A comparison of strength, ROM, laxity, and dynamic and static postural control between those at-risk and healthy

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The University of Toledo
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A Comparison of Strength, ROM, Laxity, and Dynamic and Static Postural Control

Between Those At-Risk and Healthy

by

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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the

Master of Science Degree in Exercise Science

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The University of Toledo

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An Abstract of

A Comparison of Strength, ROM, Laxity, and Dynamic and Postural Control Between Those At-Risk and Healthy

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Objective: The purposes of this study were to compare strength, ankle joint laxity, ankle dorsiflexion range of motion (DF-ROM), and static balance between individuals with poor and good performance on the Star Excursion Balance Test in the anterior reach direction (SEBT-A), as well as to identify what combination of factors contribute the most to SEBT-A performance. Design: A single-blinded, case-control design. Setting: Research laboratory. Participants: Twenty three participants with no self-reported injury were recruited from the University of Toledo community. These individuals were assigned to either at-risk (M = 4, F = 9, 21.00 ± 2.61 yrs, 74.78 ± 15.94 kg, 165.99 ± 10.28 cm) or healthy control group (M = 3, F = 7, 20.60 ± 1.51 yrs, 65.82 ± 17.27 kg, 169.36 ± 11.43 cm) based on their performance on the SEBT-A. Interventions: Participants completed five testing activities, including the SEBT-A, a single-lag balance task, the Weight Bearing Lunge Test (WBLT), concentric strength of sagittal-plane ankle and knee movers using the Biodex, and ankle laxity using an instrumented ankle arthrometer. Main Outcome Measures: The normalized reach distance of the SEBT-A was calculated as the average of the three reach distances (cm) divided by leg length (cm)
and represented as a percentage score (MAXD). Static postural control was examined with the center of pressure velocity (COPV, m/s2) and time-to-boundary (TTB, s). 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 weight-bearing dorsiflexion. The average of five peak torque productions of the sagittal-plane ankle and knee movers was normalized to body mass and represented as average peak torque (Nm/kg) from the five trials. Total anterior-posterior (AP) and inversion-eversion (IE) laxities were quantified in millimeters and degrees, respectively. Statistical Analysis: Independent t-tests were used to compare each dependent variable between the at-risk and healthy groups. Cohen’s d effect sizes with 95% confidence intervals (CI) were calculated for each comparison between groups. Additionally, a multiple linear backward regression analysis was performed to determine which dependent variables contributed to the variance of SEBT-A. Significance was set a priori at p<0.05. Results: There were statistically significant differences in the SEBT-A ($t_{18} = -5.961, p \leq 0.001$) and the WBLT ($t_{18} = -2.632, p = 0.016$) between the at-risk and healthy groups. There were no significant results for other outcome measures (p > 0.05). For the at-risk group, the combination of knee extensor strength, static postural control, and the WBLT explained 75% of the variance in SEBT-A ($R^2 = 0.750, p = 0.004$). Conclusion: Participants with shorter anterior reaching distance in the SEBT had significantly less DF-ROM compared to controls. The results of the regression analyses showed that sagittal-plane knee strength, static postural control, and AP laxity predict the most to SEBT-A performance. Sagittal-plane knee strength, static postural control, and weight-bearing ankle DF-ROM may represent clinically modifiable factors for a targeted
prevention program when decreased functional performance is identified with the SEBT-A.
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<tr>
<td>% MAXD</td>
<td>Normalized Percentage of the Reach Distance</td>
</tr>
<tr>
<td>AII</td>
<td>Ankle Instability Instrument</td>
</tr>
<tr>
<td>CAI</td>
<td>Chronic Ankle Instability</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<tr>
<td>COPV</td>
<td>Center of Pressure Velocity</td>
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<tr>
<td>DF</td>
<td>Dorsiflexion</td>
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<tr>
<td>DF-ROM</td>
<td>Dorsiflexion Range of Motion</td>
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<tr>
<td>EC</td>
<td>Eyes Closed</td>
</tr>
<tr>
<td>FAAM</td>
<td>Foot and Ankle Ability Measure</td>
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<tr>
<td>FAAM-S</td>
<td>Foot and Ankle Ability Measure Sport</td>
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<td>Star Excursion Balance Test Anterior reach</td>
</tr>
<tr>
<td>TTB</td>
<td>Time to Boundary</td>
</tr>
<tr>
<td>WB-DF</td>
<td>Weight Bearing Dorsiflexion</td>
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Chapter One

Introduction

A lateral ankle sprain (LAS) is the most common injury in many athletes.\textsuperscript{1-5} The incidence of lateral ankle sprains can occur as many as 25,000 times per day in the United States alone.\textsuperscript{6} Injury to the ankle has a major impact on healthcare costs\textsuperscript{7} and may result in time loss from activity\textsuperscript{8,9} and long-term disability such as chronic ankle instability (CAI)\textsuperscript{10} and osteoarthritis.\textsuperscript{11} Healthcare costs for acute LAS in the United States are estimated at $2 billion/year, with treatment ranging from $318 to $914 per sprain.\textsuperscript{7} It was also reported that up to 72% of individuals with an initial ankle sprain may not be able to return to activity at their previous functional level.\textsuperscript{9} Therefore, a LAS may be a significant public health concern in the physically active.

Identifying factors that increase the risk for a LAS is an important step in order to decrease the incidence and the associated long-term complications. The Star Excursion Balance Test (SEBT) is an inexpensive and efficient outcome tool that consistently identifies functional impairments in dynamic postural control associated with ankle instability.\textsuperscript{12} The SEBT has been shown to be a valid and reliable tool\textsuperscript{12,16-18} to assess postural stability by having an individual maintain a constant base of support on the stance limb and perform a series of single-limb squats using the non-stance limb to reach maximally to touch a point along one of three designated lines on the ground.\textsuperscript{13} Additionally, in previous prospective studies\textsuperscript{14-16}, high school athletes that suffered an ankle sprain during a competitive season produced shorter reach distance on the SEBT in pre-season assessment, supporting that the SEBT is able to identify athletes with a risk for an ankle sprain.
However, information gained from the outcome of the SEBT does not necessarily indicate what characteristics of the patient may be deficient and in need of modification to improve the SEBT performance. It is often theorized that SEBT performance requires a combination of optimal strength, joint motion, and neuromuscular control. Isolated investigations have reported that the SEBT performance may be influenced by the availability of ankle dorsiflexion range of motion (DF-ROM), lower extremity muscle activation patterns, and sagittal-plane kinematics.\textsuperscript{17-21} However, there is currently little evidence that provides directions to clinicians and researchers how best to correct dynamic postural control deficits identified by the SEBT.

Numerous modifiable risk factors for a traumatic LAS have been previously identified by prospective studies and meta-analyses, including poor postural control\textsuperscript{16,22-27}, a muscle strength imbalance around the ankle\textsuperscript{23,28}, the availability of (DF-ROM)\textsuperscript{23,25}, and ankle joint laxity, which may contribute to poor performance on the SEBT. Poor performance on the SEBT constitutes a score of less than 67% while good performance is composed of a score of greater than 67%.\textsuperscript{14,15} Some preliminary studies have shown those individuals scoring less than 67% on the SEBT for the anterior reach direction were more likely to suffer from an ankle sprain.\textsuperscript{14,15} Similar to this, it also been shown that those individuals scoring poorly on the SEBT are twice as likely to sustain an ankle injury.\textsuperscript{14,16} Individuals with ankle instability also have a shorter reach distance during the SEBT than those healthy individuals with no ankle injury.\textsuperscript{29}

We need to further define poor performance on the SEBT with other modifiable injury risk factors like those stated above, in order to prevent a LAS. However, it is currently unclear what factors have an impact individually and in combination on the
Identifying the potential differences in the modifiable factors between individuals with poor and good performance on the SEBT, as well as establishing which modifiable factor is the greatest contributor to the SEBT performance in those potentially at risk for ankle injury, will provide significant insight in how to use dynamic postural control outcomes from the SEBT for development of effective prevention for an ankle sprain, without the need for comprehensive evaluation of multiple factors.

Statement of the Problem

We currently know little about which risk factors impact an ankle sprain, as previously discussed. The SEBT is an easily implemented and effective screening tool to identify individuals at increased risk of ankle pathology by evaluating dynamic postural control in the lower extremity. It has been shown that athletes with poor performance on the SEBT are over twice as likely to sustain an ankle injury\textsuperscript{14,16}, and individuals with ankle instability have shorter reach distance than those without ankle instability.\textsuperscript{29} However, there is little research that has compared individuals considered at-risk for suffering a LAS based on their SEBT score compared to a healthy population not considered at-risk based on an assessment of SEBT performance. Additionally, no research has been performed to determine what factors contribute to performance on the SEBT in a healthy and at-risk group.

Statement of the Purpose

The purpose of this study is to compare strength, ankle joint laxity, ankle DF-ROM, and static balance between individuals with poor and good performance on the
SEBT. A second purpose is to identify what combination of the contributing factors mentioned above most influence SEBT performance in each group.

**Research Hypotheses**

1. LAS at-risk individuals (poor SEBT performance) will demonstrate decreased knee strength compared to those that are healthy and not considered at risk (good performance on the SEBT).

2. At-risk individuals will demonstrate decreased plantar flexion strength and dorsiflexion strength compared to those considered to be healthy and not considered at-risk.

3. At-risk individuals will demonstrate restricted ankle dorsiflexion compared to those considered to be healthy.

4. At-risk individuals will demonstrate a decreased level of static balance compared to those considered to be healthy.

5. At-risk individuals will demonstrate similar ankle laxity measurements compared to those considered to be healthy.

6. There will not be a significant amount of variance in any combination of the measured factors that will explain a significant amount of the variance of the SEBT-A performance in the healthy control group.

7. The variances in ankle dorsiflexion and static balance will significantly predict the variances in SEBT performance in the individuals at risk for a LAS.

**Significance of the Study**

Identifying modifiable factors which predict SEBT performance can help clinicians to develop effective prevention programs for ankle pathology. Screening
athletes for specific conditions such as dorsiflexion range of motion, ankle laxity, static balance, and ankle and knee strength impairments can help identify those individuals more apt to sustain a lateral ankle sprain. This may also decrease the incidence rate of lateral ankle sprains. Reduction of the incidence of LAS will ultimately lead to a decrease in the healthcare costs and long-term complications associated with ankle injury.

**Operational Definitions**

Lateral ankle sprain=LAS: instability due to damage of the ankle through an inversion of the foot which causes ligamentous and other tissue damage.\(^{30}\)

CAI=Chronic Ankle Instability: occurrence of repetitive episodes of lateral ankle instability thus resulting in numerous ankle sprains.\(^{30}\)

Balance: a position of equilibrium in which no forces are acting upon the object and stability and postural control are achieved.\(^{31}\)

FADI=Functional Ankle Dysfunction Index: a tool used to evaluate activities of daily living.\(^{32}\)

Postural Control: sustaining and upholding balance while performing functional activities or maintaining an upright stance.\(^{31}\)

Static Postural control: maintaining stability and balance in a single leg stance over a fine center of gravity.\(^{33}\)

Dynamic Postural control: the act of maintaining balance and stability while performing a specific function or movement.\(^{19}\)

ROM=Range of Motion
SEBT=Star Error Balance Test: a reliable test of dynamic postural control and involves taking a stance on one leg and reaching out with the contralateral leg in different directions while maintaining stance and balance.\textsuperscript{12,34}
Chapter Two

Literature Review

The literature review discussed etiology of lateral ankle sprains, injury screening tools, and the factors that could increase a risk for an ankle sprain.

Anatomy

The talocrural joint consists of the talus, the tibia, and the fibula. These bones are responsible for creating a stable configuration to support the weight of the body. This joint’s function is to transmit the weight of the body throughout the foot for force dissipation while weight bearing. The talus is probably the most crucial bone in this configuration as the shape and ligamentous attachments are what keep the ankle stable. Sometimes, plantar flexion can place the ankle in an unstable position because of the morphology of the talus. The closed pack position is most stable involving dorsiflexion and eversion of the ankle, and can be seen in climbing or squatting.

The most commonly injured ligament in an ankle sprain is the ATFL because of its anterior placement connecting the tibia and talus, so when forward translation of the tibia occurs, this ligament is most stressed. The second most commonly sprained ligament is the CFL located on the lateral side of the ankle complex, and is therefore stretched or potentially torn in the case of an inversion ankle rolling motion. The least common ligamentous sprain is the PTF which is located on the posterior portion of the talus. These ligaments are all designed to prevent internal rotation and inversion of the ankle, as demonstrated by their positioning on the talus and respective bones.

The most crucial muscular support to the ankle joint includes the peroneal longus and brevis. These muscles run along the lateral side of the lower leg and provide
Dynamic restraint against lateral sprain mechanisms by controlling ankle supination through eccentric contraction to slow down the ankle complex during this movement.\textsuperscript{30} Similar to the peroneal muscles, the anterior tibialis and extensor muscles also act eccentrically to slow plantar flexion moments which lead to supination and injury to the lateral ankle complex.\textsuperscript{30}

**Lateral Ankle Sprain**

**Epidemiology.** Within high school athletics, ankle sprains are the most common injury.\textsuperscript{4} In a surveillance study performed by Nelson et al\textsuperscript{4}, it was shown that football accounted for 24.1\% of all ankle injuries, followed by soccer (33.6\%), basketball was (23.8\%) and girls’ volleyball (10.6\%). In addition to being concerned regarding first time sprains, recurrent sprains are also an important component affecting the health of the ankle. A separate study gathered data showing the ankle as still being the most injured site of the body for high school recurrent injuries at 28.3\%.\textsuperscript{3}

Ankle sprains are not limited to only affecting high school athletes. Another epidemiology study summarized 16 years of National College Athletic Association (NCAA) injury surveillance data for 15 sports and reported that ankle sprains were also the most common injury among all sports, accounting for 15\% of all reported injuries.\textsuperscript{1} Lateral ankle sprains (LAS) are associated with high healthcare costs. In the United States, ankle sprains have a staggering rate of two million sprains each year and healthcare costs for a lateral ankle sprain in one year reaches $2 billion.\textsuperscript{7} Treatment for these ankle sprains can range $318 to $914 per sprain.\textsuperscript{7} In addition to high health care cost, a lateral ankle sprain may cause long term disability, specifically chronic ankle
instability (CAI)\textsuperscript{10} and eventually osteoarthritis.\textsuperscript{11} Waterman et al\textsuperscript{36} reported that 53.9% of all ankle sprains occurred between ages 10 and 19 years, and the peak incidence rate of a LAS was the ages between 15 and 19 years, with an estimated injury rate of 7.2 per 1000 person-year. It has been also reported that a LAS could lead to long–term complications such as osteoarthritis.\textsuperscript{11} Lateral ankle sprain resulting symptoms could last for months or years after an initial injury in which a substantial amount of time loss from activity may occur. Because the greatest prevalence is in these young ages, it can be detrimental for a young athlete to suffer a LAS and prove difficult to return to an optimal level of physical activity.\textsuperscript{8,9}

Pathomechanics of a Lateral Ankle Sprain. Biomechanically, the motion causing the most harm to ligamentous support, specifically the ATFL, is inversion and internal rotation along with lower leg external rotation.\textsuperscript{30} Since the inversion mechanism causes forward translation of the talus, this ligament is stressed the most. Eversion is not as harmful to ligamentous support because the fibula protrudes down far enough to prevent the motion, thus averting the medial ligaments from being stressed.

Andersen et al\textsuperscript{37} analyzed Norweigen and Icelandic football injuries and found inversion trauma was the most common mechanism, with a force to the medial side of the ankle in which the lateral force caused the athlete to land in an inverted position. The other common position was ankle plantar flexion after a kick to the ankle. In a similar study it was demonstrated that plantar flexion and therefore the subtalar joint as a whole were not as crucial of a component to an inversion ankle sprain, but instead inversion and internal rotation were the more key factors.\textsuperscript{38} Also related to this, Kristianslund, et al\textsuperscript{39} demonstrated ankle plantar flexion was similar in injured and healthy individuals until 80
milliseconds after foot contact with the ground when the injured group demonstrated more dorsiflexion. The maximum ankle inversion angle of an ankle sprain is reached as fast as 0.08 seconds.  

Fong et al documented an accidental ankle sprain during laboratory testing. After analyzing this data compared to the normal trials, they observed that the LAS had seven degrees more internal rotation and six degrees more inversion. Within the first 0.06 seconds, the pre-injured ankle was marked as having larger inversion, increased plantar flexion velocity, and greater internal rotation velocity.  

**Risk Factors.** There are numerous risk factors which can be associated with a lateral ankle sprain. One such factor can be attributed to dynamic postural control/balance. McHugh, et al showed that balance between previous ankle sprain and healthy groups showed a statistically significance difference, however this difference in groups was attributed to sex in that females had better balance than males. 

Previous history of an ankle sprain and an increased BMI have been shown to be risk factors for ankle sprain in high school football, and the previous history of an ankle sprain was a stronger predictor of an ankle sprain than BMI. Willems et al 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 also performed a similar study for male physical education students only, concluding that decreased dorsiflexion ROM (DF-ROM) and strength,
increased extension ROM in the first phalanx in the foot, and increased balance test scores increased the risk for LAS in males.²³

It has been identified that the biggest risk factor for a LAS was previous history of an ankle sprain. Ankle sprains most commonly occur in those individuals ages ten to twenty four years.³⁶ Similarly, between the ages of fifteen and nineteen years is when the peak incident of a LAS occurred.³⁶

Some other factors that may increase the risk of an ankle sprain include DF-ROM and strength, dynamic postural control, and joint positioning sense, to name a few.²²,²³ DROM has been shown to be an important risk factor for LAS. Willems, et al²² demonstrated that individuals with decreased DF-ROM and strength have a greater risk of sustaining a LAS. Also, it was reported that increased ROM at the first MTP joint increases risk of LAS.²²,²⁵

Increased postural sway has been shown to increase the risk of a LAS.²⁴,⁴³ de Noronha, et al²⁵ systematically reviewed literature that showed measures of strength, proprioception, range of motion, or postural sway can predict lateral ankle sprain. In their systematic review, while DF-ROM appeared to be the best predictor for a LAS, the key for prediction of ankle sprains is the interaction of variables such as ROM, proprioceptive factors, and postural sway.

These risk factors are important as they may lead to a LAS. However, a previous sprain seems to be the best predictor of future ankle sprain⁴², which could ultimately lead to CAI. Yeung et al⁴⁴ reported ankle sprain recurrence rates of over 70%. Residual symptoms such as pain and feelings of instability or giving way are associated with
recurrent ankle sprains. Anandacoomarasamy et al\textsuperscript{15} also reported 74\% of individuals with an initial ankle sprain had residual symptoms up to four years.

**Chronic Ankle Instability: Contributing Factors and Deficits**

Chronic ankle instability is defined as multiple episodes of lateral ankle sprains with residual symptoms, such as “giving way” and joint instability.\textsuperscript{9,30} Chronic ankle instability has been classified into functional and mechanical instabilities. Mechanical instability is associated with laxity, positional fault, alignment, ROM, and ATFL ligament damage.\textsuperscript{30} An ankle sprain usually involves an inversion mechanism in which the talus moves anteriorly compared to the lower leg which applies the greatest amount of stress to the ATFL ligament. This can cause the ATFL to stretch and remain in an elongated position which interferes with its function of providing mechanical stability to the joint.\textsuperscript{46}

This loss of alignment between the talus and mortis can also provide hypermobility or hypomobility of the ankle joint which contributes to the interference in normal glide. The hypermobility motion can cause stress to ligaments because they are overly elongated, while hypomobility can cause restricted dorsiflexion ROM because not enough ligamentous laxity is provided to allow proper movement and glide.\textsuperscript{46,47} Hubbard, et al\textsuperscript{47} showed anterior displacement of the talus was observed in the CAI group compared to the control group. The distal tibiofibular joint may present with a positional fault in a portion of those individuals who have a sprain related to CAI; and in one third of patients with an acute ankle sprain, this movement is significantly greater.\textsuperscript{48}
Functional instability is associated with altered afferent input from somatosensory around the ankle, altered sensorimotor control, strength deficits, and altered postural control. Sefton, et al\textsuperscript{49} demonstrated diminished static balance and decreased motoneuron pool excitability during single and double legged stance in the CAI patients, indicating that altered sensorimotor control may be associated with CAI.\textsuperscript{49}

There is also evidence that ankle injury may impact neuromuscular control proximal to the ankle. In CAI participants, hip abductors had a statistical correlation of being weaker on the side of an inversion ankle sprain as opposed to the ipsilateral, healthy side. A correlation was also observed between the inversion and plantar flexion ROM on the side with the inversion sprain.\textsuperscript{50} Not surprisingly inversion deficits have been seen with those individuals having CAI.\textsuperscript{51} Ankle instability also appears to negatively impact knee strength, with deficits observed in knee flexion and extension in patients with CAI.\textsuperscript{52} The deficits in strength also play a role in static postural control among patients with CAI.

CAI individuals not only activate their hip, knee, and ankle muscles later than control individuals, but also do not change order of muscle recruitment based upon visual sensory input.\textsuperscript{53} Strength may even play a role in SEBT performance. CAI individuals reach less when standing on the injured ankle compared to the healthy limb or both limbs of other healthy participants.\textsuperscript{29} The different directions of the SEBT have been shown to elicit different muscle activation patterns of the lower extremity.\textsuperscript{21} For example, the anterior reach utilizes more quadriceps activation than other directions. Therefore, a loss of strength or muscle activation following a LAS could lead to a deficit in dynamic postural control that can be assessed with the SEBT.
Balance training programs have been shown to reduce the risk of ankle sprains in athletes as well as improve outcomes with previously sprained ankles. In a study done by McGuine, et al, it was shown that those who participated in an intervention exercise decreased the risk of a lateral ankle sprain whereas those who already had an ankle sprain and did not participate in the program had an increased chance of sustaining another sprain. Balance training can also be related to other functional instabilities. For example, a separate six week balance training study performed by Sefton, et al showed increased dynamic balance, increased inversion proprioception, and improvements in motoneuron pool excitability in those individuals with CAI compared to the healthy control group who did not go through the program. Balance training is not only crucial in a rehabilitation program, but could also play a role in preventing an injury by improving proprioception and maybe even muscle activation.

Hubbard, et al found that strength about the ankle in the sagittal plane, inversion and anterior-posterior laxity, and balance deficits were strongly associated with CAI. This indicates that these factors were either affected before the initial LAS occurred or were then present because of the LAS.

**SEBT**

The SEBT is a reliable test of dynamic postural control and involves standing on a single limb and reaching out with the contralateral leg in different directions while maintaining stance and balance. The individual stands in the middle point of a grid with eight lines that branch out at 45 degree angles. The individual maintains stance on one foot while maximally reaching out the other foot to tap a line before returning back to
The SEBT has been proven a reliable source for accurate measurements.\textsuperscript{56-58}

Similarly, the SEBT is a sensitive and effective tool to use with athletes with CAI to detect deficits in postural control.\textsuperscript{12} Previous studies\textsuperscript{18,19,29,59} consistently demonstrated the decreased reach distance on the SEBT in individual with CAI.

Plisky et al\textsuperscript{16} examined the predict capability of the SEBT for lower extremity injuries in high school basketball players and found that high school basketball players with poor SEBT performance were over two times more likely to sustain a lower extremity injury.\textsuperscript{16} Our preliminary studies have also showed that athletes scoring less than 67\% for anterior reach on the SEBT (SEBT-A) were more likely to suffer from an ankle sprain.\textsuperscript{14,15} However, it is still unclear what factors influence the SEBT performance. de Noronha et al\textsuperscript{27} showed that previous history of a sprain and the poor SEBT performance in the PL direction were strong predictive factors for ankle sprain.

The SEBT can help us to predict the risk of a traumatic ankle sprain in athletic populations as well as identify deficits in postural control in individuals with ankle pathology. It was suggested that joint ROM may influence the SEBT performance.\textsuperscript{21} Earl et al\textsuperscript{21} showed that ankle and knee muscle activation were significantly associated with the specific directions in the SEBT. Additionally, Hoch et al\textsuperscript{17} reported that the weight bearing dorsiflexion (WB-DF), measured with the weight-bearing lung test (WBLT), was significantly correlated with the anterior reach distance on the SEBT. However, it is still unknown which modifiable risk factors for a traumatic ankle sprain best lead to improved performance on the SEBT. Therefore, further investigations are needed to determine what factors individually and in combination impact performance of the SEBT.
Conclusion

Lateral ankle sprains are very common injuries affecting the physically active population. An initial ankle sprain could lead to mechanical and functional instabilities related to laxity problems, strength deficits, positional faults, ROM deficits, altered sensorimotor control, and altered postural control, which may influence SEBT performance. Therefore, prevention of an initial traumatic ankle sprain is important to reduce the prevalence of CAI. The SEBT has been shown to have the ability to predict the risk of a traumatic ankle sprain in athletic populations by assessing dynamic postural control. However, it is still unclear what risk factors for ankle sprain influence individually and in combination SEBT performance. Identifying which factors contribute the most to an at-risk group by utilizing the SEBT may develop a preventative treatment program to reduce a risk for a traumatic acute ankle sprain.
Chapter Three

Procedure

Experimental Design

This study is a case-control design with one between-subject factor (2 levels: healthy and at-risk). The dependent variables include the normalized reach distance of the SEBT, knee and ankle strength, ankle DF-ROM, ankle laxity and static balance.

Participants

Twenty three participants between the ages of 18-30 years were recruited from the University of Toledo community and volunteered for this study. All participants read and signed the informed consent forms approved by the University of Toledo Institutional Review Board (IRB) prior to beginning of testing.

The participants were divided into two groups: a healthy control group and an at-risk group. All participants had no previous history of lower extremity injury, no previous surgery in the lower extremity, no history of concussion within the past three months, and scored 100% on both the Foot and Ankle Ability Measure (FAAM) and FAAM Sports questionnaires and answered no to all questions on the Ankle Instability Instrument (AII) thus scoring 0%. Normalized anterior reach direction of the SEBT was used to assess eligibility for the at-risk group. The cut-off score of the SEBT was determined by our preliminary data. Our preliminary studies showed that athletes who scored less than 67% on the SEBT in the anterior direction were more likely to suffer from an ankle sprain. Participants were classified in the control group if they score greater than 67% on the SEBT. To be included in the at-risk group, participants were required to score less than 67% on the SEBT. These participants were recruited from a
database of individuals that have been part of previous studies under the direction of the faculty advisor in which SEBT assessments were performed. Participants meeting the criteria were contacted and offered an opportunity to participate in this study. Age and anthropometrical characteristics of participants are shown in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Demographic information for At Risk and Control Groups (Mean ± SD).</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Risk</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Age (year)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
</tr>
<tr>
<td>FAAM</td>
</tr>
<tr>
<td>FAAM Sports</td>
</tr>
<tr>
<td>All</td>
</tr>
</tbody>
</table>

Instrumentation

An isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA) was used to assess the ankle and knee strength in the sagittal plane. Joint laxity in the ankle was assessed using an ankle arthrometer (Blue Bay Medical Inc., Navarre, FL). Center of pressure velocity (COPV) and time to boundary (TTB) measurements were analyzed using MotionMonitor software 8.0 (Innovative Sports Training, Inc., Chicago, IL) and a non-conductive force plate (model 4060NC; Bertec Inc., Columbus, OH).

Testing Procedure

All participants reported to the Athletic Training Research laboratory for one testing session. The height, mass, and leg length of each participant were recorded prior
to data collection and used for normalization of the dependent variables. Leg length was measured from the ASIS to the inferior portion of the medial malleolus and was recorded in centimeters.

The following measurements were taken in randomized order: static postural control, ankle joint laxity, peak torque around the ankle and knee in the sagittal-plane, the SEBT, and DF-ROM. The examiners were blinded to the group. For the at-risk group, the limb with the lowest SEBT score performance from their previous study participation was used for data collection. For the healthy control group, a randomly selected limb was used for data collection.

**Data Collection and Processing**

**Static Postural Control.** Static postural control was assessed using the force plate at a sampling rate of 50 Hz. Participants were asked to stand on the middle of the force plate on the testing leg. All trials were performed in a barefoot condition. Participants were instructed to keep their hands on their hips and hold the non-stance leg at approximately 45 degrees of knee flexion and 30 degrees of hip flexion while keeping their foot flat on the force plate. Three practice trials were given followed by three testing trials for 15 seconds each. Participants performed the three testing trials with the eyes-closed condition. A trial was discarded and repeated if the participant removed hands from the hips, if there was loss of balance and deviation from the upright position, if the non-testing limb made contact on the force plate or the stance limb, or if the participant failed to keep the eyes closed during the eyes closed trials, respectively. Participants were then asked to keep their balance for 15 seconds (Figure 3-1) while center of pressure (COP) data was collected.
The COP data were filtered by the Motion-Monitor software with a low pass, fourth order Butterworth filter set at a cutoff frequency of 10 Hz. The COPV was calculated as the path length of that trial divided by 15 seconds. The average velocity during the trial is reported in the anteroposterior (COPAPV) direction as well as the mediolateral (COPMLV) direction.

Measures of Time to Boundary (TTB) were also quantified to assess static postural control. The TTB in both the AP and ML directions were calculated using the method previously described by Hertel et al. During the testing trials, the foot was centered in a rectangle fixed to the plate in order to measure the AP and ML dimensions of the foot, allowing for separation of the AP and ML components of COP. The COP data were processed using a custom MATLAB software program. The TTB variables in this study included the TTB absolute minimum and mean of the TTB minima.
Dynamic Postural Control: Star Excursion Balance Test. Participants performed the SEBT in the anterior direction. The participants were instructed to stand with their toes on the beginning of the grid line for anterior direction. The participants were then instructed to reach out with the opposite leg and tap their toe as far as possible on the designated line while maintaining balance and keeping the hands placed on the hips (Figure 3-2). Participants were given four practice trials in each direction to minimize a learning effect. After the practice trials, three test trials were performed. The trials were repeated if the stance foot was lifted, if balance was lost, or if the participant removed their hands from their hips. Failed trials were recorded. The reaching distance of the SEBT was averaged from the three trials and then normalized by the leg length and multiplied by 100, denoted as % MAXD.18,19

Figure 3-2. SEBT-A testing procedure.
**Ankle and Knee Strength.** To examine ankle and knee strength in the sagittal plane, peak torque in the ankle and knee were measured with the Biodex. The participant received as many familiarization trials as they needed to become familiar with the testing protocol and perform five consecutive muscle voluntary contractions (MVC) through the entire ROM of the joint. A concentric-concentric protocol was used at 60 degrees per second. For testing the ankle strength, the participant was seated at a 30° backseat tilt with the ankle in 10° of plantar flexion and the knee in a slightly flexed position, approximately 10°, to minimize hamstring action (Figure 3-3-A). For knee testing (Figure 3-3-B), the participant remained in the seated position at 30°, and the hip and knee were flexed at 90°. The axis of the dynamometer was visually aligned with the rotational axis of the knee, a transverse axis through the femoral condyles. During all trials, the participants’ torso, thigh, and shank were stabilized using hook-and-loop straps, and participants were asked to place their arms across the chest.

![Figure 3-3A. Ankle strength testing procedure.](image-url)
Five trials were given for knee flexion/extension and ankle plantar flexion/dorsiflexion with a two minute rest between limbs. Average peak torque was reported for each trial for each direction at each joint and then normalized to body mass (N\(\cdot\)m\(^{-1}\)\(\cdot\)kg\(^{-1}\)).

**Ankle Laxity.** To measure ligamentous laxity, the ankle arthrometer was used. This device was secured by an adjustable plate to the plantar aspect of the foot and also had a load-measuring handle to distribute the load (Figure 3-4). Connected to the foot plate is a linkage system with 6 degrees of freedom which indicates the amount of displacement during an applied load. This information was useful in determining translational and rotational motion in the ankle. The device was connected into a computer with LabVIEW programming software.
The foot was placed into the footplate and clamped posteriorly, medially, and laterally around the calcaneus. A tibial pad was then secured around the tibia roughly five centimeters above the malleoli. The participant was told to lie down and remain relaxed to ensure similar testing procedure. Three trials were taken each of anterior, posterior (AP) drawer and heel inversion, eversion (I-E). The ankles were positioned at a neutral/zero force starting position and were loaded in a randomized order. To record total AP displacement (mm of translation), 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. For I-E, a load of 4000 N/mm of inversion and eversion torque was applied. Inversion load was applied first from the neutral position, followed by eversion loading. Total I-E motion (degrees of motion) of the foot was recorded and referred as I-E laxity. During each of the trials, participants were instructed to relax and avoid contracting the calf muscle as well as informing the examiner if the heel slipped during testing.
Ankle DF-ROM. Ankle DF-ROM was assessed using the weight bearing lung test (WBLT) (Figure 3-5). Participants positioned their great toe two centimeters from the wall to begin the measurement by planting the testing heel firmly on the floor and flexing the knee to the wall while the non-testing leg was positioned in back of the test foot to maintain a stable posture. The participants strived to achieve knee contact to the wall while they maintained heel contact on the ground. The foot was moved backward in small increments (less than 1 cm) until participants were unable to keep their heel on the ground while touching the wall with the knee. Distance from their great toe to the wall (cm) was recorded as maximum DF-ROM to the closest 0.1 cm. Participants were given three practice trials and three testing trials.75

Figure 3-5. WBLT procedure.

Statistical Analysis

Anthropometric measurements were compared between groups using independent sample t-tests to confirm at-risk participants were matched with healthy control
participants demographically. The dependent variables include \%MAXD in the anterior, PM, and PL directions and a composite score; sagittal-plane average peak torque about the knee (flexion and extension) and ankle (dorsiflexion and plantar flexion); laxity: total AP displacement and total I-E displacement; COPAPV; COPMLV; as well as the four TTB measures; and the DF-ROM. For all dependent variables, means and standard deviations were calculated from the three test trials and used for statistical analysis. Independent-tests were used to compare each dependent variable between the control and at-risk groups. Cohen’s \( d \) effect sizes using the pooled standard deviations were also calculated, along with 95% confidence intervals (CIs) to assess clinical significance for dependent variables. The strength of effect sizes were interpreted as weak (\( d \leq 0.4 \)), moderate (\( 0.40 < d \leq 0.8 \)), and strong (\( d > 0.8 \)).\textsuperscript{76,77}

We performed a backward linear regression analysis to determine which modifiable factors best predicted SEBT performance in the control and at-risk group. The remaining measures of static balance, strength, laxity, and ROM were used as the predictor variables. Using a backwards regression model, all predictor variables were entered into the regression analysis. Once the analysis was run, the variable that would be least predictive of SEBT performance was removed and another analysis was performed. This process was repeated until the variables that best predicted SEBT performance were identified for each group.

The level of significance was set a priori at \( p < 0.05 \) for all statistical analysis using SPSS 19.0 (SPSS, Inc. Chicago, IL.) for Windows for all statistical analysis.
Chapter Four

Results

Sensorimotor

**Dynamic Postural Control.** The control group demonstrating significantly greater anterior reach than the At Risk group \((t(18) = -5.961, p < 0.001)\) (Table 2). There was a strong effect size for SEBT-A, with 95% CIs that did not cross zero \((d= 2.22, 95\% \text{ CIs: } 1.11, 3.17)\).

Table 2

*Mean and Standard Deviations for Star Excursion Balance Test (SEBT).*

<table>
<thead>
<tr>
<th></th>
<th>(t_{18})</th>
<th>(p)-value</th>
<th>Effect Size</th>
<th>At Risk</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>-5.961</td>
<td>(\leq 0.001^*)</td>
<td>2.22 (1.11, 3.17)</td>
<td>59.94 ± 5.50</td>
<td>69.36 ± 1.32</td>
</tr>
</tbody>
</table>

Direction measurements are expressed as % MAXD by averaging three trials and normalizing by length and multiplying by 100.

*Significant differences between the At Risk and the control groups in anterior reach during SEBT \((p<0.05)\).

**Torque Production.** There were no statistically significant differences in ankle and knee sagittal-plane torque production \((p > 0.05)\) (Table 3). All effect sizes were small (Table 3).
Table 3

Mean and Standard Deviations for Sagittal-Plan Torque Production Measurements at the knee and ankle joint.

<table>
<thead>
<tr>
<th></th>
<th>t₁₈</th>
<th>p-value</th>
<th>Effect Size</th>
<th>At Risk</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle PF</td>
<td>0.138</td>
<td>0.891</td>
<td>0.06 (-0.77, 0.88)</td>
<td>0.355 ± 0.19</td>
<td>0.345 ± 0.16</td>
</tr>
<tr>
<td>Ankle DF</td>
<td>0.720</td>
<td>0.479</td>
<td>0.31 (-0.53, 1.12)</td>
<td>0.195 ± 0.08</td>
<td>0.173 ± 0.06</td>
</tr>
<tr>
<td>Knee Flex</td>
<td>-0.524</td>
<td>0.606</td>
<td>0.22 (-0.62, 1.04)</td>
<td>0.802 ± 0.26</td>
<td>0.857 ± 0.24</td>
</tr>
<tr>
<td>Knee Ext</td>
<td>0.527</td>
<td>0.604</td>
<td>0.22 (-0.61, 1.04)</td>
<td>1.432 ± 0.43</td>
<td>1.343 ± 0.36</td>
</tr>
</tbody>
</table>

Peak torque measured in Newton meters (Nm) and normalized by body weight(N•m⁻¹•kg⁻¹).

Static Postural Control

*Center of Pressure Velocity (COPV).* There was no statistically significant differences between the at-risk and control groups (p>0.05) (Table 4). All effect sizes were small (< 0.50).

*Time to Boundary (TTB).* TTB variables were not significantly different between the at-risk and control groups (p > 0.05). However, the effect size was moderate for the following: TTB mean minima in the ML direction (mean TTB-ML), with 95% CI that crossed zero (d = 0.55, 95% CIs: -0.31, 1.37); the TTB mean minima in the AP direction (mean TTB-AP), with 95% CIs that crossed zero (d = 0.64, 95% CIs: -0.22, 1.46) (Table 4).
Table 4

Mean and Standard Deviations for Center of Pressure Velocity (COPV) and Time to Boundary (TTB) at the knee and ankle joint.

<table>
<thead>
<tr>
<th></th>
<th>t18</th>
<th>p-value</th>
<th>Effect Size</th>
<th>At Risk</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPV AP EC</td>
<td>-0.414</td>
<td>0.683</td>
<td>0.17 (-0.66, 0.99)</td>
<td>1.128 ± 0.274</td>
<td>1.182 ± 0.356</td>
</tr>
<tr>
<td>COPV ML EC</td>
<td>-0.073</td>
<td>0.942</td>
<td>0.03 (-0.80, 0.85)</td>
<td>1.300 ± 0.476</td>
<td>1.313 ± 0.406</td>
</tr>
<tr>
<td>TTB min ML EC</td>
<td>0.159</td>
<td>0.875</td>
<td>0.07 (-0.76, 0.89)</td>
<td>2.043 ± 0.920</td>
<td>1.992 ± 0.486</td>
</tr>
<tr>
<td>TTB min AP EC</td>
<td>0.834</td>
<td>0.414</td>
<td>0.35 (-0.49, 1.17)</td>
<td>0.709 ± 0.171</td>
<td>0.632 ± 0.268</td>
</tr>
<tr>
<td>TTB mean min ML EC</td>
<td>1.303</td>
<td>0.207</td>
<td>0.55 (-0.31, 1.37)</td>
<td>9.165 ± 2.571</td>
<td>7.741 ± 2.635</td>
</tr>
<tr>
<td>TTB mean min AP EC</td>
<td>1.526</td>
<td>0.142</td>
<td>0.64 (-0.22, 1.46)</td>
<td>3.759 ± 0.903</td>
<td>3.020 ± 1.416</td>
</tr>
</tbody>
</table>

Peak ATSF and posterior GRF are expressed in N/ Body Weight (N). EC= Eyes Closed. AP= anterior, posterior. ML= medial, lateral.

* Significant differences between the At Risk and the control groups in TTB min SD AP EC (p<0.05).

Mechanical Joint Integrity

**Weight Bearing Lunge Test.** A statistically significant difference in the WBLT was observed between the at-risk and control groups (t(18) = -2.632; p = 0.016) (Table 5). The control group reached farther than the at-risk group during the test. There was a strong effect size with small range 95% CIs (d = 1.11; 95% CIs: 0.19, 1.95).

**Ankle Laxity.** For instrumented ankle laxity measures, there were no statistically significant differences between the at-risk group and control group in total AP displacement and total I-E rotation (p > 0.05) (Table 5). Effect size for total AP laxity was moderate with 95% CIs crossing zero (d = 0.47; 95% CIs: -0.38, 1.29). Effect size for total IE laxity was small (Table 5).
Table 5

*Mean and Standard Deviations for the Weight Bearing Lunge Test and Ankle Laxity Measurements.*

<table>
<thead>
<tr>
<th></th>
<th>t_{18}</th>
<th>p-value</th>
<th>Effect Size</th>
<th>At Risk</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBLT</td>
<td>-2.632</td>
<td>0.016*</td>
<td>1.11 (0.19, 1.95)</td>
<td>7.669 ± 3.30</td>
<td>10.970 ± 2.50</td>
</tr>
<tr>
<td>Laxity total AP</td>
<td>-1.026</td>
<td>0.325</td>
<td>0.47 (-0.38, 1.29)</td>
<td>14.412 ± 4.90</td>
<td>17.974 ± 10.12</td>
</tr>
<tr>
<td>Laxity total IE</td>
<td>-0.662</td>
<td>0.515</td>
<td>0.28 (-0.56, 1.10)</td>
<td>37.339 ± 10.83</td>
<td>40.532 ± 12.26</td>
</tr>
</tbody>
</table>

The WBLT was measured in centimeters (cm). Laxity measurements taken in millimeters (mm) of anterior-posterior (AP) translation and inversion-eversion (IE) translation in degrees.

*Significant differences between the At Risk and the control groups in DF-ROM using the WBLT (p<0.05).

Predictors of SEBT Performance

Anterior Reaching Direction for All Participants. The variance in knee extension strength and WBLT predicted 46.4% of the variance in SEBT-A ($R^2 = 0.464$, $p = 0.002$; Table 6). In combination with knee extension strength and WBLT, the variance in knee flexion strength explained an additional 3.2% of the variance in SEBT-A ($R^2 = 0.496$, $p = 0.004$) and DF strength explained an additional 5.5% of the variance in SEBT-A ($R^2 = 0.551$, $p = 0.004$; Table 6).
Anterior Reaching Direction for At-Risk Participants. The variance in the combination of knee extension strength, mean TTB-ML, and WBLT predicted 75.0% of the variance in SEBT-A for at-risk individuals ($R^2 = 0.750$, $p = 0.004$; Table 7). In combination with these factors, the variance in total AP laxity explained an additional 5.4% ($R^2 = 0.804$, $p = 0.006$) and knee flexion strength explained an additional 1.2% of the variance in SEBT-A for at-risk individuals ($R^2 = 0.816$, $p = 0.016$) (Table 7).

### Table 6

*A Multiple Linear Backward Regression Model Predicting SEBT Anterior Direction as a Predictor for Ankle Sprains in At Risk and Control Groups ($N = 23$).*

<table>
<thead>
<tr>
<th>Variables</th>
<th>$R^2$</th>
<th>$P$</th>
<th>% prediction in variance of SEBT-A in At-Risk and Control Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee strength (flex and ext), WBLT, DF strength</td>
<td>0.551</td>
<td>0.004</td>
<td>DF strength = 5.5%</td>
</tr>
<tr>
<td>WBLT, Knee strength (flex and ext)</td>
<td>0.496</td>
<td>0.004</td>
<td>Knee flex strength = 3.2%</td>
</tr>
<tr>
<td>Knee ext strength, WBLT</td>
<td>0.464</td>
<td>0.002</td>
<td>Knee ext strength, WBLT = 46.4%</td>
</tr>
</tbody>
</table>

COP = Center of Pressure; WBLT = Weight Bearing Lunge Test; AP = Anterior Posterior; EC = eyes closed.
Table 7

*A Multiple Linear Backward Regression Model Predicting SEBT Anterior Direction as a Predictor for Ankle Sprains in At Risk Individuals (N = 13).*

<table>
<thead>
<tr>
<th>Variables</th>
<th>$R^2$</th>
<th>$P$</th>
<th>% prediction in variance of SEBT-A in At-Risk and Control Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee ext strength, TTB mean min ML, WBLT, total AP laxity, knee flex strength</td>
<td>0.816</td>
<td>0.016</td>
<td>Knee flex strength = 1.2%</td>
</tr>
<tr>
<td>Knee ext strength, TTB mean min ML, WBLT, total AP laxity</td>
<td>0.804</td>
<td>0.006</td>
<td>Total AP laxity = 5.4%</td>
</tr>
<tr>
<td>Knee ext strength, TTB mean min ML, WBLT</td>
<td>0.750</td>
<td>0.004</td>
<td>Knee ext strength, TTB mean min ML, WBLT = 75.0%</td>
</tr>
</tbody>
</table>

TTB = Time to Boundary; AP = Anterior Posterior; DF = Dorsiflexion; WBLT = Weight Bearing Lunge Test.
Chapter Five

Discussion

The most important finding of our preliminary study was that participants with shorter anterior reaching distance of the SEBT (at-risk group) had significantly less ankle DF-ROM compared to controls. These findings agree with previous work that suggested that performance on the SEBT-A may be associated with restricted DF-ROM.\textsuperscript{17,78}

Previous work has suggested that the SEBT in the anterior direction might be useful in predicting future lower extremity injuries in physically active young populations.\textsuperscript{15,31,50,56,79-81} The SEBT provides the clinician the ability to assess an individual globally; however, this test does not necessarily indicate what factors may be altered and in need of modification. It is important to determine which factors make the greatest contribution to the SEBT in individuals potentially at risk for lower extremity injury; therefore, clinicians can address the most influential clinical impairments to prevent lower extremity injury after global dysfunctions are identified by the SEBT.

Hoch et al.\textsuperscript{17,75} noted that the WBLT was significantly correlated with the SEBT-A in individuals with and without ankle pathology. In the current study, participants with poor SEBT performance exhibited less weight-bearing DF-ROM compared to controls. Taken together, the SEBT-A may be a good clinical test to assess the effects of the amount of DF-ROM availability on dynamic balance. However, in the study by Hoch et al.\textsuperscript{17}, the WBLT explained 28\% of variance in the SEBT-A, and 72\% of the variance remains unexplained. Other factors such as strength, ankle joint stability, and static postural control also play important roles in the SEBT performance. Therefore, in
addition to the WBLT, we examined strength, ankle joint stability, and static balance to determine what factor(s) makes the greatest contribution to the anterior normalized reach distance of the SEBT. When we performed the regression analysis for all participants in this preliminary study, the combination of the WBLT and knee sagittal plane strength explained approximately 50% of the variance in the SEBT-A. This finding indicates that the sagittal plane knee strength and closed chain ankle DF-ROM may be a clinical indicator of lower extremity function for individuals with shorter anterior reach distance of the SEBT.

To support our findings, Robinson and Gribble\textsuperscript{82} reported that sagittal-plane knee and hip kinematics account for approximately 78% of the variance in the normalized anterior reach distance of the SEBT in healthy individuals. In our preliminary study, knee sagittal-plane strength made the greatest contribution to performance on the SEBT. The sagittal-plane knee and hip kinematics are controlled by the knee flexors and extensors. Strength imbalance about the ankle has been shown to increase the risk for a lateral ankle sprain.\textsuperscript{23,28} de Noronha et al\textsuperscript{25} also concluded that strength deficits in combination with other factors have an increased risk of an ankle sprain. As previous literature described, a knee strengthening program may be a key component in a prevention program to minimize risk for an ankle injury in healthy individuals with poor performance on the SEBT.\textsuperscript{23,25} Knee strength appears to account for part of the ability to reach in the SEBT-A, so by improving this factor, one could potentially expect to see an increase in SEBT-A performance.

When examining the regression model only for participants with poor performance on the SEBT-A, the strongest contributors to the SEBT-A were knee
extension strength, mean TTB-ML, and the WBLT. The combination of these three measures explained 75% of the variance in the anterior normalized reach distance. Decreased performance on the SEBT-A may be associated with alterations in knee strength, static balance, and hypermobility at the ankle joint. While significant differences existed in the WBLT between the at-risk and control groups, in this preliminary study, we observed no differences in knee extension strength and mean TTB-AP between the at-risk and control groups.

In order to complete the SEBT task, numerous options within the involved degrees of freedom are utilized by the sensorimotor system.\textsuperscript{80,83} If one of these motions available cannot be utilized because of a physiological or anatomical deficit such as restricted ankle DF-ROM, then another movement solution may be used.\textsuperscript{80,83} In our study, a deficit in ankle DF-ROM may be due to organismic constrains that can hinder the sensorimotor system in its ability to accomplish movement goals\textsuperscript{80,84}, therefore resulting in a reduction in the SEBT performance. It is possible that the sensorimotor system may rely on other options including knee strength, static balance, and ankle joint laxity during the SEBT because the amount of availability of the weight-bearing DF-ROM was restricted, likely due to the triceps surae tightness\textsuperscript{81,85} or ankle arthrokinematic restriction.\textsuperscript{10,46,86} Hoch et al.\textsuperscript{87} demonstrated that a two-week joint mobilization intervention targeting restricted posterior talar glide improved measures of ankle DF-ROM and dynamic postural control in patients with CAI. Future studies should examine the relationship between increases in ankle DF-ROM and functional performance on the SEBT-A in individuals with poor SEBT performance following stretching or joint mobilization interventions.


**Limitations**

The significant limitation of this study is how we determined the cut-off scores to include participants in the at-risk group. We established the cut-off score for SEBT-A to be 67% based on previous work from our laboratory\(^{14,15}\), reporting adolescent and young adult athletes who scored less than 67% on the SEBT-A are five times more likely to suffer an ankle injury. However these studies recruited high school and college football, basketball, volleyball, and soccer players. The age range for this current study was 18-30 years, so there was a broader range of years of the participants. It is possible that age could have attributed to decreased performance. Our participant population in this study was not specifically athletes, but instead recreationally active individuals.

Another limitation is sample size. Our non-significant findings were associated with low to moderate statistical power (observed power = 0.05-0.45). More participants should be tested in order to obtain the most significant results. A third limitation was that we only examined WBLT, static balance, dynamic balance, laxity, and ankle and knee strength (concentric/concentric). Other various factors such as hip strength, core stability, activity level, and flexibility may also influence SEBT performance.\(^{49,88}\) Future studies should examine other factors that may contribute to SEBT performance.

**Clinical Implication**

Previous work has established the SEBT to be a valid and reliable tool for evaluating dynamic postural control.\(^{12,16,17,57}\) Discovering the modifiable factors that are associated with SEBT performance in healthy individuals may lead to the development of programs aimed at preventing the initial episode of an ankle sprain. We found that the
WBLT and sagittal plane knee strength predicts the variance of normalized anterior reach of the SEBT in healthy individuals. Decreased performance on the SEBT-A in healthy individuals may be indicative of ankle DF-ROM, knee flexor weakness, and/or extensor weakness. Clinicians should consider including knee strengthening in the implementation of a prevention program after altered dynamic postural control is detected on the SEBT-A. The combination of knee extensor strength, static balance, and WBLT made the greatest contribution to decreased performance on the SEBT-A, as well as a deficit in DF-ROM was observed in participants with poor performance on the SEBT-A and is possibly considered a limiting factor for performance on SEBT-A. Increased ROM or potentially a strengthening program more focused on DF and achieving DF-ROM could be warranted. The increase in DF-ROM could include joint mobilizations or stretching of surrounding musculature.

**Conclusion**

We found that healthy individuals scoring less than 67% on the SEBT-A had less DF-ROM than those scoring more than 67%, and the amount of DF-ROM availability strongly explain the variance in the SEBT-A. For individuals at-risk, knee extension strength, WBLT, and static postural control were the leading predictors of the variance in the SEBT-A. When examining the regression model performed for all healthy participants in our studies, the WBLT and knee flexor/extensor strength were the leading predictors of variance in the SEBT-A. Therefore, the sagittal-plane knee strength and weight-bearing DF-ROM may represent appropriate factors to be included for a targeted prevention program if decreased functional performance is identified with the SEBT-A.
References


55. Sefton JM, Yarar C, Hicks-Little CA, Berry JW, Cordova ML. Six Weeks of Balance Training Improves Sensorimotor Function in Individuals With Chronic


Appendix A

Informed Consent

UT IRB # 107888
ICF Version Date: 07/13/2012

Department of Kinesiology
Mailstop #119
Toledo, Ohio 43606
Phone # (419)530-2741
Fax # (419)530-2744

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 Bolsey, ATC, Co-investigator
Sara Carey, ATC, Co-investigator
Elizabeth Ruelstad, ATC, Co-investigator
Masafumi Terada, MS, ATC, Co-investigator
Megan Quinleven 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) to determine which factor (a) 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 a 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 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
- 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 >97% 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 of 15 and 35 years
- Participate in at least 30 minutes of vigorous activity, three or more days per week.
- Have history of any self-reported musculoskeletal and neurovascular injury and disorder in the lower extremity
- Have no history of surgery in the lower extremity
Are free of balance or vestibular dysfunction
- No history of concussion in the previous 6 months
- Have no history of low back pain in the previous 12 months
- Score >97% on the SEBT
- Have a score of > 90% on the FADI and the FADI Sport Subscale.
- Answer no to the question, "Do you have a history of ankle sprain?" on the All

You will be in the control group if you:
- Would like to voluntarily participate in this study
- Between the ages of 15 and 35 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 away) 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 fractures 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 "no" to the question, "Do you have a history of ankle sprain?" on the All.
- Have a score > 90% on the FADI and > 93% 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: 1400A), Joint Injury and Muscle Activation Laboratory (Room: 1402), 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 (All) questionnaire to allow us to better understand your history of the lower extremity injury. Following completion of questionnaire, 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.

UNIVERSITY OF TOLEDO IRB
APPROVAL DATE: 8/7/2014
EXPIRATION DATE: 4/7/2017
This space for IRB Approval Date Stamp
The SEBT will be performed in the anterior, posterior, and posterolateral directions. For the anterior reach, you will stand with your toes on the grid line and reach out with the opposite foot to tap as far as possible along the top measure without raising the test foot. For PM and PL directions, the heel will be at the grid line 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 ankle and knee 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 the knee flexed to 90 degrees. Your torso, thigh, and shank will be stabilized using straps and your hips 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 10 degrees and the ankle will be maximally moved through full range of motion. Five trials will be recorded with a two minute rest between trials.

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 loading 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 dorsiflexion 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 hand to 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 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 0° and the ankle plantarflexed at 90°. 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. Laxity 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 examination 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 time 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 receive 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 it.

**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 addresses 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 Gribble, PhD, ATC (419) 530-2601.
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 Gerible, PhD, ATC (419) 530-2991.

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 419-383-6798.

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 authority or Legal Guardian)  Time: a.m.  p.m.

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

FAAM Form

<table>
<thead>
<tr>
<th>Activity</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>
</tr>
</thead>
<tbody>
<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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<tr>
<td>Personal care</td>
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<tr>
<td>Light to moderate work (standing, walking)</td>
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<tr>
<td>Heavy work (pushpulling, climbing, carrying)</td>
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<tr>
<td>Recreational activities</td>
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</tr>
</tbody>
</table>

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.

__ __ %

Foot and Ankle Ability Measure (FAAM)
Activities of Daily Living Subscale

Please Answer every question with one response that most closely describes your condition within the past week.
If the activity in question is limited by something other than your foot or ankle mark "Not Applicable" (N/A).

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td></td>
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<tr>
<td>Walking on even ground</td>
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<tr>
<td>Walking on even ground without shoes</td>
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<tr>
<td>Walking up hills</td>
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<tr>
<td>Walking down hills</td>
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<tr>
<td>Going up stairs</td>
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<tr>
<td>Going down stairs</td>
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<tr>
<td>Walking on uneven ground</td>
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<tr>
<td>Stepping up and down curbs</td>
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<tr>
<td>Squatting</td>
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<tr>
<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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<tr>
<td>Walking approximately 10 minutes</td>
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<tr>
<td>Walking 15 minutes or greater</td>
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</tbody>
</table>
Appendix C

All Form

Ankle Instability Instrument

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

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? Yes No
   a) If Yes, when was the most recent incident? ____________________
      What injuries have your 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 your 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? 
   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 Recording Forms

**Demographics**

<table>
<thead>
<tr>
<th>Participant #</th>
<th>CCCPROJ_</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>CAI</td>
</tr>
<tr>
<td>Involved Limb:</td>
<td>Right</td>
</tr>
<tr>
<td>Dominant Limb</td>
<td>Right</td>
</tr>
</tbody>
</table>

| Age           |         |
| Height        | Inches: | Centimeters: |
| Weight        | Pounds: | Kilograms:   |
| Physical      | Days/week: | Hours/ day: |
| Activity Level|         |            |

**Order of Testing**

<table>
<thead>
<tr>
<th>Limb Order</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;:</th>
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</thead>
<tbody>
<tr>
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<td>2&lt;sup&gt;nd&lt;/sup&gt;:</td>
</tr>
<tr>
<td>Testing Order</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;:</td>
</tr>
<tr>
<td></td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;:</td>
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<tr>
<td></td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;:</td>
</tr>
<tr>
<td></td>
<td>4&lt;sup&gt;th&lt;/sup&gt;:</td>
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</tr>
<tr>
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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>Ant.(Max)</th>
<th>Post.(Min)</th>
<th>Total</th>
<th>Inv.(Min)</th>
<th>Ev.(Max)</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Right</td>
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<tr>
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<td>Avg.</td>
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## Weight-Bearing Lunge Test Form

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<td>Trial</td>
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<td>cm</td>
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<tr>
<td>Note</td>
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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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<th>Right</th>
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<tbody>
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<td><strong>Extension</strong></td>
<td><strong>Flexion</strong></td>
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<tr>
<td><strong>Avg.</strong></td>
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<tr>
<td><strong>STDV</strong></td>
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## Ankle Strength Test Form

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<th>Dorsiflexion</th>
<th>Plantar flexion</th>
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<table>
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<tbody>
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## Star Excursion Balance Test Form

<table>
<thead>
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<th>Leg Length: Right= _______ cm</th>
<th>Left= _______ cm</th>
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### Right

<table>
<thead>
<tr>
<th>Trial</th>
<th>Anterior</th>
<th>PM</th>
<th>PL</th>
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</table>

**Avg.**

**Normalized**

**# of failed trials**

### Left

<table>
<thead>
<tr>
<th>Trial</th>
<th>Anterior</th>
<th>PM</th>
<th>PL</th>
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</thead>
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**Avg.**

**Normalized**

**# of failed trials**