A comparison of strength, ROM, laxity, and static and dynamic postural control between ankle copers and patients with chronic ankle instability

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A Thesis
titled
A Comparison of Strength, ROM, Laxity, and Static and Dynamic Postural Control
Between Ankle Copers and Patients With Chronic Ankle Instability
by
Heather A. Boley, ATC
Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Exercise Science

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May 2013
Objective: The purpose of this study was to examine differences between ankle sprain copers and those with CAI in selected measures that are known to differentiate CAI and healthy individuals. Increased ankle laxity and diminished strength, ankle range of motion (ROM), and static and dynamic postural control have consistently characterized persons with CAI. The second purpose of this study was to determine which measures best predict SEBT performance in copers, and to determine if these measures differed from those that predict SEBT performance in those with CAI. Design: Case-control study with single blinding of the investigator. Participants: Forty-two participants between 18 and 30 years of age were recruited from the University of Toledo community. These participants were placed into either the CAI or coper group based on specific inclusion criteria. Methods: Participants completed the FAAM, FAAM-sport, AII, and a health history questionnaire before entering the lab for testing. The single, randomized testing session included ankle laxity testing, ankle and knee strength measurements, performance of static balance, the weight-bearing lunge test to estimate dorsiflexion ROM, and the SEBT as a measure of dynamic postural control. Main Outcome Measures: Ankle laxity was reported for the A-P direction (mm) and the I-E directions (°). Strength was reported
as average peak torque, normalized to the participant’s body mass (N·m⁻¹·kg⁻¹). COPV was reported for the A/P and M/L directions, and TTB measures were reported in seconds (s). The maximum distance achieved during the WBLT was reported in centimeters (cm). Three trials of reach direction of the SEBT (cm), as well as a composite score, were reported as a percentage of limb length (cm) of the participant (%MAXD).

**Statistical Analysis:** Group means and standard deviations of the SEBT trials, laxity measurements, COPV measures, and strength assessments were used for analysis, while the maximum value from the WBLT was used. The mean of the three static balance trials with eyes closed was calculated for each TTB measure. Individual t-tests were performed for each of the dependent variables in order to detect differences between the CAI and ankle coper groups. Effect sizes (Cohen’s $d$) with 95% confidence intervals were calculated. Two separate linear backward regression analyses were performed in order to determine which measures predict SEBT performance in copers and CAI participants. Significance was set a priori at $P<.05$. **Results:** Significant group differences were observed only for the number of failed trials during static balance in the eyes closed condition ($p=.037$). The CAI group had more failed trials than the coper group (CAI=4.88±4.11; coper=2.41±3.29). Moderate effect sizes were identified for all SEBT measures, COPV M/L with eyes closed, TTB A/P and M/L S.D. of the minima, and ankle dorsiflexion strength. The WBLT was able to significantly predict 34% of the variance in both the CAI and coper groups’ performance on the anterior reach of the SEBT. Plantar flexion strength and WBLT best predicted the CAI group’s performance on the PM and PL reaches, as well as the composite score. Knee flexion strength best predicted coper’s performance on the PM reach and the composite score. Static balance measures best
predicted the coper group’s performance on the PL reach. **Conclusion:** Participants with CAI demonstrated decreased dynamic and static postural control compared to copers. These outcome measures appear to differentiate CAI patients and copers. Furthermore, we observed that copers exhibited increased variability compared to the CAI group when performing the SEBT. Future research should identify the mechanism by which copers are able to retain these higher levels of postural control and variability compared to patients with CAI.
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List of Abbreviations

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

A/P ....................Anterior/Posterior

CAI ......................Chronic Ankle Instability
CI ........................Confidence Interval
COPV ........................Center of Pressure Velocity

DROM ..................Dorsiflexion Range of Motion

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

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

Inv/Ev .....................Inversion/Eversion

PF ........................Plantar Flexion
PL ..........................Posterolateral
PM ..........................Posteromedial

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

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

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

Introduction

Lower extremity injuries are common among athletes and the physically active population, with ankle ligament sprains representing the most prevalent diagnosis.\(^1,2,3\) Lateral ankle sprains often result in pain, disability, and days missed from work or athletics. Those who sprain their ankle are at an increased risk for re-injury, with reported recurrence rates over 70%.\(^4\) Repetitive bouts of lateral ankle instability resulting in numerous ankle sprains are typically associated with chronic ankle instability (CAI).\(^5\) Devised by Hertel in 2006, the original model of CAI describes two categories of contributing factors, mechanical instability (MAI) and functional instability (FAI), which in some combination lead to recurrent ankle sprain.\(^5\)

Mechanical ankle instability occurs when an initial ankle sprain results in anatomic changes to the ankle complex. These changes include pathologic laxity, impaired arthrokinematics, synovial changes, and degenerative joint disease, which may be predispositions to further injury.\(^5\) Functional ankle instability may be associated with the sensation of the ankle “giving way”. It has been suggested that damage to the lateral ligaments of the ankle concomitantly results in damage to the mechanoreceptors and
nerve fibers, leading to permanent defects, including neuromuscular, postural control, and proprioception impairments.\(^6\)

Chronic ankle instability has consistently been characterized by diminished strength\(^7\), range of motion\(^8\) (ROM), static postural control\(^9,10\), and star excursion balance test (SEBT) performance\(^11,12,13\), as well as increased laxity about the ankle\(^14\). Gribble and Robinson\(^7\) reported reductions in ankle plantar flexion, knee flexion, and knee extension torque production in individuals with CAI compared with non-injured participants. Furthermore, a meta-analysis by Arnold et al\(^9\) concluded that FAI demonstrated impaired static and dynamic balance. The star excursion balance test (SEBT) has been deemed a reliable clinical test to assess dynamic balance\(^15,16\), that consistently is able to differentiate diminished reach distances representing dynamic postural control between pathological and healthy subjects\(^11,12,13\). This test requires the subject to maintain a stable base of support on one leg, while reaching in 8 directions with the opposite leg. It has been suggested that the SEBT is a global functional assessment of strength, balance, range of motion, and neuromuscular control, but which of these factors most influences performance has not been specifically identified.

Hoch et al\(^17\) found that the anterior reach direction is significantly related to the weight-bearing lunge test (WBLT), a closed-chain assessment of ankle dorsiflexion. It can be inferred that those with CAI may have decreased reach distance in part, due to restricted dorsiflexion ROM. Decreased dorsiflexion ROM has also been detected during functional activities, such as jogging, in those with CAI.\(^8\) Participants with CAI have significantly more anterior displacement and inversion rotation in their pathological ankle as compared to their uninjured ankle and those in a healthy population.\(^14\)
Expanding on Hertel’s original model, Hiller et al proposes that there are 7 subgroups of CAI. Mechanical ankle instability, FAI, and recurrent sprain are still included, with the addition of groups presenting with different combinations of these pathologies. While 4 of these subgroups experience recurrent sprain, the remaining 3 do not, demonstrating that it is possible to have MAI and FAI without experiencing recurrent sprain.

Individuals with a history of an initial sprain, but no subsequent recurrent injury or complaints of instability, have been termed ankle sprain “copers”. It may be useful to compare CAI sufferers to copers, instead of individuals who have never sprained their ankle, as this comparison may highlight the alterations that develop after initial sprain, possibly elucidating why some develop CAI, while others do not. However, few studies to date have used copers as a comparison group. Brown et al compared the movement variability and motion patterns of those with FAI, MAI, copers, and healthy controls. Copers were reported to demonstrate less ankle frontal plane displacement than MAI and FAI during walking, altered hip kinematics compared to MAI in a stop-jump task, and less variability than healthy controls for knee rotation and flexion during a single-leg jump landing. In a study by Wikstrom et al, self-assessed disability questionnaires showed greater disability in CAI than copers and uninjured controls, while copers and controls did not differ in self-assessed disability. A series of hop tests failed to reveal significant differences in functional performance between groups, however, a larger percentage of individuals with CAI perceived ankle instability on their involved limb during hop testing, compared to copers and uninjured controls. Lastly, in another study by Wikstrom et al, three postural control measures were found that could successfully
detect differences between copers and those with CAI. However, besides these results, there are many characteristics of copers that still remain unknown.

1.1 Statement of the Problem

Many characteristics of ankle copers still remain unclear. While static balance has been briefly addressed, potential limitations in dynamic postural control, ankle and knee strength, ankle laxity, and dorsiflexion ROM have not been addressed in the coper group. It is important to define the characteristics of copers in order to compare them to individuals with CAI, which may help to describe the development of CAI.

1.2 Statement of the Purpose

Because ankle copers have yet to be fully defined by clinical and laboratory measures, the purpose of this study was to define ankle sprain copers through selected measures known to differentiate CAI and healthy individuals (ankle and knee strength, ankle ROM, ankle laxity, and dynamic postural control) but have not yet been compared using an ankle sprain coper group. The second purpose of this study is to determine which measures, alone or in combination, best predict SEBT performance in copers, and to determine if these measures differ from those that predict SEBT performance in those with CAI.

1.3 Research Hypotheses:

1. The CAI group will exhibit significantly increased laxity compared with the ankle coper group.

2. The CAI group will exhibit significantly decreased ankle and knee torque compared with the ankle coper group.
3. The CAI group will exhibit significantly decreased dorsiflexion ROM compared with the ankle coper group.

4. The CAI group will exhibit significantly decreased static postural control compared with the ankle coper group.

5. The CAI group will exhibit significantly decreased normalized SEBT reach distances compared with the ankle coper group.

6. Variances in knee extension and ankle plantar flexion strength, and ankle laxity will explain a significant amount of variance in SEBT performance in the CAI group.

7. Variances in ankle dorsiflexion and static postural control will explain a significant amount of variance in SEBT performance in the coper group.

1.4 Potential Limitations:

This study is retrospective in nature, as the participants have already sustained ankle sprains and developed CAI or coping mechanisms. We are also relying on participant’s self-reported symptoms and previous history of ankle injury.

1.5 Significance:

Ankle sprain copers are a fairly new comparison group in ankle research and this study will be an important step towards defining this population. The results may shed light as to where we need to focus rehabilitation to keep individuals with a previous ankle sprain episode from experiencing recurrent sprains and developing CAI. These results will be an important contribution to the creation of a model of ankle copers that can be used to create prevention and intervention strategies for patients with ankle pathology as the outcomes that we will be assessing all represent clinically modifiable factors.
Understanding the measurable differences and similarities between copers and CAI patients will be critical in developing prevention and rehabilitation programs for ankle sprains. The rationale for this study is that by determining measures that are likely to represent deficiency in those with CAI, but not in copers, we hope to guide future research devoted to the prevention and rehabilitation of ankle pathology, including interruption of recurrent ankle sprain. Our results may be the foundation for development of randomized control trials focused on interventions to convert CAI sufferers into copers, with the long-term goal in reducing recurrent sprain and degenerative changes.

1.6 Operational Definitions:

Chronic Ankle Instability (CAI): a condition that develops after an ankle sprain, characterized by repetitive bouts of lateral ankle instability resulting in numerous subsequent ankle sprains.

Mechanical Ankle Instability (MAI): a contributing factor of CAI, where initial ankle sprain results in anatomic changes to the ankle complex.

Functional Ankle Instability (FAI): a contributing factor of CAI associated with neuromuscular impairments; the sensation of the ankle “giving way”

Star Excursion Balance Test (SEBT): a functional balance test used to assess dynamic postural control by utilizing a single leg stance and a maximal reach along each of the “points” on a “star” taped to the ground.

Weight-bearing Lunge Test (WBLT): a test used to estimate maximal weight-bearing dorsiflexion range of motion.
Chapter 2

Literature Review

2.1 Lateral Ankle Sprain

Ankle sprains are among the most common injuries sustained during physical activity.\(^3\) A study of U.S. Marine Corps recruits revealed that 82\% of the injuries during boot camp training were to the lower extremity, with the most common diagnosis being an ankle sprain.\(^1\) An epidemiology study of high school basketball injuries reported that the ankle/foot was most commonly injured (39.7\%) and the most frequent injury diagnoses were ligament sprains (44\%).\(^2\) Collegiate athletes also suffer injuries to the lower extremity at a rate over 50\% of all injuries, with ankle ligament sprains being the most common injury in 15 different sports.\(^3\) Most lateral ankle sprains are a result of an inversion force resulting in injury to the lateral ligament complex, which includes the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the posterior talofibular ligament (PTFL). The most common predisposing factor to suffering a lateral ankle sprain is the history of at least one previous ankle sprain.\(^25-27\) Recurrence rates of over 70\% have been reported, and up to 59\% of individuals with recurrent sprain have significant disability which leads to impairment of their athletic performance.\(^4\)
Individuals who suffer from residual symptoms after an initial ankle sprain, such as giving way and instability, are described as having chronic ankle instability (CAI).

2.2 Chronic Ankle Instability (CAI)

Individuals with CAI often complain of repetitive bouts of lateral ankle instability or of the ankle “give out” resulting in numerous recurrent sprains and overall decreased function. CAI has also been associated with decreased range of motion, strength, and postural control, as well as increased laxity. There are two categories of factors recognized in contributing to CAI: mechanical ankle instability (MAI) and functional ankle instability (FAI), which in some combination lead to recurrent sprain.

2.2.1 Mechanical Ankle Instability (MAI). MAI has been associated with anatomic abnormalities of the ankle that occur after initial ankle sprain. In Hertel’s original model of CAI, mechanical insufficiencies were described as pathologic laxity, arthrokinematic restrictions, degenerative changes, and synovial changes, which may occur alone, or in combination. Some of the abnormalities observed include alterations of the osteochondral cartilage, a more anterior position of the talus in relation to the tibia, a more posterior position of the lateral malleolus, and ligament laxity.

2.2.2 Functional Ankle Instability (FAI). FAI has been associated with changes to the neuromuscular system that provides dynamic support to the ankle following injury to the lateral ligaments. First describing functional instability, Freeman et al attributed impaired balance in those with lateral ankle sprains to damaged articular mechanoreceptors, resulting in proprioceptive deficits. More recently, Hertel described functional insufficiencies as impaired proprioception, impaired neuromuscular control, strength deficits, and impaired postural control.
2.3 Star Excursion Balance Test (SEBT) & CAI

The SEBT has been shown to be a highly reliable and valid instrument for assessing dynamic postural control. The test requires the participant to maintain a base of support with one leg, while reaching maximally in one of eight directions with the opposite leg. Larger reach distance translates into better dynamic postural control. Hertel et al\textsuperscript{15} and Kinzey and Armstrong\textsuperscript{16} have demonstrated strong intra-rater reliability of measurements with the SEBT. It is also sensitive in screening for functional deficits related to musculoskeletal injury and pathology, such as CAI.\textsuperscript{11,12} Olmsted et al\textsuperscript{11} reported decreased reaching distances on the SEBT in those with CAI compared to matched, healthy controls. Although there are eight directions of the SEBT, Hertel et al\textsuperscript{31} has recommended using only the anterior, posterior medial (PM), and posterior lateral (PL) reach directions when screening for CAI. Decreasing from eight to three reach distances simplifies the test and avoids capturing redundant information.\textsuperscript{31}

When using the SEBT for experimental or clinical purposes, it is suggested that participants’ excursion distances be normalized to leg length to allow for a more accurate comparison of performance among participants.\textsuperscript{32} Gribble et al\textsuperscript{32} found that leg length has the highest correlation with excursion distance when compared to other factors such as height, hip ROM, and ankle ROM. Additionally, it was originally proposed that six practice trials were necessary to remove the learning effect on the SEBT.\textsuperscript{15} However, more recently Robinson et al\textsuperscript{33} found that maximum reach distance was achieved within the first four reaches of the SEBT in healthy participants, shifting the accepted number of practice trials from six to four.\textsuperscript{33}

2.4 Strength & CAI
Gribble et al\textsuperscript{7} examined the torque production of ankle, knee, and hip flexion and extension range of motion in individuals with CAI. Fifteen participants with CAI and fifteen healthy participants performed 5 maximum-effort repetitions with a concentric/concentric protocol at 60°·s\textsuperscript{-1} for both extremities using an isokinetic device. The CAI group demonstrated significantly less average peak torque (APT) production for knee flexion and extension, and ankle plantar flexion in their injured limb compared to the healthy controls. No significant differences existed between groups for ankle dorsiflexion or hip flexion/extension APT production.\textsuperscript{7} These results suggest that CAI not only affects the ankle, but proximal joints as well, such as the knee.

2.5 Dorsiflexion Range of Motion (DROM) & CAI

Dorsiflexion deficits have been identified in those with CAI.\textsuperscript{8} Decreased dorsiflexion has been detected in persons with CAI during functional activities, such as jogging, as well as range of motion testing.\textsuperscript{8,17} Hoch et al\textsuperscript{17} used the weight-bearing lunge test (WBLT), which has been gaining notoriety, in order to assess closed-chain ankle DROM. Within the healthy population, performance on the anterior reach direction of the SEBT and the WBLT have been significantly correlated, suggesting that the SEBT may be a good clinical test to assess dorsiflexion ROM restrictions on dynamic balance.\textsuperscript{17} It can be inferred that those with CAI may have decreased reach distance, in part, due to restricted DROM.

2.6 Static Balance & CAI

2.6.1 Center of Pressure (COP). Instrumented postural control assessments include evaluating COP through the measures of mean COP velocity, standard deviation of COP, and range of COP in both the anterior/posterior (A/P) and medial/lateral (M/L)
directions. In a comparison of subjects with and without unilateral CAI during a single leg stance task, it was found that the CAI group had significantly lower scores for A/P COP velocity than controls, indicating impaired postural control.\textsuperscript{34} No other COP measures were different between groups.\textsuperscript{34} Another study comparing static balance of those with and without CAI reported significantly more displacement in both the M/L and A/P directions, as well as increased velocity in the CAI group.\textsuperscript{35} There are conflicting results in the literature pertaining to static postural control deficits associated with CAI, especially with traditional COP measures.\textsuperscript{36} More sophisticated measures of postural control, such as time to boundary (TTB) of COP excursions, may be able to detect differences more clearly.

\textbf{2.6.2 Time to Boundary (TTB).} TTB is a spatiotemporal analysis, providing a theoretical estimate of the time an individual has to make postural corrections while maintaining an upright stance within their boundaries of support.\textsuperscript{34,37-39} These measures estimate the time required for the COP to reach the boundary of the base of support if it were to continue on its instantaneous trajectory and velocity.\textsuperscript{37} Common variables within TTB measures are the absolute minimum, mean of minimum samples, and standard deviation (SD) of minimum samples in the ML and AP directions.\textsuperscript{34,37,39} To calculate TTB measures, the foot is modeled as a rectangle to allow for separation of the anterior-posterior (AP) and mediolateral (ML) components of COP.\textsuperscript{40,41} For each ML COP data point, the instantaneous ML COP position and velocity are used to calculate TTB\textsubscript{ML}. TTB\textsubscript{AP} is calculated similarly, using the AP COP data.

The intrasession reliability of TTB measures have been found to be comparable to traditional COP based measures.\textsuperscript{37} However, correlation analysis between TTB and
COP measures of healthy participants revealed a weak relationship, indicating that TTB measures capture different aspects of postural control than traditional COP measures.\textsuperscript{37} A lower TTB measure indicates worse postural control, or that the COP moves faster to the boundary of the base of support and back.\textsuperscript{42} Hertel et al\textsuperscript{34} reported that those with CAI had significantly lower scores for five of the six TTB measures, and only one of eight traditional COP measures (A/P COP velocity) when compared to a control group. TTB measures appear to detect postural control deficits related to CAI that traditional COP measures do not, indicating the benefit of using TTB within the CAI population.\textsuperscript{34}

\textbf{2.7 Laxity}

Mechanical instability is often evaluated through laxity assessments about the ankle in those with CAI. Hubbard\textsuperscript{14} used an instrumented ankle arthrometer to assess ankle joint motion for anterior/posterior displacement and inversion/eversion rotation between those with and without CAI. There was significantly more anterior displacement and inversion rotation for the ankles with CAI.

Following an acute ankle sprain, increased laxity of the ankle has been reported.\textsuperscript{43} In order to establish the improvement in mechanical laxity after an acute ankle sprain, researchers examined the ankles of individuals who recently sustained an acute ankle sprain and healthy participants using an ankle arthrometer. Participants with an ankle sprain were assessed 3 days after injury and again 8 weeks later, while healthy participants were assessed first at their convenience, and then again 8 weeks later. There was significantly more anterior displacement and inversion rotation of the ankle-subtalar joint complex at day 3 and at week 8 in the injured group compared with the healthy group.\textsuperscript{43} These results suggest that healing of the ligaments and recovery of laxity takes
longer than 8 weeks. However it may be possible that these ligamentous changes are permanent in some individuals, affecting them long after initial injury.

2.8 Ankle Sprain Copers

Those with a history of initial, or single ankle sprain, but no functional limitations have been identified as copers. This fairly new group may offer a more relevant clinical comparison to those with CAI, possibly highlighting the differences that develop following initial sprain. To date, only a handful of studies have included a coper group. Inclusion criteria in a coper group includes having only 1 moderate-severe ankle sprain, demonstrating no ankle laxity, and no recurrent episodes of giving way. Copers consistently report increased function compared to persons with CAI on self-reported measures such as the Cumberland Ankle Instability Tool (CAIT), Foot and Ankle Disability Index (FADI), and Foot and Ankle Disability Index-Sport (FADI-S).

Brown et al has examined differences between copers and other groups including FAI, MAI, and controls. One study compared movement variability during a single leg jump landing between all four groups. Too little variability may hinder the ability of an individual to include a variety of degrees of freedom into an effective movement solution, indicating an inability to adapt to changing situations, while too much variability of movement has been linked to musculoskeletal injury. No significant differences were found at the ankle or trunk. However, copers and those with FAI were significantly less variable for knee rotation during pre-initial contact compared to the controls. Additionally, copers were less variable in knee flexion during an anterior jump compared to the control group. Lastly, the MAI, FAI, and the coper groups had less
variability in hip flexion than controls during pre-initial contact. It has been speculated
that the decrease in variability at the hip and knee may be an attempt to avoid ankle
injury. If so, the coper group was successful, and the instability groups were not, as they
reported decreased function compared to the coper group and more than 2 episodes of
giving way in the past 12 months.

Brown et al has assessed movement variability using a stop-jump task as well to
determine if individuals with MAI or FAI exhibit greater movement variability compared
to a group of copers. Those with FAI demonstrated a greater coefficient of variation (CV)
for ankle inversion/eversion than the MAI group and copers. The MAI group
demonstrated greater CV for anterior-posterior GRF than the FAI group. Increased
movement variability may play a role in the repeated bouts of instability in those with
CAI.

In a study comparing movement patterns, Brown et al reported that those with
MAI displayed less ankle sagittal plane angular displacement than those with FAI and
copers during a drop jump and step down task. Individuals with MAI also exhibited less
plantar flexion at initial contact and at maximum than copers, and greater maximum
eversion than those with FAI and copers in the drop jump. Greater ankle frontal plane
displacement was seen in the MAI group when compared to copers during walking and a
step down task, and both copers and the FAI group in the stop jump task. The FAI group
demonstrated greater ankle frontal plane displacement than the coper group. They believe
that the lack of difference in movement patterns between those with FAI and copers,
despite differences in reported function, may indicate that joint kinematics alone are not
responsible for the repeated episodes of instability in the FAI group. It can also be
inferred that joint kinematics do not alone make up the potential mechanism to avoid injury in the coper group.

Brown et al\textsuperscript{22} also compared hip kinematics and ground reaction forces (GRF) during a stop-jump task between groups of MAI, FAI, and copers. The MAI group displayed greater hip flexion at initial contact, hip flexion maximum, and hip external rotation maximum than the coper group, and greater hip flexion displacement during stance than both the coper and FAI groups. No group differences were found in hip abduction or GRF variables.

Wikstrom et al\textsuperscript{23,24,44} has also used a coper comparison group in addition to a healthy comparison group when examining postural control, functional performance, and self-assessed disability scores in CAI. The researchers found that those with CAI had greater self-assessed disability according to the FADI, FADI-S, and a questionnaire of ankle function,\textsuperscript{23,44} whereas copers and uninjured controls did not differ in self-assessed disability\textsuperscript{23}. Perceptual outcomes such as these have demonstrated diagnostic accuracy in discriminating between copers and people with CAI.\textsuperscript{44} Four hop tests were also completed to assess functional performance, but produced no significant differences between groups. This suggests that the hop tests used (figure-8 hop, side-to-side hop, triple-crossover hop for distance, and single-leg hop for distance) may not be sensitive enough to detect functional differences between those with CAI and copers, and therefore do not appear to be appropriate screening tools for this group. Center of pressure (COP), time-to-boundary (TTB), and center of pressure-center of mass (COP-COM) moment arm measures were used to assess postural control among controls, copers, and subjects with CAI.\textsuperscript{24} Subjects stood on a force plate, in single-leg stance with eyes open for two,
30 second trials. The results indicated that mediolateral and anteroposterior COP velocity was greater in the CAI group compared to copers and controls. The peak COP-COM moment arm in the anteroposterior direction and the resultant mean COP-COM moment arm were also increased in those with CAI relative to copers. The primary finding of this study was that the three postural control measures of COP ML velocity, COP AP velocity, and COP-COM resultant mean moment arm, can successfully detect differences between copers and individuals with CAI. These particular measures may represent part of an unidentified mechanism that allows copers to function as if uninjured.

2.9 Conclusion

CAI has been studied extensively, yet the pathology still isn’t fully understood. Participants with CAI are often compared to a group of healthy individuals, who have never had an ankle sprain, but a group of copers may be a more relevant comparison. Though recent studies have begun to examine ankle sprain copers, many characteristics of this group still remain unclear. Static balance has been briefly addressed, but the outcomes of dynamic postural control, ankle and knee strength, ankle laxity, and dorsiflexion ROM are still unknown in the coper group. Because these outcomes, which are known to differentiate CAI and healthy individuals, have yet to be assessed using an ankle coper group, we aim to define ankle sprain copers through these selected measures (ankle and knee strength, ankle ROM, ankle laxity, and dynamic postural control). We also aim to determine which of these measures best predict SEBT performance in copers, and to determine if these measures differ from those that predict SEBT performance in participants with CAI. It is important to define the characteristics of copers in order to
compare them to individuals with CAI, which may help to elucidate how the pathology of CAI develops after initial injury.
Chapter 3

Methods

3.1 Research Design

A controlled laboratory study design with single blinding of the investigator was used to compare measures of ankle and knee strength, ankle ROM, ankle laxity, and static and dynamic postural control measures between groups of CAI participants and ankle sprain coper participants. Testing procedures were performed for all participants, using a single-session experimental design.

3.2 Participants

A total of 42 participants between the ages of 18 and 30 were recruited from the University of Toledo community and volunteered to participate in the study. Exclusion criteria for all participants included a significant ankle sprain within the past 3 months with associated signs of acute injury or inflammation, a history of lower back or lower extremity musculoskeletal and neurovascular injuries within the past 12 months, a history of lower extremity surgery, and any diagnosed balance or vestibular disorders. All participants signed an informed consent form approved by the Institutional Review Board.

Participants were allocated into two groups based on specific inclusion criteria.
Both groups had a history of at least one significant acute lateral ankle sprain that caused more than one day of disrupted activity, pain, and swelling. Individuals in the CAI group (n=18) self-reported more than 2 episodes of the ankle giving way in the past 3 months. The second group, ankle copers (n=24), self-reported the same initial history of an acute ankle sprain, but without self-reported recurrent injury or bouts of instability.

All participants were asked to complete a health history questionnaire, as well as the Foot and Ankle Ability Measure (FAAM) and Foot and Ankle Ability Measure Sports Scale (FAAM Sport), and the Ankle Instability Instrument (AII), which assesses self-reported ankle impairments and was used to confirm group designation. It has been suggested that CAI may be defined in part by a score of <90% on the FAAM and <80% on the FAAM Sport along with answering yes to at least three questions on the AII. There is not a precedent for these scores among copers. We used scores of >90% on the FAAM, >80% on the FAAM Sport, and <3 yes answers on the AII.

Based on previously published data investigating similar outcome measures of ankle and knee strength, SEBT performance, and the weight-bearing lunge test, 15 participants were needed in the CAI group. A previously published paper comparing ankle copers, CAI and a healthy group on measures of static postural control utilized 16 participants per group; therefore, we anticipated needing at least 16 participants per group in our proposed study which used a similar study design. Therefore, we estimated that 16 participants were needed per group, for a total of 32 participants.
Table 3.1. Demographic Information and Foot and Ankle Ability Measure (FAAM), FAAM Sports Scale (FAAM Sport), and Ankle Instability Instrument (AII) Scores for Chronic Ankle Instability (CAI) and Coper Groups (Mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Coper</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>18 (10 male, 8 female)</td>
<td>24 (10 male, 14 female)</td>
<td>-</td>
</tr>
<tr>
<td>Age (year)</td>
<td>20.16 ± 2.09</td>
<td>21.04 ± 3.34</td>
<td>.335</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.45 ± 9.40</td>
<td>169.07 ± 9.05</td>
<td>.410</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>75.66 ± 14.71</td>
<td>70.99 ± 15.23</td>
<td>.324</td>
</tr>
<tr>
<td>FAAM (%)</td>
<td>89.08 ± 6.54</td>
<td>98.80 ± 1.87</td>
<td>.000*</td>
</tr>
<tr>
<td>FAAM Sport (%)</td>
<td>77.76 ± 10.50</td>
<td>95.05 ± 6.45</td>
<td>.000*</td>
</tr>
<tr>
<td>AII</td>
<td>5.61 ± 0.97</td>
<td>2.45 ± 1.02</td>
<td>.000*</td>
</tr>
</tbody>
</table>

3.3 Instrumentation

Three 4-foot long tape measures were secured to the floor with clear packing tape to serve as the lines indicating the 3 reach directions of the SEBT used for this study. A fourth tape measure was secured to the floor with clear packing tape, perpendicular to a wall for the weight-bearing lunge test measurements. A Biodex System 3 dynamometer (Biodex Medical Systems Inc, Shirley, NY) was used to assess isokinetic strength of the test ankle and knee at 60°·s⁻¹ in the sagittal plane. To assess static balance, data was collected at 50hz, using a force plate (Bertec NC-4060, Bertec, Corp; Columbus, OH). Laxity about the ankle was assessed using a portable ankle arthrometer (Blue Bay Medical Inc, Navarre, FL).

3.4 Variables

Independent Variables

1) Group
   a. CAI
   b. Copers

Dependent Variables

1) Ankle Laxity
a. Total Anterior-Posterior displacement (mm)
b. Total Inversion-Eversion angular displacement (°)

2) Static Balance
   a. TTBML absolute minimum eyes closed (s)
   b. TTBAP absolute minimum eyes closed (s)
   c. TTB ML mean of minimum samples eyes closed (s)
   d. TTBAP mean of minimum samples eyes closed (s)
   e. TTBML standard deviation of minimum samples eyes closed (s)
   f. TTBAP standard deviation of minimum samples eyes closed (s)
   g. Average COPV A/P (cm/s) eyes open
   h. Average COPV M/L (cm/s) eyes open
   i. Average COPV A/P (cm/s) eyes closed
   j. Average COPV M/L (cm/s) eyes closed

3) Isokinetic Strength
   a. Ankle dorsiflexion average peak torque (N·m-1·kg-1)
   b. Ankle plantar flexion average peak torque (N·m-1·kg-1)
   c. Knee flexion average peak torque (N·m-1·kg-1)
   d. Knee extension average peak torque (N·m-1·kg-1)

4) Weight-Bearing Lunge Test
   a. Estimated maximal dorsiflexion ROM (cm)

5) Star Excursion Balance Test
   a. Anterior reach distance (% MAXD)
   b. Posterolateral reach distance (% MAXD)
c. Posteromedial reach distance (% MAXD)

d. Composite score (% MAXD)

3.5 Procedures

After a potential participant indicated interest in volunteering for the study, the Primary Investigator interviewed the participant and administered the injury history questionnaire and the FAAM, FAAM Sport and AII instruments to determine group inclusion, as well as test limb selection. This enabled the research assistant to be blinded to group inclusion during the testing session. If a member of the CAI or coper group reported a history of bilateral ankle instability, the limb with the lowest FAAM and FAAM Sport and highest AII scores were used for testing from the CAI participants; and the limb with the highest FAAM and FAAM Sport scores were used for testing from the coper group participants.

Upon arrival to the laboratory, all participants were provided a standardized explanation of the study via a brief document. Before testing of outcome measures, the participant’s height and mass were recorded, and leg length of the selected testing limb will be measured with the participant lying supine. The distance from the anterior superior iliac crest to the inferior portion of the lateral malleolus was recorded in centimeters (cm) in order to normalize SEBT performance of all participants. Assessments of outcome measures were performed in a randomized order after leg length measurement. Participants were barefoot during testing for all outcomes.

3.5.1 Dynamic Postural Control. The SEBT was performed to assess dynamic postural control. In order to avoid capturing redundant information, participants performed only the anterior, posterolateral (PL), and posteromedial (PM) reaches of the
SEBT on the test limb. Participants were instructed to perform maximal reaches with the uninvolved limb while standing on the test limb, lightly touching their toe to the tape measure before returning to their beginning double-leg stance, without compromising their base of support. Participants were instructed to keep their hands on their hips and to keep the heel of the stance leg in contact with the ground during each trial. For anterior reach performance, the toes of the stance leg were placed at the 0 position of the grid line; and for the PM and PL reach performances, the heel of the stance limb were placed at the 0 position of those grid lines. Participants performed 4 practice trials in each reach direction. After a short rest period, three test reaches were performed. The order of reaching directions was randomized. Failed trials were recorded any time the participant lost balance, could not return to the beginning stance under control, made a heavy touch, or came to rest on the tape measure.

Figure 3-1: Performance of the SEBT in the anterior direction
Figure 3-2: Performance of the SEBT in the posteromedial direction

Figure 3-3: Performance of the SEBT in the posterolateral direction
3.5.2 Ankle Dorsiflexion. To estimate maximal dorsiflexion in a weight-bearing position, participants performed the weight-bearing lunge test (WBLT).\(^7\) The test limb was positioned over a tape measure perpendicular to the wall and secured to the floor with clear packing tape in order to measure the distance from the great toe to the wall (cm). With the opposite limb positioned behind the test limb on the floor, and hands on the wall, the participant flexed the knee of the test limb, attempting to touch the knee to the wall, while also keeping the heel flat. The test limb foot was moved away from the wall, and the movement repeated, until the participant could no longer keep the heel flat while touching the wall with the knee. Three practice trials were allowed, then the participant completed trials until no more distance could be obtained for 3 consecutive attempts.

![Figure 3-4: Performance of the WBLT](image)

3.5.3 Ankle and Knee Strength. Isokinetic strength of the test ankle (dorsiflexion, plantar flexion) and knee (flexion, extension) were assessed at 60°·s\(^{-1}\) in the sagittal plane using a concentric/concentric protocol on the Biodex.\(^7\) Participants were positioned in the isokinetic dynamometer with the test knee in 90 degrees of flexion.
while assessing knee strength, and the ankle in 10 degrees of plantar flexion and knee in 30 degrees of flexion while assessing ankle strength. During both assessments, straps in an “X” fashion secured the upper body, and the thigh was also secured with a strap in an effort to limit the participant from utilizing compensatory muscle groups. Participants were instructed to keep their arms crossed over their chest during each trial. Five warm-up trials and a 2-minute rest period were given to the participant before completing 5 maximum effort trials continuously in both directions for each joint tested. The order of joint testing (ankle and knee) was randomized.

Figure 3-5: Starting position for isokinetic strength testing of the knee

Figure 3-6: Starting position for isokinetic strength testing of the ankle
3.5.4 Static Postural Control. Static postural control assessment consisted of measuring center of pressure velocity (COPV) in the anterior and posterior (A/P) as well as medial and lateral (M/L) directions, and time to boundary (TTB). COPV was sampled at 50hz during each 15 second trial. To assess static postural control, participants performed a single leg balance task. Participants stood in a barefoot single leg stance on the middle of the force plate. They were asked to keep their hands on their hips while keeping their foot flat on the force plate. The non-stance leg was held at 45 degrees of knee flexion and 30 degrees of hip flexion. Participants were allowed three practice trials and then asked to perform six testing trials; three with their eyes closed and three with their eyes open looking forward at a target. Participants were instructed to stand for 15 seconds while COP data was collected. A trial was discarded and repeated if (1) the non-testing limb touched down, (2) contact was made with the stance limb, (3) participants hopped or took a step with the stance limb, (4) they failed to keep their hands on their hips, (5) and/or they failed to keep their eyes closed during an eyes closed trial.
3.5.5 Ankle Laxity. Participants lay supine on a treatment table during ankle laxity assessment. The test foot was extended over the edge of the table and placed in the arthrometer. A strap was placed around the thigh, and another around the lower leg, 1 cm above the malleoli. The sole of the foot was secured on the footplate and the heel and dorsal clamps were adjusted for comfort of the participant. The tibial pad was placed 5 cm above the malleoli and secured with a strap around the lower leg. Anterior-posterior (A-P) loading was performed first at 125 N, followed by inversion-eversion (I-E) loading at 4,000 N/mm. Three trials of each were performed. Each assessment began with the ankle positioned in 0 degrees of plantar flexion. During each trial, participants were instructed to relax and avoid contracting the calf muscles.
3.6 Data Collection and Processing

SEBT performance is reported as a percentage of leg length. The maximum reach distance of the three trials in each direction was normalized by dividing by leg length. A composite score (mean of the three directions) was also calculated from the normalized mean scores from the three reaches and reported as a fourth outcome variable for SEBT testing.

The maximum distance achieved from the great toe to the wall during the WBLT is reported in cm and represents estimated maximal dorsiflexion ROM.

Normalized average peak torque (N·m⁻¹·kg⁻¹) from each isokinetic trial is reported in each direction. The peak torques from each trial in each joint movement direction (knee flexion, knee extension, ankle plantar flexion, ankle dorsiflexion) were averaged and the outcome variable reported as average peak torque, normalized to body mass.

COPV data was collected at 50hz and filtered with a low pass, fourth order Butterworth filter, with a cutoff frequency of 10 Hz. Instantaneous velocities were
averaged and reported for the A/P and M/L directions. The TTB measures are reported in seconds (s) using a custom MATLAB file.

Ankle laxity in the A-P direction is reported in millimeters (mm), while the I-E directions are reported in degrees.

3.7 Statistical Analysis

Means and standard deviations of the SEBT test trials, laxity measurements, COPV measures, and strength assessments were used for analysis, while the maximum value from the WBLT was used. The mean of the three static balance trials with eyes closed was calculated for each TTB measure. Individual t-tests were performed for each of the 21 dependent variables in order to detect differences between the CAI and ankle coper groups. Effect sizes (Cohen’s $d$) with 95% confidence intervals using the pooled standard deviations were calculated and interpreted as small<0.4, moderate: 0.4-0.80, strong: >0.80.48 Two separate linear backward regression analyses were performed in order to determine which measures predict SEBT performance in copers and CAI participants separately. Significance was set a priori at $P<.05$. Statistical Package for the Social Sciences (SPSS) 19.0 statistical software was used for all statistical analyses.
Chapter 4

Results

There were no statistically significant differences between the CAI and coper groups in age ($t(40)=-0.975$, $p=0.335$), height ($t(40)=0.832$, $p=0.41$), or body mass ($t(40)=0.998$, $p=0.324$). There were significant group differences in FAAM ($t(40)=-6.115$, $p<0.001$), FAAM Sport ($t(40)=-6.588$, $p<0.001$), and AII scores ($t(40)=10.082$, $p<0.001$). This indicates that groups were similar at baseline in age, height, and body mass, but different in self-reported function, supporting the group inclusion. (Table 3.1)

4.1 Comparison of Mechanical Joint Measures Between the Chronic Ankle Instability and Coper Groups

There were no statistically significant group differences in the total A/P or total I-E measures for ankle laxity ($p>.05$). Effect sizes were both small ($d<0.39$), and both 95% CIs crossed zero. (Table 4.1)

There were no significant group differences in estimated dorsiflexion range of motion ($p>.05$). The effect size was small ($d=0.38$), and the associated 95% CI crossed zero. (Table 4.1)
Table 4.1. Mechanical Joint Measures for the Chronic Ankle Instability (CAI) and Coper Groups (Means ± SD).

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Coper</th>
<th>t</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total A/P (mm)</td>
<td>13.35 ±4.66</td>
<td>14.72 ±4.36</td>
<td>-0.984</td>
<td>.331</td>
<td>0.31 (-0.31, 0.92)</td>
</tr>
<tr>
<td>Total Inv/Ev (°)</td>
<td>34.07 ±10.02</td>
<td>37.35 ±8.81</td>
<td>-1.122</td>
<td>.268</td>
<td>0.35 (-0.27, 0.96)</td>
</tr>
<tr>
<td>WBLT (cm)</td>
<td>10.31 ±4.13</td>
<td>11.77 ±3.67</td>
<td>-1.209</td>
<td>.234</td>
<td>0.38 (-0.25, 0.99)</td>
</tr>
</tbody>
</table>

4.2 Comparison of Sensorimotor Measures Between the Chronic Ankle Instability and Coper Groups

No statistically significant differences were found between groups in any of the static balance measures (p>.05), except in failed trials for the eyes closed condition (p=.037). Most effect sizes were small ($d<0.39$), except for COPV M/L eyes closed ($d=0.45$), TTB A/P standard deviation of the minimum ($d=0.42$), TTB M/L standard deviation of the minimum ($d=0.47$), and failed trials with eyes closed ($d=0.67$), which all showed moderate effect sizes between groups. The 95% CI associated with failed trials with eyes closed was the only 95% CI to not cross zero. (Table 4.3)
Table 4.2. Static Balance Measures for the Chronic Ankle Instability (CAI) and Coper Groups (Means ± SD).

<table>
<thead>
<tr>
<th>Measure</th>
<th>CAI</th>
<th>Coper</th>
<th>t</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>COPV A/P eyes open</td>
<td>0.68 ± 0.24</td>
<td>0.63 ± 0.24</td>
<td>.692</td>
<td>.493</td>
<td>0.22 (-0.40, 0.82)</td>
</tr>
<tr>
<td>COPV M/L eyes open</td>
<td>0.54 ± 0.17</td>
<td>0.57 ± 0.14</td>
<td>-.464</td>
<td>.645</td>
<td>0.15 (-0.47, 0.75)</td>
</tr>
<tr>
<td>COPV A/P eyes closed</td>
<td>1.62 ± 0.36</td>
<td>1.59 ± 0.45</td>
<td>.227</td>
<td>.822</td>
<td>0.07 (-0.54, 0.68)</td>
</tr>
<tr>
<td>COPV M/L eyes closed</td>
<td>1.40 ± 0.28</td>
<td>1.28 ± 0.24</td>
<td>1.456</td>
<td>.153</td>
<td>0.45 (-0.17, 1.06)</td>
</tr>
<tr>
<td>TTBAP abs. min.</td>
<td>1.64 ± 0.41</td>
<td>1.60 ± 0.55</td>
<td>.220</td>
<td>.827</td>
<td>0.07 (-0.54, 0.68)</td>
</tr>
<tr>
<td>TTBML abs. min.</td>
<td>0.61 ± 0.22</td>
<td>0.59 ± 0.15</td>
<td>.463</td>
<td>.646</td>
<td>0.14 (-0.47, 0.75)</td>
</tr>
<tr>
<td>TTBAP mean of min.</td>
<td>5.91 ±1.17</td>
<td>6.50 ± 1.97</td>
<td>-1.187</td>
<td>.242</td>
<td>0.35 (-0.27, 0.96)</td>
</tr>
<tr>
<td>TTBML mean of min.</td>
<td>2.59 ± 0.62</td>
<td>2.82 ± 0.67</td>
<td>-1.076</td>
<td>.289</td>
<td>0.34 (-0.28, 0.95)</td>
</tr>
<tr>
<td>TTBAP S.D. of min.</td>
<td>3.98 ± 0.97</td>
<td>4.58 ± 1.66</td>
<td>-1.429</td>
<td>.161</td>
<td>0.42 (-0.21, 1.03)</td>
</tr>
<tr>
<td>TTBML S.D. of min.</td>
<td>2.29 ± 0.89</td>
<td>2.74 ± 1.02</td>
<td>-1.464</td>
<td>.151</td>
<td>0.47 (-0.16, 1.08)</td>
</tr>
<tr>
<td>Failed Trials eyes open</td>
<td>0.72 ± 2.82</td>
<td>0.08 ± 0.28</td>
<td>.956</td>
<td>.352</td>
<td>0.35 (-0.28, 0.95)</td>
</tr>
<tr>
<td>Failed Trials eyes closed</td>
<td>4.88 ± 4.11</td>
<td>2.41 ± 3.29</td>
<td>2.16</td>
<td>.037</td>
<td>0.67 (0.03, 1.29)</td>
</tr>
</tbody>
</table>

COPV values are expressed as (cm/s). TTB values are expressed in (s).

No significant group differences were found in strength (p>.05). However, ankle dorsiflexion average peak torque approached significance between groups (t(40)=1.817, p=0.077), and had a moderate effect size (\(d=0.57\)). All other strength variables had small effect sizes (\(d\leq0.39\)). The 95% CIs for all of the isokinetic strength measures crossed zero. (Table 4.4)
Table 4.3. Isokinetic Strength for the Chronic Ankle Instability (CAI) and Coper Groups (Means ± SD).

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Coper</th>
<th>t</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee extension</td>
<td>1.44 ± 0.42</td>
<td>1.43 ± 0.34</td>
<td>.053</td>
<td>.958</td>
<td>0.02 (-0.59, 0.63)</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>0.88 ± 0.17</td>
<td>0.83 ± 0.21</td>
<td>.727</td>
<td>.472</td>
<td>0.23 (-0.39, 0.84)</td>
</tr>
<tr>
<td>Ankle dorsiflexion</td>
<td>0.20 ± 0.04</td>
<td>0.17 ± 0.06</td>
<td>1.817</td>
<td>.077</td>
<td>0.57 (-0.07, 1.18)</td>
</tr>
<tr>
<td>Ankle plantarflexion</td>
<td>0.42 ± 0.17</td>
<td>0.36 ± 0.15</td>
<td>1.241</td>
<td>.222</td>
<td>0.39 (-0.24, 1.00)</td>
</tr>
</tbody>
</table>

Isokinetic strength is expressed as average peak torque (N·m·1·kg⁻¹).

There were no significant group differences in %MAXD for any of the SEBT reach directions, as well as the composite score (p>.05). However, all SEBT variables presented moderate effect sizes between groups, with the Copers producing longer reach distances compared to the CAI group (Ant: d=0.42; PM: d=0.47; PL: d=0.53; Composite: d=0.51). However, all 95% CIs crossed zero. (Table 4.2)

Table 4.4. Star Excursion Balance Test (SEBT) Reach Distances for the Chronic Ankle Instability (CAI) and Coper Groups (Means ± SD).

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Coper</th>
<th>t</th>
<th>p-value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>63.99 ± 8.09</td>
<td>66.84 ± 5.52</td>
<td>-1.358</td>
<td>.182</td>
<td>0.42 (-0.20, 1.03)</td>
</tr>
<tr>
<td>Posteromedial</td>
<td>75.76 ±13.93</td>
<td>81.22 ±9.57</td>
<td>-1.505</td>
<td>.140</td>
<td>0.47 (-0.16, 1.08)</td>
</tr>
<tr>
<td>Posterolateral</td>
<td>66.74 ±15.03</td>
<td>73.45 ±10.69</td>
<td>-1.612</td>
<td>.118</td>
<td>0.53 (-0.10, 1.14)</td>
</tr>
<tr>
<td>Composite</td>
<td>68.77 ±11.24</td>
<td>73.49 ±7.42</td>
<td>-1.549</td>
<td>.133</td>
<td>0.51 (-0.12, 1.12)</td>
</tr>
</tbody>
</table>

SEBT reach distances are expressed as a percentage of the participant’s leg length (% MAXD).
4.3 Regression Analysis

A regression analysis was performed to determine which measures could predict SEBT performance in copers and CAI participants groups individually. Variables entered into the regression included knee flexion strength, knee extension strength, ankle dorsiflexion strength, ankle plantar flexion strength, total A/P ankle laxity, total Inv/Ev ankle laxity, WBLT, COPV A/P eyes closed, COPV M/L eyes closed, TTB mean of the minimum A/P eyes closed, and TTB mean of the minimum M/L eyes closed.

4.3.1 Anterior Reach. Variances in total I-E laxity, plantar flexion strength, and WBLT were able to explain 55.9% of the variance in anterior reach performance of the SEBT in the CAI group (R^2=0.559; p=0.012).

Dorsiflexion strength, TTB mean of the minimum M/L, COPV M/L, and WBLT were able to significantly predict 43.3% of the variance in anterior reach performance of the SEBT in the coper group (R^2=0.433; p=0.023).

The WBLT alone was able to significantly predict 34% of the variance in both the CAI (R^2=0.343; p=0.013) and coper (R^2=0.342; p=0.003) groups. (Table 4.5)
4.3.2 Posteromedial Reach. Variances in COPV A/P, TTB A/P, plantar flexion strength, and WBLT explained 58.8% of the variance in CAI on the posteromedial reach performance of the (R²=0.588; p=0.022). After removing variables that were weak contributors, plantar flexion strength and WBLT remained in the final model, explaining 48.4% of the variance on the posteromedial reach of the SEBT in the CAI group (R²=0.484; p=0.01).

COPV M/L, total A/P laxity, Total Inv/Ev laxity, and knee flexion strength explained 41.4% of the variance in posteromedial reach performance of the SEBT in the coper group (R²=0.414; p=0.031). After removing variables that were weak contributors, knee flexion strength remained in the final model and explained 21.8% of the variance in the performance of the posteromedial reach in the coper group (R²=0.218; p=0.021).

(Table 4.6)
4.3.3 Posterolateral Reach. Variances in total I-E laxity, COPV A/P, plantar flexion strength, and WBLT in combination explained 59% of the variance in posterolateral reach performance of the SEBT in the CAI group ($R^2=0.59; p=0.022$). After removing variables that were the weakest predictors of posterolateral reach performance, plantar flexion strength and WBLT remained in the final model and explained 46.5% of the variance in performance of the posterolateral reach ($R^2=0.465; p=0.013$).

Variances in knee flexion strength, total A/P laxity, TTB A/P, and COPV A/P in combination explained 23.7% of the variance in posterolateral reach performance of the SEBT in the coper group ($R^2=0.237; p=0.206$). When the weakest predictors were removed from the model, TTB A/P and COPV A/P remained, and explained 10.4% of the variance in performance of the posterolateral reach ($R^2=0.104, p=0.55$). (Table 4.7)
Table 4.7. A Linear Backward Regression Model Predicting Star Excursion Balance Test Posterolateral Reach Performance for the Chronic Ankle Instability (CAI) and Coper Groups.

<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>$R^2$</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>1</td>
<td>Total Inv/Ev Laxity, COPV A/P Eyes Closed, PF Strength, WBLT</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>COPV A/P Eyes Closed, PF Strength, WBLT</td>
<td>0.522</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>PF Strength, WBLT</td>
<td>0.465</td>
</tr>
<tr>
<td>Coper</td>
<td>1</td>
<td>Knee Flex. Strength, Total A/P Laxity, TTB A/P Eyes Closed, COPV A/P Eyes Closed</td>
<td>0.237</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Total A/P Laxity, TTB A/P Eyes Closed, COPV A/P Eyes Closed</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>TTB A/P Eyes Closed, COPV A/P Eyes Closed</td>
<td>0.104</td>
</tr>
</tbody>
</table>

4.3.4 Composite. Variances in COPV A/P, total I-E laxity, plantar flexion strength, and WBLT, together, were able to explain 59.4% of the variance in composite performance of the SEBT in the CAI group ($R^2=0.594; p=0.02$). After removing the weakest predicting variables of composite performance, plantar flexion strength and WBLT remained in the final model, and were able to explain 53.9% of the variance in composite performance ($R^2=0.539, p=0.004$).

Variances in dorsiflexion strength, total A/P laxity, TTB M/L, and knee flexion strength explained 36.9% of the variance in composite performance of the SEBT in the coper group ($R^2=0.369, p=0.057$). Knee flexion strength remained in the final model after removing the weakest predicting variables, being able to explain 15.6% of the variance in composite performance in the coper group ($R^2=0.156, 0.056$). (Table 4.8)
<table>
<thead>
<tr>
<th>Model</th>
<th>Factors</th>
<th>( R^2 )</th>
<th>( p )-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI</td>
<td>1 COPV A/P Eyes Closed, Total Inv/Ev Laxity, PF Strength, WBLT</td>
<td>0.594</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>2 Total Inv/Ev Laxity, PF Strength, WBLT</td>
<td>0.571</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>3 PF Strength, WBLT</td>
<td>0.539</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>Coper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 DF Strength, Total A/P Laxity, TTB M/L Eyes Closed, Knee Flex. Strength</td>
<td>0.369</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td>2 Total A/P Laxity, TTB M/L Eyes Closed, Knee Flex. Strength</td>
<td>0.321</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>3 TTB M/L Eyes Closed, Knee Flex. Strength</td>
<td>0.232</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>4 Knee Flex. Strength</td>
<td>0.156</td>
<td>0.056</td>
</tr>
</tbody>
</table>

Table 4.8. A Linear Backward Regression Model Predicting Star Excursion Balance Test Composite Performance for the Chronic Ankle Instability (CAI) and Coper Groups.
Chapter 5

Discussion

The primary objective of this study was to examine selected clinical and laboratory measures that potentially could differentiate ankle sprain copers from persons with CAI. These measures, including dynamic and static balance, ankle laxity, knee and ankle strength, and dorsiflexion ROM, have been shown to discriminate individuals with CAI from healthy individuals. The present study found that the only variable to statistically differentiate between copers and CAI was the number of failed trials when persons performed static, single leg balance with their eyes closed, with the CAI group having significantly more failed trails (approximately 5) compared to the coper group (approximately 2).

The difference in ankle dorsiflexion strength between groups approached statistical significance (p=0.077). The CAI group had increased ankle dorsiflexion strength (0.20 ± 0.04) compared to the coper group (0.17 ± 0.06). However, many variables, including failed trials with eyes closed, ankle dorsiflexion strength, all SEBT measures, COPV M/L eyes closed, and TTB A/P and M/L standard deviation of the minimum, had moderate effect sizes, indicating that there may be clinical significance between copers and those with CAI when using these measures.
The secondary objective of this study was to determine which measures best predict SEBT performance in copers, and whether these measures differ from those that predict SEBT performance in CAI sufferers. Overall, individuals with CAI seem to rely heavily on WBLT and PF strength when performing the SEBT. Copers seem to employ a few different strategies, relying on WBLT for the anterior reach, knee flexion strength for the posteromedial reach and composite score, and static balance measures for the posterolateral reach.

5.1 Discussion of Main Outcome Measures

5.1.1 Ankle Laxity. Increased anterior displacement and inversion rotation about the ankle has been reported in individuals with CAI compared to those without, when using an instrumented arthrometer. We found no significant differences in ankle laxity between individuals with CAI and copers. After initial trauma via ankle sprain to the ligaments, it is possible that full healing never occurs and the ligaments remain flaccid. While laxity may not be able to differentiate between copers and those with CAI, it highlights a similarity between the groups. Copers may have the same mechanical instability as those with CAI, but function better according to their self-reported levels of function and disability (FAAM, FAAM Sport, and AII scores). Hence, copers may rely on strategies to compensate for mechanical instability that persons with CAI do not. The specific coping mechanisms are not yet known, however a better neuromuscular control strategy among copers is plausible. Future research could incorporate surface electromyography using a coper group, and look at muscle activation of the lower extremity.
5.1.2 Weight-Bearing Lunge Test. We found no significant differences between groups in estimated dorsiflexion range of motion (ROM) measured with the weight bearing lunge test. Deficits in ankle dorsiflexion ROM have been identified in those with CAI compared to controls using both laboratory and clinical testing measures.\textsuperscript{8,17} Our study suggests that copers exhibit similar dorsiflexion ROM to CAI subjects. This may be the consequence of ligamentous laxity, primarily of the anterior talofibular ligament (ATF), sustained during the initial ankle sprain. When the ATF is sprained it can result in altered arthrokinematics of either the talocrural and/or tibiofibular joints, allowing the talus to shift anteriorly, restricting posterior glide ROM, and thus limiting the available dorsiflexion ROM. Anterior talar position has been reported to be significantly greater in the involved CAI limb compared to a matched control.\textsuperscript{49} Hoch et al\textsuperscript{50}, examining the effect of anterior-to-posterior ankle joint mobilizations on a group of CAI participants, found that six treatments over two weeks, with a one week retention period, resulted in significant improvement in dorsiflexion ROM, reach distance in all directions on the SEBT, and the FAAM. Others have examined manipulations at the proximal or distal tibiofibular joint.\textsuperscript{51}

With an ankle sprain, it is hypothesized that the fibula can translate anteriorly relative to the tibia, disrupting the talocrural joint and limiting dorsiflexion range of motion.\textsuperscript{52} An anterior to posterior joint mobilization utilized to correct the anterior displacement of the fibula have been shown to increase dorsiflexion ROM in not only the CAI group, but also a control group. However, the CAI group reported no improvement in functional movements via the FAAM Sport scores. It remains unclear if rehabilitation directed towards increasing dorsiflexion ROM can improve functional deficits reported
by individuals with CAI. Future research should examine talar and fibular positional faults of a coper group compared to a CAI and control group.

5.1.3 Isokinetic Strength. Those with CAI have previously demonstrated significantly less average peak torque production during knee flexion and extension, and ankle plantar flexion in their injured limb when compared to healthy controls, while showing no significant differences in ankle dorsiflexion average peak torque production. In our study, copers were similar in all strength measures to those with CAI. However, copers tended to have a decreased average peak torque in ankle dorsiflexion compared to the CAI group. This difference approached statistical significance, and had a moderate effect size. Perhaps those with CAI exhibited increased strength as a result of a rehabilitation protocol, or maybe the increased strength is part of an effort to prevent further injury, by pulling the ankle into a closed-packed position. Lower self-reported function and recurrent ankle sprains in individuals with CAI compared to copers indicates that this strategy is unsuccessful. It is important that rehabilitation after an ankle sprain focus on more than just strength.

Copers in our study exhibited decreased strength, yet reported better function on the FAAM, FAAM Sport, and AII, and demonstrated better function on the SEBT. Perhaps it is not the strength of the muscle, but rather the timing of the muscle activation that is critical in providing ankle joint stability. Kavanagh et al\textsuperscript{53} reported significantly slower reaction time for ankle eversion, specifically slower activation onset of the peroneous longus, on the affected side of those with CAI compared to a control group. Perhaps CAI sufferers never regain the neuromuscular control they once had prior to the initial ankle injury. There is limited to moderate evidence supporting the effectiveness of
neuromuscular training in improving dynamic and static postural stability, as well as active and passive joint position sense. Future studies should look at neuromuscular training during rehabilitation routines for copers and those with CAI, possibly integrating electrical stimulation to aid in the process.

5.1.4 Static Postural Control. Impaired static postural control has been observed in individuals with CAI. It has been reported that individuals with CAI demonstrate significantly greater COP displacement in both the M/L and A/P directions, as well as increased COP velocity when compared to both copers and controls. Those with CAI have also been found to exhibit significantly lower absolute minima, mean minima, and standard deviation of minima TTB measurements compared to controls. We found no statistically significant differences in COPV or TTB measures when comparing copers and those with CAI. Interestingly, the number of failed trials during static balance with eyes closed demonstrated both statistical and clinical significance. Individuals in the CAI group had approximately double the amount of failed trials than individuals in the coper group. These findings suggest that those with CAI rely a great deal on visual input during static balance tasks. Copers seem to be able to rely on somatosensory and vestibular information when visual input is taken away. Alterations in plantar cutaneous somatosensation have been reported in those with CAI compared to healthy controls. Participants with CAI had significantly less sensitivity on the plantar surface of the foot than controls. Kinesthetic awareness deficits have also been reported in a CAI group compared to a healthy group in the threshold to detection of passive motion and in active position sense. It is not yet known if these deficits are present in copers, but either or both of these deficits could explain why the CAI group had
significantly more failed trials when attempting to balance in a single-leg stance with eyes closed.

5.1.5 **Star Excursion Balance Test.** Decreased reach distances, and therefore decreased dynamic postural control, has been observed in individuals with CAI when compared to healthy individuals.\textsuperscript{11-13,31} When we compared these measures between CAI and copers, no significant differences were found between the groups. However, the effect sizes for all reaching distances were moderate (0.42 to 0.53). Copers were able to achieve a higher \%MAXD than those with CAI in all reach directions, and the composite score. This indicates that the coper group exhibited better dynamic postural control than the CAI group. The SEBT shows the potential to become a clinical test that can differentiate between copers and individuals with CAI.

Although there were moderate clinical differences between the CAI and coper groups in performance of the SEBT, it has yet to be determined why the differences exist. Copers may have performed better on the SEBT with the use of alternate strategies that the CAI individuals are unable to perform. Additional investigation of these movement patterns (kinematics, muscle activation patterns, etc) is needed.

5.2 **Regression**

COPV measures during eyes closed trials were included in the regression because we found no statistically significant differences or moderate effect sizes between groups during the eyes open condition. TTB mean of the minimum samples were the only TTB measures included in the regression because previous research has found that the mean of TTB minima significantly decreased in the CAI group when vision was removed from the static balance task.\textsuperscript{38}
5.2.1 Anterior Reach. Performance on the anterior reach of the SEBT has been significantly correlated with performance on the WBLT in a healthy population.\textsuperscript{17} It is not surprising that the WBLT also predicted both coper and CAI participants’ anterior reach performance as well. Participants are required to keep the heel of their stance foot in contact with the floor while they are performing a reach on the SEBT. Ankle dorsiflexion appears to be critical to reaching farther in the anterior direction.

The other factors that helped to predict anterior reach performance were different between groups. When plantar flexion strength was combined with WBLT for the CAI group, they were able to predict 11.9\% more of the variance. Copers combined the static balance measures of COPV M/L and TTB M/L mean of the minima with eyes closed to the WBLT, adding 5.8\% to the prediction model. It seems that those with CAI are unable to rely on the sensorimotor system for balance in the same way that copers can. Copers may not have developed these same deficits, or may have found a strategy to overcome them.

5.2.2 Posteromedial Reach. Copers and those with CAI differed in the strategy used to perform the posteromedial reach of the SEBT. While copers relied on knee flexion strength, those with CAI relied on ankle plantar flexion strength and the WBLT. Ankle plantar flexion strength and the WBLT better predicted CAI performance compared to knee flexion strength predicting copers’ performance. This suggests that there may be other variables, such as knee or hip ROM, or hip strength that may better predict posteromedial reach performance in the coper group. Previous studies have found no differences between controls and those with CAI in peak torque production at the hip, but this still needs to be compared to a coper group.\textsuperscript{7,62} Knee and hip ROM should be
further assessed using coper, CAI, and control groups. If these variables are not found to
differentiate between groups, perhaps neuromuscular adaptations account for the
differences in posteromedial reach performance in copers and individuals with CAI.

5.2.3 Posterolateral Reach. Static balance measures were the main predicting
factor for posterolateral reach performance in the coper group. Alternatively, those with
CAI relied again on ankle plantar flexion strength and the WBLT. However, the static
balance measures were not as predictive of copers’ performance as ankle plantar flexion
strength and the WBLT were of the CAI group’s performance. This suggests that there
may be other variables that can predict posterolateral reach performance in the coper
group. Hip strength, knee or hip ROM, or altered neuromuscular patterns are possibilities
that may also better predict coper’s performance on the posterolateral reach of the SEBT
and therefore should be investigated.

5.2.4 Composite. Overall performance on the SEBT was achieved through
different strategies between the CAI and coper groups. Ankle plantar flexion strength and
the WBLT together were strong predicting factors in composite performance for those
with CAI. Copers relied most on knee flexion strength, but the predictive value was low.
The CAI group seems to depend on function at the ankle, while the coper group relies on
function at the knee, and possibly the hip. Limited degrees of freedom within the joints of
the lower extremity may decrease the ability of those with CAI to rely on proximal joints
during a dynamic balance task. This suggests that the whole kinetic chain should be
addressed during the rehabilitation of an ankle sprain.

5.3 Limitations
Due to the availability of participants and time constraints, we were only able to collect data from 18 CAI participants out of the 22 we had originally planned on. It will be important to continue collecting data from more participants to fully realize these relationships. This study was also retrospective, and we relied on participant’s self-reported symptoms and previous history of ankle injury. However, the instruments used to rate self-reported function and disability related to ankle injury have been widely accepted for this purpose. We only compared CAI and copers. It will be important to examine these groups with a healthy control group to elucidate the deficits and similarities in CAI and coper groups. This study was part of a larger investigation that does have a healthy control group included and in the future these comparisons will be made. Finally, strength was assessed concentrically. It is possible that eccentric torque data may provide other interesting relationships.

5.4 Clinical Implications

Based on this study, dynamic balance performance measured with the SEBT, static balance with eyes closed, and ankle dorsiflexion strength show the greatest potential for differentiating CAI and copers. The CAI group exhibited decreased normalized SEBT reach distances, and increased ankle dorsiflexion average peak torque production. Those with CAI also exhibited increased M/L COPV and decreased TTB A/P and M/L S.D. of the minimum during static balance with eyes closed, as well as a significant increase in failed trials compared to copers. This deficit in dynamic and static balance may be due to constraints on the sensorimotor system. Altered motoneuron pool excitability has been observed in those with CAI in muscles about the ankle and in the proximal leg muscles, indicating spinal level motor control deficits.63
The measures that best predict SEBT performance in copers differ from the measures that predict SEBT performance in those with CAI. Overall, plantar flexion strength and estimated dorsiflexion ROM best predicted performance within the CAI group. The copers utilized a more varied approach, relying on different strategies for each reach direction. Dorsiflexion ROM was important in performance of the anterior reach, knee flexion strength in the posteromedial reach, and TTB A/P mean of the minimum and COPV A/P in the posterolateral reach. Knee flexion strength best predicted composite score performance. This suggests the need for a multivariate approach to understanding these relationships, as no single variable could predict over 35% of SEBT performance in copers.

These results may shed light on the coping mechanisms that result in higher self-reported function among the coper group compared to the CAI group. Future studies should examine neuromuscular control within a coper group, because it is possible that with treatment targeted towards neuromuscular control that individuals with CAI could learn to function as copers. Ultimately, this could decrease or prevent recurrent ankle sprains related to CAI.

In this study, those with CAI presented with a lack of variability in their movement strategies when performing the SEBT compared to the coper group. Although they had similar knee flexion strength, TTB A/P mean of the minimum, and COPV A/P during eyes closed trials, the CAI group was unable to rely upon these skills when performing the dynamic stability task. The CAI group relied primarily upon plantar flexion strength and dorsiflexion ROM instead of varying strategies, like the coper group. Movement variability is theorized to be essential for the stability and function of the
sensorimotor system. Within a normal environment, the sensorimotor system has numerous options when executing specific movement tasks, due to the redundancy within the biomechanical degrees of freedom of the joints. Having multiple possible ways to accomplish a task may reduce the repeated stress on tissues and allow for more movement choices when dealing with unexpected perturbations. Olmsted and Hertel found that CAI participants had a significantly lower standard deviation of minima TTB measure than healthy individuals, indicating significantly less variability in TTB. In addition to traditional ankle sprain rehabilitation regimens which include strength and balance exercises, it may also be important to teach those with CAI to increase their variability with movement tasks by learning to use new strategies during these tasks.

5.5 Conclusion

In conclusion, dynamic and static postural control, as measured by the SEBT, COPV, TTB, and failed trials, show the potential to differentiate ankle sprain copers and those with CAI. Individuals with CAI and copers rely on different strategies when completing the SEBT. Future research should focus on comparing neuromuscular control and motoneuron pool excitability between these groups. Additionally, knee and hip ROM, and strength should be compared between coper and CAI groups, as well as their contributions to the SEBT. Ultimately this research will improve rehabilitation protocols for those with CAI that focus on those variables, as well as increasing variability and learning to use new strategies during static and dynamic balance tasks.
References


47. Gribble P HJ, Plisky P. Using the star excursion balance test to assess dynamic postural control deficits and outcomes in lower extremity injury. *Journal of Athletic Training*. accepted for publication, April 28, 2011.


Appendix A

Human Subjects Consent Form

Prinicipal investigator: Phillip Grizzle, Ph.D., ATC
Other Staff (identified by role): Heather Boley, ATC, Co-investigator
Sarah Carey, ATC, Co-investigator
Elizabeth Rulfaest, ATC, Co-investigator
Masadumi Torada, M.S., ATC, Co-Investigator
Megan Quinlivan MS, ATC, Co-Investigator

Contact Phone number(s): Dr. Phillip Grizzle: (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
You were selected as someone who may want to take part in this study because you have the following criteria:

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

**You will be in the poor SEBT performance group if you:**
- Would like to voluntarily participate in this study
- Between the ages 15 and 35 years
- Participate in at least 30 minutes of vigorous activity three or more days per week.
- Have no history of any self-reported musculoskeletal and neurovascular injury and disorder in the lower extremity.
- Have no history of surgery in the lower extremity.
- 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 >67% on the SEBT
- Have a score of 190% 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 upper group if you:
- Would like to voluntarily participate in this study
- Between the ages of 18 and 56 years
- Participate in at least 30 minutes of vigorous activity three or more days per week.
- Have a history of 1 significant acute lateral ankle sprain, causing more than 1 day of disrupted activity, pain, and swelling.
- Have no recurrent injury/instability after the initial sprain.
- Have no functional impairment (pain and giving-way) after the initial sprain.
- No history of any musculoskeletal and neurovascular injury in the lower extremity other than the ankle in the previous two years
- No previous 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 “yes” to the question, “Do you have a history of ankle sprain?” on the All
- Answer “no” to all symptom questions on the All.
- Score >60% on the FADI and >95% 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: 1406A), Joint Injury and Muscle Activation Laboratory (Room: 1436), and Motion Analysis Lab (Room: 1412) in the Health Science 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-motion 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: 07/13/2012  
EXPIRATION DATE: 07/12/2015

This page for IRB approval 12/2/2012
The SEBT will be performed in the anterior, posteromedial, 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 tap measure without moving the test foot. For PM and PL directions, the heel will be at the gridline and you will reach back as far as possible in each direction to tap the measuring tape. Four practice trials are given followed by three test trials in each direction for a total of nine successful trials.

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

Ankle laxity will be assessed by placing the ankle in an ankle arthrometer and securing 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 great toe two centimeters from the wall and keep the heel firmly planted on the floor while flexing the knee to the wall. The purpose is to maintain knee contact with the wall while maintaining heel contact on the ground. Your foot will be moved back less than one centimeter at a time until you are unable to keep your heel on the ground while touching the knee to the wall. Three successful testing trials will be recorded.

The length of lateral ankle ligaments will be assessed with Doppler ultrasound. A plastic probe with gel will be placed on your ankle to acquire an image of your ligaments. This assessment involves the transmission of sound waves reflected with your ankle ligaments. Ultrasound images will be taken in three positions (neutral, inversion, anterior drawer, and ankle dorsiflexed at 90°). Between each neutral image, you will be asked actively to plantarflex or dorsiflex three times and return to the neutral position for the subsequent images. During inversion images, you will be asked to lie down on your back on the chair of the dynamometer, with the knee extended at 0° and the ankle plantarflexed at 30°. You will be instructed to relax the lower extremity muscles while your ankle will be passively inverted to the end range of ankle inversion by the examiner and stabilized by the dynamometer. The inversion stress will be released following each image, and the ankle will be then re-positioned in the same end-range of inversion previously determined at the first. Lastly, images will be taken during anterior drawer test, you will be asked to lie down on your stomach with the foot hanging over the edge of the examination table while the examiner pulls 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

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**UNIVERSITY OF TOLEDO IRB**

**APPROVAL DATE:** 07/08/2022  
**EXPIRATION DATE:** 07/07/2023

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Page 5 of 8
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 study and complete all testing procedures in this study, you will receive a $15 stipend. The University of Toledo will send a check to mailing address which you will provide to us. Other compensations including free treatment, free medications, or free transportation will not be provided for this study.

**Payment or Other Compensation to the Research Site**

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

**Alternative(s) to Taking Part in This Research**

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

**Confidentiality**

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

**In the Event of a Research-Related Injury**

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

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

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

OTHER IMPORTANT INFORMATION
There is no additional information.

ADDITIONAL ELEMENTS
There are no additional elements to the study.

Continued On Next Page
OFFER TO ANSWER QUESTIONS
Before you sign this form, please ask any questions on any aspect of the 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) 530-2891.

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 419-383-6708.

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

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

| Name of Subject (please print) | Signature of Subject or Person Authorized to Consent | Date |
| Relationship to the Subject (Healthcare Power of Attorney or Legal Guardian) | | a.m. |
| Name of Person Obtaining Consent (please print) | Signature of Person Obtaining Consent | Time | p.m. |
| 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

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?:
   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 you experienced?  

b) Did the injury require surgery?  
   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?  

12. Have you ever suffered from a significant ankle/foot injury (other than ankle sprains) causing you to interrupt your sports activity?  
   a) If Yes, when was the most recent incident?  
      What injuries have you experienced?  
   b) Did the injury require surgery?  
      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 C

FAAM & FAAM Sports Scale

<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>
<td></td>
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<tr>
<td>Activities of daily living</td>
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<td></td>
</tr>
<tr>
<td>Personal care</td>
<td></td>
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<tr>
<td>Light to moderate work (standing, walking)</td>
<td></td>
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</tr>
<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational activities</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 0 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.

[Rating] 0 %
### 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>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on even ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on even ground without shoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking up hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking down hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going up stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going down stairs</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on uneven ground</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Stepping up and down curbs</td>
<td></td>
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</tr>
<tr>
<td>Squatting</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Coming up on your toes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></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>
<td></td>
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<tr>
<td>Walking 15 minutes or greater</td>
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</tbody>
</table>
Appendix D

AII

<table>
<thead>
<tr>
<th>Ankle Instability Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instructions</strong></td>
</tr>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

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
## Data Collection Form

**Demographics**

<table>
<thead>
<tr>
<th>Participant #</th>
<th>CCCPROJ_</th>
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</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>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>Inches:</td>
</tr>
<tr>
<td>Weight</td>
<td>Pounds:</td>
</tr>
<tr>
<td>Physical Activity Level</td>
<td>Days/week:</td>
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### Order of Testing

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<thead>
<tr>
<th>Limb Order</th>
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<th>2&lt;sup&gt;nd&lt;/sup&gt;:</th>
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<tbody>
<tr>
<td>Testing Order</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;:</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;:</td>
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### Ankle Laxity Test Form

<table>
<thead>
<tr>
<th></th>
<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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<tbody>
<tr>
<td><strong>Right</strong></td>
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<td></td>
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<td></td>
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<tr>
<td>1</td>
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<tr>
<td>Avg.</td>
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<tr>
<td><strong>Left</strong></td>
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<td>1</td>
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<td>2</td>
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<tr>
<td>Avg.</td>
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</table>
Weight-Bearing Lunge Test Form

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<tr>
<th>Trial</th>
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<tbody>
<tr>
<td></td>
<td>cm</td>
<td>cm</td>
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</tbody>
</table>

Note

Static Balance Test Form

- Right: _________cm
- Left: _________cm

Number of Failed Trials

EO
- Right: ______________________
- Left: ______________________

EC
- Right: ______________________
- Left: ______________________
<table>
<thead>
<tr>
<th>Right</th>
<th>Extension</th>
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<tr>
<td>5</td>
<td></td>
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</tr>
<tr>
<td>Avg.</td>
<td></td>
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<tr>
<td>STDV</td>
<td></td>
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<tr>
<td>Left</td>
<td></td>
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<td>1</td>
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<td>5</td>
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</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STDV</td>
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## Ankle Strength Test Form

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<tr>
<th>Trial</th>
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<th>Plantar flexion</th>
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<tbody>
<tr>
<td>1</td>
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<td></td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td></td>
<td></td>
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<tr>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
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</table>

**Avg.**

**STDV**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Dorsiflexion</th>
<th>Plantar flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>5</td>
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</tbody>
</table>

**Avg.**

**STDV**
## Star Excursion Balance Test Form

<table>
<thead>
<tr>
<th>Leg Length: Right= ___________ cm</th>
<th>Left= ___________ cm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right</strong></td>
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