has suggested that the SEBT might be a useful screening tool to predict future lower extremity injuries in physically active population. If individuals produce poor SEBT performance, deficits in knee strength and static postural control may be associated with global dysfunctions measured by the SEBT. Therefore, clinicians may want to consider implementing knee strength and static balance training as part of an ankle prevention program. Supporting this, McGuine and Keene reported that the rate of an ankle injury was lower in adolescent athletes who participated in balance training compared to those who did not.

5.2 Limitations

There were few limitations to this study. The first is the number of participants. We calculated that we would need 22 participants to have power and significant results. While our significant findings had moderate to strong statistical power (observed power =0.649-0.858), all of our non-significant findings were associated with low statistical power (observed power = 0.05-0.384). Also, some of our non-significant findings were associated with moderate effect sizes. The addition of more participants would likely have shown significance in some of these relationships. This study is ongoing and will continue to recruit participants.
The study was retrospective meaning that we do not know if the impairments we observed were present prior to injury. This is a factor that we cannot control and we cannot make causal links between SEBT performance and clinically modifiable factor deficits in those with CAI. We also looked at only concentric sagittal-plane strength at the knee and ankle. During the SEBT task, the knee extensors and ankle plantar flexors are working eccentrically from starting position to the maximum reach. Future studies should examine eccentric lower extremity strength and its contribution to SEBT performance.

Lastly, we assessed the clinical impairments that have been commonly observed in patients with CAI, including static balance, ankle laxity, DF-ROM, and ankle and knee strength. However, various factors such as flexibility, muscle activation level, activity level, and core stability are also potential contributors to the SEBT. The presence of CAI has been associated with decreased activity levels\(^9,110,111\), altered muscle activation patterns\(^58,59\), and altered trunk stability.\(^112\) Future research should comprehensively examine other potential factors that may contribute to the SEBT.

### 5.3 Clinical Implications

The results of this study will help to develop more effective intervention and prevention strategies for ankle injury. We found deficits in static postural control in participants with CAI. Balance training has been used successfully to restore static and dynamic postural control in those with CAI.\(^62,64\) With their results and the results of this study, we can implement balance training to create more beneficial and efficient intervention programs for those with CAI.
With the results of this study, we can propose a suggested treatment program to help regain normal function in those with ankle instability. The regression model for the CAI group suggested that ankle plantar flexion strength and DF-ROM should be addressed to improve global function if poor SEBT performance is detected in CAI population. Joint mobilizations and a stretching program can be used to restore DF-ROM. Joint mobilizations can be used to help restore the talus and fibular positional fault. The regression model for the control group revealed that the prevention program should be aimed more at knee strengthening and balance training if deficits in dynamic postural control are identified with the SEBT.

5.4 Conclusion

In conclusion, participants with CAI demonstrated poor static postural control compared to healthy controls. This indicates that altered sensorimotor function is present in participants with CAI. Based on results of the regression models, the CAI group was more influenced by ankle strength and DF-ROM, whereas knee strength and static postural control are contributing to SEBT performance in the control group. These factors may represent targets for intervention and preventions that need to be addressed to produce the best outcome in patients with CAI or with altered dynamic postural control detected on the SEBT. Future studies should prospectively investigate changes in sensorimotor functions measured with the SEBT after an ankle sprain by examining various contributors from the distal and proximal joints using both clinical and laboratory measures.
References


88. McKeon PO, Hertel J. Spatiotemporal postural control deficits are present in those with chronic ankle instability. *Bmc Musculoskeletal Disorders.* Jun 2 2008;9.


Appendix A

IRB Informed Consent

ADULT RESEARCH SUBJECT INFORMATION AND CONSENT FORM
A COMPARISON OF STRENGTH, ROM, LAXITY, AND DYNAMIC AND STATIC POSTURAL CONTROL BETWEEN THOSE WITH CAI, THOSE AT-RISK, AND ANKLE SPRAIN COPERS

Principal Investigator: Phillip Gribble, Ph.D., ATC
Other Staff (identified by role): Heather Boyle, ATC, Co-investigator
Sara Caney, ATC, Co-investigator
Elizabeth Rulkestad, ATC, Co-investigator
Masafumi Terada, MS, ATC, Co-investigator
Megan Quintino, MS, ATC, Co-investigator

Contact Phone number(s): Dr. Phillip Gribble: (419) 530-2691

What you should know about this research study:

- We give you this consent/authorization form so that you may read about the purpose, risks, and benefits of this research study. All information in this form will be communicated to you verbally by the research staff as well.

- The main goal of research studies is to gain knowledge that may help individuals in the future.

- We cannot promise that this research will benefit you. This research can have side effects that can be serious or minor.

- You have the right to refuse to take part in this research, or agree to take part now and change your mind later.

- If you decide to take part in this research or not, or if you decide to take part now but change your mind later, your decision will not affect your routine care.

- Please review this form carefully. Ask any questions before you make a decision about whether or not you want to take part in this research. If you decide to take part in this research, you may ask any additional questions at any time.

- Your participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)
You are being asked to take part in a research study that examines Star Excursion Balance Test (SEBT) performance related to lower extremity strength, ankle ligament length, static balance, dorsiflexion range of motion, and ankle laxity. The purposes of the study are (1) to identify differences between chronic ankle instability (CAI) and Copers (individuals who are able to avoid developing chronic ankle instability after an ankle sprain), CAI and poor SEBT performance individuals; and healthy and poor SEBT...
performance individuals in lower extremity strength, static balance, ankle ligament length, ankle range of motion, ankle laxity, and SEBT, as well as (2) determine which factor(s) have the greatest impact on the SEBT in each group. This study may help to identify contributing factors to SEBT performance in order to create a more effective intervention and prevention program for lateral ankle sprain. Also, this study may help clinicians to identify risk for ankle sprain with the SEBT as a pre-participation examination tool.

You were selected as someone who may want to take part in this study because you have the following criteria:

You will be in the CAI group if you:
- Would like to voluntarily participate in this study
- Between the ages 15 and 35 years
- Participate in at least 30 minutes of vigorous activity, three or more days per week
- Have previous history of at least one significant ankle sprain that causes pain, swelling, and temporary loss of function
- Have at least 2 episodes of feeling unstable or “giving way” in the past 6 months
- Have no significant injury to the ankle in the past 3 months
- No history of any musculoskeletal and neurovascular injury in the lower extremity other than the ankle in the previous two years
- No previous fractures or surgery in the lower extremity
- Are free of balance or vestibular dysfunction
- Have no history of concussion in the previous 6 months
- Have no history of low back pain in the previous 12 months
- Answer “yes” to the question, “Do you have a history of ankle sprain?” on the Ankle Instability Instrument (AII).
- Answer “yes” to at least three symptom questions on the AII.
- Report a score of ≤ 90% on the Functional Ankle Disability Index (FADI) and ≤ 80% on the FADI Sport Subscale.

You will be in the control (healthy) group if you:
- Would like to voluntarily participate in this study
- Between the ages 15 and 35 years
- Participate in at least 30 minutes of vigorous activity, three or more days per week.
- Are free of balance or vestibular dysfunction
- Have no history of concussion in the previous 6 months
- Have no history of any self-reported musculoskeletal and neurovascular injury and disorder in the lower extremity
- Have no history of surgery in the lower extremity
- Have no history of low back pain in the previous 12 months
- Score >67% on the SEBT
- Have a score of ≤ 100% on the FADI and the FADI Sport Subscale.
- Answer no to the question, “Do you have a history of ankle sprain?” on the AII.

You will be in the poor SEBT performance group if you:
- Would like to voluntarily participate in this study
- Between the ages 15 and 35 years
- Participate in at least 30 minutes of vigorous activity three or more days per week.
- Have no history of any self-reported musculoskeletal and neurovascular injury and disorder in the lower extremity
- Have no history of surgery in the lower extremity
You will be in the control group if you:

- Would like to voluntarily participate in this study
- Between the ages of 15 and 55 years
- Participate in at least 30 minutes of vigorous activity three or more days per week.
- Have a history of 1 significant acute lateral ankle sprain, causing more than 1 day of disrupted activity, pain, and swelling.
- Have no recurrent injury/instability after the initial sprain.
- Have no functional impairment (pain and giving-way) after the initial sprain.
- No history of any musculoskeletal and neurovascular injury in the lower extremity other than the ankle in the previous two years.
- No previous fracture or surgery in the lower extremity.
- Are free of balance or vestibular dysfunction.
- Have no previous history of concussion in the previous 6 months.
- Have no history of low back pain in the previous 12 months.
- Answer "yes" to the question, "Do you have a history of ankle sprain?" on the All.
- Answer "no" to all symptom questions on the All.
- Score >90% on the FADI and >90% on the FADI-Sport.

We will be enrolling a total of 120 participants. This research study will be conducted in the Athletic Training Research Laboratory (Room: 1404), Joint Injury and Muscle Activation Laboratory (Room: 1407), and Motion Analysis Lab (Room: 1412) in the Health Sciences and Human Services building at the University of Toledo.

DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR INVOLVEMENT

If you decide to take part in this study, you will be asked to complete one testing session. The session will take approximately 2.5 hours. At the beginning of the session, your pre-participation screening will be conducted.

After reading and signing the informed consent, you will be asked to complete a health history questionnaire, an ankle questionnaire, called the Functional Ankle Disability Index (FADI) including daily activity and sport sections, and the Ankle Instability Instrument (AI) questionnaire to allow us to better understand your history of the lower extremity injury. Following completion of questionnaires, your leg length, height, and weight will be assessed. The following measurements will then be taken in randomized order: static postural control, ankle ligament length, ankle joint laxity, peak torque at the knee and ankle, SEBT, and weight bearing dorsiflexion.

Static postural control will be assessed by balancing barefoot on a forceplate. The weakest leg with the lowest SEBT performance from preliminary testing will be used for balancing. You will be asked to place your hands across your chest and hold the opposite leg at approximately 30 degrees hip flexion and 45 degrees knee flexion while keeping the test foot flat on the forceplate. Three practice trials are given and six total trials will be recorded, three with eyes open and three with eyes closed. You will focus on a fixed point marked as an x roughly 1.524 meters away. Failed trials will be repeated until six successful trials are recorded for data analysis.
The SEBT will be performed in the anterior, posteriormedial, and posterolateral directions. For the anterior reach, you will stand with your toes on the grid line and reach as far as possible along the top measure without raising the test foot. For PM and PL directions, the heel will be at the gridline and you will reach back as far as possible in each direction to tap the measuring tape. Four practice trials are given followed by three test trials in each direction for a total of nine successful trials.

Strength in your knee and ankle will be assessed on a specialized machine in a seated position. For testing the knee, you will be seated with a backward tilt of 30 degrees and hip and knee flexed to 90 degrees. Your torso, thigh, and shank will be stabilized using straps and your arms will be placed across the chest. You will maximally take the knee through full range of motion hitting the end points five times. For testing the ankle, the knee will be flexed to approximately 90 degrees and the ankle will be maximally moved through full range of motion. Five trials will be recorded with a two minute rest between limits.

Ankle laxity will be assessed by placing the ankle in an ankle arthrometer and securely fastening the footplate and clamps. You will lie down and avoid any movement in your leg. The examiner will begin with the ankle in a neutral position then test anterior to posterior displacement first. Anterior testing will be applied first followed by posterior loading. Next, an inversion to eversion load will be applied. Inversion will be applied from neutral first followed to eversion. You will remain relaxed to avoid calf contraction for this entire process.

Ankle dorsification range of motion will be assessed using the Weight Bearing Lunge Test (WBLT). This is the motion of the ankle in which your toes get closer to your shin that happens when you squat down. You will position your great toe two centimeters from the wall and keep the heel firmly planted on the floor while flexing the knee to the wall. The purpose is to maintain knee contact with the wall while maintaining heel contact on the ground. Your foot will be moved back less than one centimeter at a time until you are unable to keep your heel on the ground while touching the knee to the wall. Three successful testing trials will be recorded.

The length of lateral ankle ligaments will be assessed with Doppler ultrasound. A plastic probe with gel will be placed on your ankle to acquire an image of your ligament. This assessment involves the transmission of sound waves reflected with your ankle ligaments. Ultrasound images will be taken in three positions (neutral, inversion, anterior drawer, and ankle dorsiflexed at 90°). Between each neutral image, you will be asked actively to plantarflex or dorsiflex three times and return to the neutral position for the subsequent images. During inversion images, you will be asked to lie down on your back on the chair of the dynamometer, with the knee extended at 90° and the ankle plantarflexed at 30°. You will be instructed to relax the lower extremity muscles while your ankle will be passively inverted to the end range of ankle inversion by the examiner and stabilized by the dynamometer. The inversion stress will be released following each image, and the ankle will be then re-positioned in the same end-range of inversion previously determined at the first. Lastly, images will be taken during anterior drawer test, you will be asked to lie down on your stomach with the foot hanging over the edge of the examining table while the examiner pull the forefoot anteriorly.

RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH

When participating in any research study, you may encounter some risks. Although the risk for taking part in this study is very low, you may experience one or more of the following:

1. There is a small, but unlikely risk that you may experience mild discomfort during the testing procedures. To minimize this risk, we will ensure that all equipment is fitted properly and that you are given adequate practice and familiarization with each task, and you will have plenty of rest in between trials to avoid any fatigue. If at any point you experience discomfort, you will be...
encouraged to inform the researcher so that any adjustments can be made to ensure your comfort.

If you are pregnant, it is advised that you remove yourself from the study during your pregnancy. There are no known risks for pregnant women taking part in this study.

POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH

We cannot and do not guarantee or promise that you will receive any benefits from this research. The benefit of participating in this study is to help further research regarding chronic ankle instability.

COST TO YOU FOR TAKING PART IN THIS STUDY

You are not directly responsible for making any type of payment to take part in this study. However, you are responsible for providing your own means of transportation to and from the Health Science and Human Services Building at The University of Toledo. You will not be compensated for gas for travel or any other expenses to participate in this study. You will receive a one-day parking permit for participation in this study by the investigators if you do not have one.

PAYMENT OR OTHER COMPENSATION TO YOU FOR TAKING PART IN THIS RESEARCH

If you decide to take part in this research and complete all testing procedures in this study, you will receive a $15 stipend. The University of Toledo will send a check to mailing address which you will provide to us. Other compensations including free treatment, free medications, or free transportation will not be provided for this study.

PAYMENT OR OTHER COMPENSATION TO THE RESEARCH SITE

The University of Toledo is not receiving money or other benefits from the sponsor of this research as reimbursement for conducting the research.

ALTERNATIVE(S) TO TAKING PART IN THIS RESEARCH

There is no alternative to taking part in this research. Exclusion from the study, however, will not affect the quality of care you may receive at the sports medicine/physical therapy facility, doctor’s office, or other medical facilities.

CONFIDENTIALITY

The researchers will make every effort to prevent anyone who is not on the research team from knowing that you provided this information, or what that information is. The consent forms with signatures will be kept separate from the information we collect, which will not include names and which will be presented to others only when combined with other responses. Although we will make every effort to protect your confidentiality, there is a low risk that this might be breached.

IN THE EVENT OF A RESEARCH-RELATED INJURY

In the event of injury resulting from your taking part in this study, treatment can be obtained at a health care facility of your choice. You should understand that the costs of such treatment will be your responsibility. Financial compensation is not available through The University of Toledo or The University of Toledo Medical Center. By signing this form you are not giving up any of your legal rights as a research subject.

In the event of an injury, contact Phillip Grizzle, PhD, ATC (419) 530-2691.
VOLUNTARY PARTICIPATION
Taking part in this study is voluntary. You may refuse to participate or discontinue participation at any time without penalty or a loss of benefits to which you are otherwise entitled. If you decide not to participate or to discontinue participation, your decision will not affect your future relations with the University of Toledo or The University of Toledo Medical Center.

NEW FINDINGS
You will be notified of new information that might change your decision to be in this study if any becomes available.

OTHER IMPORTANT INFORMATION
There is no additional information.

ADDITIONAL ELEMENTS
There are no additional elements to the study.

Continued On Next Page
OFFER TO ANSWER QUESTIONS
Before you sign this form, please ask any questions on any aspect of this study that is unclear to you. You may take as much time as necessary to think it over. If you have questions regarding the research at any time before, during or after the study, you may contact Phillip Gribble, PhD, ATC (419) 530-2691.

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-383-6795.

SIGNATURE SECTION (Please read carefully)

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED, AND YOU HAVE DECIDED TO TAKE PART IN THIS RESEARCH.

The date you sign this document to enroll in this study, that is, today’s date, MUST fall between the dates indicated on the approval stamp affixed to the bottom of each page. These dates indicate that this form is valid when you enroll in the study but do not reflect how long you may participate in the study. Each page of this Consent Form is stamped to indicate the form’s validity as approved by the UT Biomedical Institutional Review Board (IRB).

Name of Subject (please print)  Signature of Subject or Person Authorized to Consent  Date
Relationship to the Subject (Healthcare Power of Attorney or Legal Guardian)  Time
Name of Person Obtaining Consent (please print)  Signature of Person Obtaining Consent  Date
Name of Witness to Consent Process (when required by ICH Guidelines) (please print)  Signature of Witness to Consent Process (when required by ICH Guidelines)  Date

YOU WILL BE GIVEN A SIGNED COPY OF THIS FORM TO KEEP.
Appendix B

Foot and Ankle Ability Measure (FAAM) and FAAM Sport

<table>
<thead>
<tr>
<th>Activity</th>
<th>No Difficulty</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
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</thead>
<tbody>
<tr>
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<td>Walking on even ground</td>
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<td>Walking up hills</td>
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<td>Walking down hills</td>
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<td>Going up stairs</td>
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<td>Going down stairs</td>
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<td>Walking on uneven ground</td>
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<tr>
<td>Squatting</td>
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<td>Coming up on your toes</td>
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<tr>
<td>Walking initially</td>
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<tr>
<td>Walking 5 minutes or less</td>
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<td>Walking approximately 10 minutes</td>
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<tr>
<td>Walking 15 minutes or greater</td>
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</tr>
</tbody>
</table>
Foot and Ankle Ability Measure (FAAM)
Activities of Daily Living Subscale
Page 2

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

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty at all</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
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<tr>
<td>Home responsibilities</td>
<td>□</td>
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<td>□</td>
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<tr>
<td>Activities of daily living</td>
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<td>□</td>
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<tr>
<td>Personal care</td>
<td>□</td>
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<td>□</td>
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<tr>
<td>Light to moderate work (standing, walking)</td>
<td>□</td>
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<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
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How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities.

□ □ □ 0 %

Foot and Ankle Ability Measure (FAAM) Sports Subscale

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

<table>
<thead>
<tr>
<th>Activity</th>
<th>No Difficulty at all</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Severe Difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
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<tbody>
<tr>
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<td>Landing</td>
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<tr>
<td>Starting and stopping quickly</td>
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<tr>
<td>Cutting/lateral Movements</td>
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<tr>
<td>Ability to perform Activity with your Normal technique</td>
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<tr>
<td>Ability to participate In your desired sport As long as you like</td>
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</table>

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?

[Blank line]

[Blank line]

[Blank line]

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

- Normal
- Nearly Normal
- Abnormal
- Severely Abnormal

Appendix C

Ankle Instability Instrument (AII)

<table>
<thead>
<tr>
<th>Ankle Instability Instrument</th>
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**Instructions**

This form will be used to categorize your ankle instability. A separate form should be used for the right and left ankles. Please fill out the form completely. If you have any questions, please ask the administrator of the survey. Thank you for your participation.

1. Have you ever sprained an ankle? □ Yes □ No
2. Have you ever seen a doctor for an ankle sprain? □ Yes □ No

   If yes,
   2a. How did the doctor categorize your most serious ankle sprain?
       □ Mild (grade 1) □ Moderate (grade 2) □ Severe (grade 3)

3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain? □ Yes □ No

   If yes,
   3a. In the most serious case, how long did you need to use the device?
       □ 1–3 days □ 4–7 days □ 1–2 weeks □ 2–3 weeks □ >3 weeks

4. Have you ever experienced a sensation of your ankle “giving way”? □ Yes □ No

   If yes,
   4a. When was the last time your ankle “gave way”? 
       □ <1 month □ 1–6 months ago □ 6–12 months ago □ 1–2 years ago □ >2 years

5. Does your ankle ever feel unstable while walking on a flat surface? □ Yes □ No
6. Does your ankle ever feel unstable while walking on uneven ground? □ Yes □ No
7. Does your ankle ever feel unstable during recreational or sport activity? □ Yes □ No □ N/A
8. Does your ankle ever feel unstable while going up stairs? □ Yes □ No
9. Does your ankle ever feel unstable while going down stairs? □ Yes □ No
Appendix D

Health History Questionnaire

Participant #____________

Name: ________________________________________________________________________

Age: ____________
Height: ____________
Weight: ____________

Sex:    M    F

1. How many hours and days do you participate in physical activities? : ________________

2. Which foot do you kick a ball with?: Right_______ Left_______

3. Have you sprained your ankle?: Yes    No
   If Yes, which have you sprained, RIGHT or LEFT ankle? __________
   How many times have you sprained your ankle? __________
   When was the most recent? __________

4. Have you ever experienced more than 2 repeated episodes of your ankle “giving way” in the past 12 months?
   Yes    No
   a. When was the last time your ankle “gave way”?
      ____<1 month  ____1-6 months ago  ____6-12 months ago  ____1-2 years ago  ____>2years
5. Have you had a concussion in the past twelve months?: Yes______  No_______
   If yes, explain:____________________________________________________
   ________________________________________________________________

6. Have you ever experienced a head injury beside concussion?       Yes    No
   If Yes, what was the injury? ________________________________
   when was the most recent? ________________________________

7. Have you ever suffered from a significant back injury causing you to interrupt your sports
   activity?       Yes    No
   If Yes, when was the most recent incident? ________________________________
   What was the cause of the back injury/pain? ________________________________

8. Have you ever suffered from a fracture to any part of your leg, knee, ankle, hip, back, thigh, or foot?
   Yes    No
   If Yes, when did the fracture occur? ________________________________
   Which bone (s) was fractured? ________________________________

9. Have you ever suffered from a significant hip/thigh injury causing you to interrupt your
   sports activity?
   a) If Yes, when was the most recent incident? ________________________________
      What injuries have you experienced? ________________________________
   b) Did the injury require surgery?
      Yes    No
      If yes, when was the surgery? ________________________________
10. Have you ever suffered from a significant knee injury causing you to interrupt your sports activity? Yes No
   a) If Yes, when was the most recent incident? ____________________
      What injuries have you experienced? ____________________
   b) Did the injury require surgery? Yes No
      If yes, when was the surgery? ____________________

11. Have you ever suffered from a significant lower leg injury causing you to interrupt your sports activity? Yes No
   c) If Yes, when was the most recent incident? ____________________
      What injuries have you experienced? ____________________
   d) Did the injury require surgery? Yes No
      If yes, when was the surgery? ____________________

12. Have you ever suffered from a significant ankle/foot injury (other than ankle sprains) causing you to interrupt your sports activity? Yes No
   a) If Yes, when was the most recent incident? ____________________
      What injuries have you experienced? ____________________
   b) Did the injury require surgery? Yes No
      If yes, when was the surgery? ____________________

13. Do you suffer from vertigo, or any other neurological disorders?: Yes No
    If Yes, explain: ____________________________________________

14. Are you currently suffering from the effects of a cold or flu?: Yes No
Appendix E

Data Collection Forms

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<tr>
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<tr>
<td>Group</td>
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<td>CAI</td>
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<td>At-risk</td>
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<tr>
<td>Involved Limb:</td>
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<td>Right</td>
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<td>Dominant Limb</td>
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<td>Age</td>
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<td>Hours/ day:</td>
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Order of Testing

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<td>8&lt;sup&gt;th&lt;/sup&gt;:</td>
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### Ankle Laxity Test Form

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<th>Ev.(Max)</th>
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### Weight-Bearing Lunge Test Form

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Static Balance Test Form

Number of Failed Trials

EO
- Right: ____________________________
- Left: ____________________________

EC
- Right: ____________________________
- Left: ____________________________
# Knee Strength Test Form

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Ankle Strength Test Form

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### Star Excursion Balance Test Form

**Leg Length:** Right= __________ cm  Left= __________ cm

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