A Thesis Entitled

Effects of Chronic Ankle Instability and Ankle Bracing on Plantar Pressure during a Jump Landing Task

By

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

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The University of Toledo

August 2011
An Abstract of

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Objective: The purpose of this study was to investigate the differences in plantar pressure distribution between individuals with and without chronic ankle instability. A secondary purpose was to explore the potential changes in pressure during a dynamic task while wearing a prophylactic ankle brace. Design and Setting: The mean peak plantar pressures over three regions and total foot for the braced and non-braced trials was used for statistical analysis. From these regions and the total foot, four dependant variables for medial/lateral pressure ratios were calculated. For each dependant variable, a two-way ANOVA was performed with one between (CAI and control) and one within (braced and non-braced) independent variables. Significance was set at p<0.05. Subjects: Ten healthy (6 male, 4 female; 22.2+/-2.16 yrs; 69.9+/-3.37in; 179.9+/-21.57) individuals, and ten CAI (6 male, 4 female; 21.2+/-1.72 yrs; 68.6+/-3.60in; 167+/-23.93lbs) individuals participated in the study. Measurements: Each subject reported to the lab one time for testing. For the non-braced trial the subject was asked to perform 3 vertical jumps at 50% of vertical jump maximum with a single-leg jump landing. To perform the jump-
landing task, the subjects started with both feet together 70 cm from the center of the force plate. They performed a two-footed take off jump, reaching for their 50% Max vertical jump height on the Vertec, and then landed on the single testing limb on the force plate, attempting to stabilize as fast as they could with hands on hips. The subject removed the shoe on the testing limb and the Swede-O Universal Lace Up Brace was applied by the same certified Athletic Trainer. Data collecting procedure followed the same protocol as the above described for the non-braced trial.

Results: For the medial-lateral midfoot and rearfoot ratios there was statistical significance (p=.041 and .001) when comparing the braced and non-braced trials. For the total foot ratio there was also statistical significance (p=.02) for the braces versus non braced trials.

Conclusion: The evidence from this study suggests that ankle braces causes an increase in lateral foot pressure, which may be due to the rigid nature of the brace keeping the foot in a more neutral position during landing. This may be important to understanding how a brace application may be beneficial to preventing additional ankle injury. To our knowledge, this research is the first step in utilizing the F-scan plantar pressure system to analyze plantar pressure during a jump landing. Future research should be done utilizing larger sample sizes as well as variations of ankle braces.
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Chapter 1

Introduction

Ankle injuries are one of the most frequent injuries associated with contact sports. Ankle sprains are the most common injury in men and women who participate in soccer, basketball, and volleyball. Most ankle sprains are inversion injuries that damage the lateral ligaments of the ankle.\(^1\) Approximately 73% of individuals who sprain their ankles have residual symptoms including pain, repeated sprains, and episodes of “giving way”.\(^2\) Chronic ankle instability (CAI) is a result from multiple disruptions to the ankle joint integrity. Individuals with CAI experience frequent sprains, pain, and instability.\(^3\)

The effects of CAI on static stability have been heavily researched\(^4\), demonstrating a decline in postural control associated with this pathology. Similarly, deficits in dynamic postural control and stability have been presented using clinical measures such as the star excursion balance test\(^5\) as well as laboratory measures using force plate data during landing tasks.\(^6\textit{-}^\text{10}\) Along a similar vein, the benefits of ankle bracing on dynamic stability during landing have been examined in healthy subjects\(^7\) and in subjects with chronic ankle instability\(^9\). While the use of force plates to assess dynamic stability has shown to be a useful tool, there may be other alternatives to assessing dynamic stability deficits in individuals with CAI during functional tasks. One measurement of stabilization that has not been widely examined is the use of plantar pressure systems.
Plantar pressure systems measure the amount of mass or force being distributed across the plantar surface of the foot. Plantar pressure systems are computerized insole sensor systems. The plantar sensor is a bipedal thin shoe insole that has 960 individual pressure-sensing locations. The insoles use resistive based technology to measure applied pressure. While multiple plantar pressure systems are available, previous studies have found that the F-Scan has fair to good reliability.\textsuperscript{11,12}

Plantar pressure systems have been used in applications studying a variety of foot pathologies and the differences observed in pressure distribution, such as over pronation or the diabetic foot.\textsuperscript{11,13} However, there has been little application of these systems in the study of ankle instability. The limited information that exists suggests a more pronounced lateral pressure distribution during gait in CAI subjects, which may help explain increased incidence of excessive supination and inversion\textsuperscript{14}.

Similarly, there is limited information about what influence prophylactic ankle support may have on plantar pressure distribution. Two studies have examined the effects of low-dye tape application, used in the prevention of excessive pronation.\textsuperscript{11,13} These studies have found that low-dye tape does reduce the amount of rearfoot motion, and also changes the pattern of plantar pressure distribution especially in the midfoot and forefoot.\textsuperscript{11,13} Although this particular intervention is intended to change the pressure distribution, it initiates questions about other prophylactic tape/braces changing plantar pressure distributions, as well as what effect may exist among subjects with CAI.

**Purpose Statement**
The purpose of this study was to investigate the differences in plantar pressure distribution between individuals with and without chronic ankle instability. Little is known about the effects that chronic ankle instability may have upon the distribution of pressure on the plantar surface of the foot during the dynamic task of landing from a jump. A secondary purpose was to explore the potential changes in pressure during a dynamic task while wearing a prophylactic ankle brace.

**Specific Aims and Hypotheses**

Specific Aim #1: to determine if there is a difference in peak plantar pressure distributions between a healthy population and a CAI population during a dynamic jump landing task.

Hypothesis #1: the CAI group will have a greater plantar pressure distribution under the lateral portion of the foot compared with the Healthy group during landing

Specific Aim #2: To examine the role of prophylactic ankle bracing on plantar pressure distribution during dynamic stabilization tasks in subjects with and without CAI.

Hypothesis #2: the application of an ankle brace will increase medial plantar pressure distribution in the CAI and Healthy groups
Hypothesis #3: the CAI group will experience a larger shift of lateral to medial plantar pressure distribution with the application of the ankle brace compared with the Healthy group

Limitations

The CAI subjects will be self-reporting their injury history and episodes of giving way. Subjects will be bringing in their own shoes to wear in the study, which may affect the measurement of plantar pressure. Another limitation is that the software will automatically analyze the data into a gait cycle. Therefore the jump landing will have to be found by utilizing a graph that will show the exact frame in which contact is made. This leaves some room for error because the frame being analyzed for peak pressure may not be the same for each subject due to the residual pressure that is always on the sensor. Therefore the researcher must determine when there is a spike in pressure indicating landing.
Chapter 2

Chronic ankle instability

Ankle injuries are one of the most frequent injuries associated with contact sports. Ankle sprains are the most common injury among men and women who participate in soccer, basketball and volleyball. Once injury has been sustained it is very likely for re-injury to occur, with an 80% chance for reoccurrence among active individuals. The repetitive disruptions and instability has been classified as chronic ankle instability and has been reported to in a high number of people with a previous history of lateral ankle sprains. Typically, individuals that have chronic ankle instability report feelings of the ankle “giving away” and weakness at the joint. They experience frequent sprains, pains and instability as well as unknown long term consequences to joint health.

Two primary causes have been found to be responsible for chronic ankle instability. Mechanical ankle instability and functional ankle instability have both be identified. There are a variety of insufficiencies that leads to these two types of instabilities. Mechanical ankle instability includes pathologic laxity, impaired arthrokinematics and synovial and degenerative changes. Functional ankle instability includes impaired proprioception, altered neuromuscular control, strength deficits, and diminished postural control. Hubbard et al. reports that although these two types of instabilities have different properties, it is important for them to be studied together.
because deficits in one may lead to the other and they both need to be assessed for treatment of chronic ankle instability.\textsuperscript{16}

In addition to the altered mechanical joint stability, perceived and observed deficits in neuromuscular control helps to define chronic ankle instability.\textsuperscript{15} Neuromuscular control may be quantified through measures of postural control, both statically and dynamically. Dynamic postural control may be defined as attempting to maintain a stable base of support while performing a prescribed movement.\textsuperscript{18} Although static postural control has been widely studied; investigations into dynamic postural control related to chronic ankle instability are limited.\textsuperscript{5}

Gribble et al.\textsuperscript{5} investigated the effects of fatigue and chronic ankle instability on dynamic postural control measured with the star excursion balance test (SEBT). Measurements of three reaching directions of the SEBT were recorded before and after a fatigue protocol. The results from this studied found that subjects with chronic ankle instability displayed smaller reach distances than the control subjects, and this was exaggerated after the fatigue protocol. These results showed that chronic ankle instability and fatigue both disrupt dynamic postural control.\textsuperscript{5}

Brown et al.\textsuperscript{6} examined balance deficits among recreational athletes with chronic ankle instability. The purpose of the study was to investigate the effects of chronic ankle instability on dynamic stability in a more subtle task such as a double-leg stance. Perturbation was used to test for dynamic balance deficit in the chronic ankle instability and control groups. The results showed there were deficits in dynamic stability during a
double-leg stance in the chronic ankle instability group. Although the findings were subtle, they were found during a very simple dynamic task.6

Through the use of functional test such as the star excursion balance test and dynamic tasks such as a jump landing researchers are able to determine deficits in the subjects with chronic ankle instability.5-7 Although these findings give us valuable information about what is happening at the ankle, little is still known about the changes in pressure distribution as the foot contacts the ground. The use of force plates has allowed researchers to observe postural sway and time to stabilize7, but research is limited when it comes to the changes in pressure across the plantar surface of the foot in patients with chronic ankle instability.

Ankle bracing

One of the most common methods used to prevent a lateral ankle sprain is the use of a prophylactic support. In the past, it was more common to use an ankle taping technique to provide support to the ankle. Over time it was found that the adhesive tape did not hold a consistent amount of support during longer periods of activity. More common now is the use of a manufactured ankle stabilizer.19 Ankle bracing provides many advantages over ankle taping. Some of the benefits are that they are self applied without needing the assistance of qualified personnel, they are convenient to apply and remove, reusable, adjustable to maintain consistent support and washable.20

With the rising cost of athletic tape, it has become more cost and time effective to utilize an ankle brace as an alternative to taping. The braces are categorized as either
“non-rigid” or “semi-rigid”. The non-rigid braces are usually made of canvas or neoprene-type material. They can easily be slipped on and off and often have additional lacing. The semi-rigid braces consists of bimalleolar struts made of thermoplasetic with Velcro straps for attachment.\textsuperscript{20}

A concern with the application of a semi-rigid or lace-up brace is that it may hinder athletic functional performance in vertical jump height, speed and agility. Many studies have been done to investigate this topic on semi-rigid braces such as the Active Ankle and lace up braces like the Swede-O Universal ankle brace.\textsuperscript{21-25} In a functional assessment study both the Active Ankle and Swede-O Universal ankle brace were used to determine how they affect function in tasks such as vertical jump, jump shots and sprinting drills. The study found that both braces significantly affected vertical jump, but there was no significant difference between the two, and for jump shots the Active Ankle brace showed the least performance impairment. There was no impairment in sprint time with either brace application.\textsuperscript{23} Other studies have found the Swede-O universal ankle brace to have no effect on vertical jump, speed or agility.\textsuperscript{21-24} Shaw et al. examined the effects of ankle bracing and fatigue on time to stabilize in collegiate volleyball athletes. This study found that between the active ankle and the Swede-O Universal lace-up ankle braces the Swede-O brace provided the best dynamic stability in the anterior-posterior direction during a jump landing task.\textsuperscript{7}

By utilizing a prophylactic ankle brace it aids in preventing ankle sprains by restricting ankle inversion and eversion. This allows the ankle to stay in a more neutral position which limits the amount of stress placed on the joints ligaments. By restricting
the frontal plane motions the ankle is protected from injury. However, Robbins and Waked found that although you may restrict the range of motion it is unrelated to preventing ankle injuries because the force produced by the sprain mechanism is greater than the tape or brace can withstand. What they found the brace does do is place the ankle joint into a more neutral and stable position prior to ground contact which can reduce the risk of improper foot positions upon landing.

Shaw et al. examined the effects of fatigue and ankle bracing on time to stabilization from a jump landing in athletes who exhibit chronic ankle instability. Dynamic postural stability was examined by looking at the time it took the subjects to stabilize during the jump landing. The study tested three different types of ankle braces to determine which brace best improved dynamic stability and time to stabilization. The results of this study found that the Swede-O Universal Lace-Up Brace improved dynamic stability through a decreased TTS measure.

Wikstrom et al. studied postural stability in subjects with braced functionally unstable ankles. The study wanted to determine whether prophylactic ankle stabilizers improve dynamic postural stability in subjects with functional ankle instability when compared to a control group. The subjects performed a jump landing task onto a force plate and the directional components and ground reaction forces of the landing were recorded. The results of the study found that soft and semirigid prophylactic ankle stabilizers did not improve dynamic postural stability, but it may aid in the attenuation of ground reaction forces.
A review of the literature found that ankle taping and bracing improved both mechanical and functional stability in those with acute and chronic ankle instability. It is suggested that the ankle brace provides longer lasting benefits due to its ability to maintain their restrictive properties throughout activity.\textsuperscript{20}

**Plantar pressure**

Plantar pressure is a measurement of the pressure distributed across the plantar surface of the foot. The F-scan is a bipedal system consisting of thin 1.8mm plastic insole that measures pressure distributions at the foot and shoe interface. It consists of 960 pressure sensing points along the insole. The insole is attached to a cuff unit that is placed on the subject’s lower leg via Velcro strap. A cable connects the cuff unit to a computer that has the TekScan software to record the plantar pressure data.\textsuperscript{28} The Fscan system has shown moderate to good reliability. When analyzing the data in the Tekscan software most research has chosen to divide the plantar surface of the foot into a six or seven part grid. The parts consist of a medial and lateral forefoot, hindfoot and rearfoot, and some times there is a central forefoot to make the seventh part of the grid.\textsuperscript{13,28}

Most research conducted using plantar pressure has concentrated on foot pathologies related to pressure. These patients that have pressure pathologies are most commonly attributed to over-pronation or a diabetic patient that is dealing with diabetic foot.\textsuperscript{11,13} The most common research topic for prophylactic taping/bracing that relates to this topic of interest examines the effects of the low-dye tape application.\textsuperscript{11,13} Low-dye tape is used to prevent excessive pronation.\textsuperscript{11} Studies have found that low-dye tape does
reduce the amount of rearfoot motion, and also changes the pattern of plantar pressure
distribution especially in the midfoot and forefoot.¹¹ ¹³

There is very little research done when looking at the changes in plantar pressure
in CAI patients as well as with ankle bracing or taping. Most research uses either a
functional test, such as the Star excursion balance test, or jump landings onto a platform
to determine dynamic postural stability.⁵ ⁷ ²⁶ One estimation of postural control that has
not been widely utilized is plantar pressure distributions during a dynamic task such as a
jump landing.

Shmidt et al.¹⁴ examined the effects of chronic ankle instability on plantar
pressure distributions. Previously plantar pressure patterns in chronic ankle instability
patients had been identified by conducting barefoot walking over a pressure mat. The
results found that there was more time spent and pressure on the lateral aspect of the foot
in the chronic ankle instability groups. This study was the first to use an insole plantar
pressure system to measure distributions while jogging. The study found that there were
greater plantar pressure forces on the lateral forefoot, midfoot and rearfoot in the CAI
groups when compared to the control group.

Germanowski et al.²⁹ examined the effects of ankle taping and bracing in subjects
with chronic ankle instability on plantar pressure and force distributions while walking
and jogging. Previous to this study there was no published research on this topic. This
study found that ankle taping and bracing did not diminish the forces on the lateral aspect
of the foot in the subjects with CAI. Taping and bracing did tend to increase peak
pressures and forces on the medial aspect of the foot in jogging.
**Summary**

Chronic ankle instability and ankle bracing and their effects on dynamic postural control have been thoroughly examined together. Although research exists on both topics, the relationship of CAI and ankle bracing has not been heavily examined in regards to the changes in plantar pressure distribution. By utilizing plantar pressure systems it may give researchers more options about how to study CAI and bracing and to understand mechanisms of recurrent ankle injury, as well as how these injuries may be prevented with prophylactic support devices such as ankle braces.
Chapter 3

Study Design

This laboratory cohort study will made comparisons between CAI and Healthy subjects with repeated measures for brace condition.

Independent Variables

1. Group (Chronic Ankle Instability; Healthy/Control)
2. Condition (Brace, No brace)

Dependant Variable

1. Forefoot Medial/Lateral Pressure Ratio
2. Midfoot Medial/Lateral Pressure Ratio
3. Rearfoot Medial/Lateral Pressure Ratio
4. Total Foot Medial/Lateral Pressure Ratio

Subjects

For this study twenty physically active individuals between the ages of 18-25 volunteered to participate. Ten of the volunteers were healthy physically active individuals with no self-reported lower limb injury. The other ten were healthy and physically active, but had self-reported chronic ankle instability.
CAI was defined by a history of at least one acute ankle sprain that resulted in swelling, pain, and temporary loss of function (but none in the previous 3 months); and a history of multiple episodes of the ankle “giving way” in the past 6 months. All subjects were matched by height, weight, sex and involved leg. All subjects were given a questionnaire to fill out regarding their previous ankle injuries, and the Foot and Ankle Disability Index (FADI). Healthy subjects must score 100% on both sections of the FADI; while CAI subjects must score less than 90% on the FADI ADL section and less than 80% on the FADI sports section. All subjects read and signed an informed consent form that was be approved by the University Institutional Review Board.

**Instrumentation**

The F-Scan (Tekscan Inc.) Plantar Pressure System with Tekscan software was used to measure and analyze peak plantar pressure. The insole was divided in a 6 area grid that will represent the plantar surface of the foot. The 6 areas were medial and lateral forefoot, medial and lateral midfoot and medial and lateral hindfoot. A Vertec vertical

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**Table 1**

<table>
<thead>
<tr>
<th>Subject Demographics</th>
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<tr>
<td><strong>Sex</strong></td>
</tr>
<tr>
<td>CAI (n=10)</td>
</tr>
<tr>
<td>F=4</td>
</tr>
<tr>
<td>Control (n=10)</td>
</tr>
<tr>
<td>F=4</td>
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</table>
jump tester (Sports Imports, Columbus, OH) was used to measure the subjects’ standing, maximum and 50% maximum vertical jump height. The Swede-O Universal Lace-Up Brace was used for the braced trials.

**Procedure**

Each subject reported to the lab one time for testing. They were asked to wear athletic shoes and clothing to the testing session. Each session lasted approximately one hour. Upon arrival the subjects filled out four forms (informed consent, injury history, two FADI instruments). To begin set-up the F-scan insole was matched to the subject’s shoe size. Next, the subject’s height, weight, and vertical jump max was assessed using the Vertec vertical jump tester. Subjects’ standing reach height was measured first by having the subject stand next to the Vertec and instructing them to reach up with one hand and touch the highest point possible while keeping both feet flat on the ground. Next, the subject performed maximal effort jumps off both feet and reach up to touch the highest point possible on the Vertec. They completed three trials and their maximum height was recorded. Each subject’s maximum vertical jump height ($\text{Vert}_{\text{max}}$) was calculated by subtracting their standing reach height from their maximum height during the jumping trials.

The plantar pressure system was calibrated before data collection starts. To calibrate the system the insoles was inserted into the subject’s shoes and the subject were instructed to “load” each insole with full body weight for 1 second.11
After performing the vertical jump maximum test and calibrating the insoles, the subjects had five minutes to rest and walk around to allow the plantar pressure system to adjust to being in the shoe and adapt to the subject’s body heat.

For the non-braced trial the subject was asked to perform 3 vertical jumps at 50% of vertical jump maximum with a single-leg jump landing. To perform the jump-landing task, the subjects started with both feet together 70 cm from the center of the force plate. They performed a two-footed take off jump, reaching for their 50% Max vertical jump height on the Vertec, and then landed on the single testing limb, attempting to stabilize as fast as they could with hands on hips. Any trials that the subject hopped upon landing, or touched down the non-testing limb were discarded and repeated until 3 acceptable trials were acquired.

The subject was given a five minute rest period before starting the braced trial. The order of brace condition was not randomized because additional data was being collected as part of a larger project that prohibited the brace trials to be randomized so that the pressure insoles could be calibrated for the second part of the project once the brace was removed. The subject removed the shoe on the testing limb and the Swede-O Universal Lace Up Brace was applied by the same certified Athletic Trainer. The braced foot was placed back into the shoe, and the subjects had one minute to walk around and adjust to the brace. Data collecting procedure followed the same protocol as the above described for the non-braced trial.

Data Processing
Plantar pressure data was collected at a sampling rate of 100 frames per second. The peak plantar pressure was calculated from the six assigned areas (medial/lateral forefoot, medial/lateral midfoot and medial/lateral rearfoot). The average of peak pressure was used from the three jump trials. The first one hundred frames after initial contact were analyzed to determine peak pressure. Initial contact was be determined by identifying the frame in which there was a spike in pressure.

**Statistical Analysis**

The mean peak plantar pressures over each of the three regions and total foot for the braced and non-braced trials was used for statistical analysis. From these regions and the total foot, 4 dependant variables for medial/lateral pressure ratios were calculated. A value of greater than 1 indicated more medial pressure and a value of less than one indicated more lateral pressure. For each dependant variable, a two-way ANOVA was performed with one between (CAI and control) and one within (braced and non-braced) independent variables. In the event of statistically significant interactions, a Tukey’s post-hoc test was applied. Statistical significance was set \textit{a priori} at \( p<.05 \). Effect sizes (Cohen’s \( d \)) using the pooled standard deviations, along with 95% confidence intervals were calculated.

**Health Risks**

Subjects were given verbal and visual instructions and adequate practice time for the jump-landing task in order to minimize the risk of injury. Subjects also were monitored closely during this time to make sure they demonstrated proper landing technique to minimize risk.
Chapter Four

Forefoot Ratio

The Group by Brace interaction was not statistically significant ($F_{1,18} = 0.96$; $P=0.33$). For both groups in both conditions, the ratio indicated more medial pressure distribution with the ratio. There were weak associated effect sizes for the CAI group between the braced and non-braced comparison ($d = -0.26; 95\% CI: -1.13, 0.63$); as well as for the control groups braced vs. non-braced comparisons ($d = 0.08; 95\% CI: -0.80, 0.95$). There was a strong associated effect size for the non-braced between group comparison ($d=0.80; 95\% CI:-1.4, 1.67$) indicating that subjects in the CAI group demonstrated greater medial forefoot pressure than those in the healthy group in the non-braced jump trials (Table 1). Additionally, subjects within the CAI group demonstrated greater medial forefoot pressure following the brace application when compared to the healthy group ($d= 0.56; 95\% CI: -0.36, 1.43$). However, these effect sizes did have 95% confidence intervals that did cross zero.

The effect size for Group main effect was moderate to strong, but there was no statistical significance ($F_{1,18}=2.90; P=0.10; d=0.70; 95\% CI: -0.23, 1.57$) (Table 1). Finally, the main effect for Brace was not statistically significant and had a low effect size ($F_{1,18}=0.55; P=0.46; d=-0.14; 95\% CI: -1.01, 0.75$) (Table 2).
**Table 2**

**FOREFOOT RATIO**

<table>
<thead>
<tr>
<th>Group Main Effect</th>
<th>Brace Main Effect</th>
<th>Group by Brace Interaction</th>
<th>CAI</th>
<th>Control</th>
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<tr>
<td>F&lt;sub&gt;1,18&lt;/sub&gt;=2.90</td>
<td>F&lt;sub&gt;1,18&lt;/sub&gt;=.55</td>
<td>F&lt;sub&gt;1,18&lt;/sub&gt;=.96</td>
<td>1.66+/-.88</td>
<td>1.47+/-.62</td>
</tr>
<tr>
<td>P=.10</td>
<td>P=.46</td>
<td>P=.33</td>
<td>No Brace</td>
<td>Brace</td>
</tr>
<tr>
<td>Power=.36</td>
<td>Power=.10</td>
<td>Power=.15</td>
<td>No Brace</td>
<td>Brace</td>
</tr>
<tr>
<td>ES=.70(-.23,1.57)</td>
<td>ES=-.14(1.01,.75)</td>
<td>CAI Brace vs CAI NB</td>
<td>ES=-0.26(-1.13,.63)</td>
<td></td>
</tr>
<tr>
<td>Control Brace vs Control NB</td>
<td>ES=0.08(-.80,.95)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NB CAI vs NB Control</td>
<td>ES=0.80(-.14, 1.67)</td>
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<tr>
<td>Brace CAI vs Brace Control</td>
<td>ES=0.56(-.36,1.43)</td>
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</table>
Midfoot Ratio

For the midfoot regardless of Group, without a brace the ratio suggests more medial plantar pressure; but with when the brace was applied, the ratios suggest more lateral pressure distribution. Statistical significance was found for the Brace main effect when comparing the braced to non-braced trials for the midfoot indicating a greater ratio of medial midfoot pressure in the non-braced trials (p=.041). However, the effect size for this main effect was weak with wide confidence intervals that cross zero (d=-.36; 95%CI: -1.22, .54). This could be due to the relatively small sample size used (Table 2).

The group comparison produced no statistical significance or a strong effect size (F_{1,18}=35.27; p= .94; d=.03; 95%CI:.91, .85). The group by interactions produced no statistical significance or significant effect sizes (Table 3).
### Table 3

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<thead>
<tr>
<th>Group Main Effect</th>
<th>Brace Main Effect</th>
<th>Group by Interaction</th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F_{1,18} = .006$</td>
<td>$F_{1,18} = 4.83$</td>
<td>$F_{1,18} = .00$</td>
<td>1.11+/-.85</td>
</tr>
<tr>
<td>$P=0.94$</td>
<td>$P=0.041$</td>
<td>$P=0.99$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power=0.05</td>
<td>Power=0.54</td>
<td>Power=0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ES=-.03(-.91, .85)$</td>
<td>$ES=-.36(-1.22,.54)$</td>
<td>$CAI Brace vs CAI NB$</td>
<td>$ES=-.36(-1.23,.54)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Control Brace vs Control NB$</td>
<td>$ES=-.33(-1.2,.56)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$NB CAI vs NB Control$</td>
<td>$ES=-.03(-.90,.85)$</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Brace CAI vs Brace Control$</td>
<td>$ES=-.04(-.92,.84)$</td>
<td></td>
</tr>
</tbody>
</table>

- **CAI Brace vs CAI NB**: $ES=-.36(-1.23,.54)$
- **Control Brace vs Control NB**: $ES=-.33(-1.2,.56)$
- **NB CAI vs NB Control**: $ES=-.03(-.90,.85)$
- **Brace CAI vs Brace Control**: $ES=-.04(-.92,.84)$
**Rearfoot Ratio**

The group comparison produced no statistical significance ($F_{1,18}=1.22; p=.28, d=.42; 95\%CI=-.48,1.29$). The group by brace interaction model was not statistically significant ($F_{1,18}=.50; p=.48$). However, within the model, the effect sizes were strong for the CAI group braced versus non-braced comparison ($d=-1.10;(99\%CI=-1.99,-.12)$ and the control braced versus non-braced comparison ($-.88;(99\%CI=-1.75,.08$). Both of these interactions indicate a decrease in medial rear foot pressure after the application of an ankle brace. The between group interactions for non-braced ($d=.53;95\%CI=-.38,1.40$) and braced ($d=.27;95\%CI=-.62, 1.14$) conditions did not produce strong effect sizes. and

The brace main effect did produce statistical significance accompanied with a strong effect size ($F_{1,18}=16.09; p=.001;d=-.99;CI-1.88,-.03$). This indicates that there is a shift in the rearfoot ratio of pressure with the application of an ankle brace to more lateral pressure. Although the CI are large, they do not cross zero and the width may be due to the small sample size utilized (Table 4)
### Table 4

**REARFOOT RATIO**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group Main Effect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brace Main Effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group by Interaction</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>No Brace</strong></td>
<td>.89+/-11</td>
<td>.98+/-13</td>
</tr>
<tr>
<td><strong>Brace</strong></td>
<td>.98+/-13</td>
<td>.86+/-14</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>F&lt;sub&gt;1,18&lt;/sub&gt;=.50</td>
<td>F&lt;sub&gt;1,18&lt;/sub&gt;=1.22</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>P=0.28</td>
<td>P=0.001</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Power=.18</td>
<td>Power=.966</td>
</tr>
<tr>
<td><strong>ES</strong></td>
<td>ES=.42(-.48,1.29)</td>
<td>ES= -.99(-1.88, -.03)</td>
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</tbody>
</table>

**CAI Brace vs CAI NB**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong></td>
<td>ES=-1.10(-1.99, -.12)</td>
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</tr>
</tbody>
</table>

**Control Brace vs Control NB**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong></td>
<td>ES=-.88(-1.75, .08)</td>
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</tr>
</tbody>
</table>

**CAI NB vs Control NB**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong></td>
<td>ES=.53(-.38, 1.40)</td>
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</tr>
</tbody>
</table>

**CAI Brace vs Control Brace**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong></td>
<td>ES=.27(-.62, 1.14)</td>
<td></td>
</tr>
</tbody>
</table>
**Total Foot Ratio**

The total foot ratio produced no significance main effect for Group (F\(_{1,18}\)=2.51; p=.13; d=.64; 95% CI=-.29, 1.51); however the effect size was moderate indicating that the CAI group may display more medial total foot pressure than the control group, but the CI was large and crossed zero. (Table 4)

The group by brace interaction also was not statistically significant (F\(_{1,18}\)=1.24; p=.18). However, within the model, the braced versus non-braced comparison in the CAI group did yield a moderate effect size (d=-.73; 95% CI=-1.60,.21) indicating that there might be a shift in total foot pressure to the lateral side after the application of a brace, and this might become more statistically significant if there were a larger sample size. Additionally, comparing the CAI and control groups non-braced performance also produced a moderately strong effect size (d=.73; 95% CI=.20,1.60), indicating that CAI group displayed more medial pressure without a brace application. Both the Control group’s braced and non-braced comparison (d = -.34; 95% CI=1.21,.56), or the CAI versus control braced comparison(d=.48; 95% CI=-.43, 1.35) showed weak effect sizes.

The main effect for Brace comparison produced statistical significance along with a moderate effect size (F\(_{1,18}\)=6.18; p=.02; d=-.53; 95% CI=-1.4, .38). This indicates that the application of a brace changed the overall total foot pressure from more medial without the brace, to more lateral pressure with the brace. The moderate
effect size and large confidence intervals may be attributed to the small sample size (Table 5).

**Table 5**

<table>
<thead>
<tr>
<th></th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL FOOT RATIO</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Group Main Effect</strong></td>
<td>Brace Main Effect</td>
<td>Group by Interaction</td>
</tr>
<tr>
<td>$F_{1,18}=2.51$</td>
<td>$F_{1,18}=6.18$</td>
<td>$F_{1,18}=1.24$</td>
</tr>
<tr>
<td>$P=.13$</td>
<td>$P=.02$</td>
<td>$P=.27$</td>
</tr>
<tr>
<td>Power=.324</td>
<td>Power=.65</td>
<td>Power=.18</td>
</tr>
<tr>
<td>ES=(.64-.29,1.51)</td>
<td>ES=-.53(-1.4,.38)</td>
<td>CAI NB vs CAI Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control NB vs Control Brace</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CAI NB vs Control NB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CAI Brace vs Control Brace</td>
</tr>
</tbody>
</table>
Chapter Five

Discussion

The purpose of this study was to investigate the differences in plantar pressure distribution between individuals with and without chronic ankle instability as well as ankle bracing. Little is know about the effects that chronic ankle instability may have upon the distribution of pressure on the plantar surface of the foot during the dynamic task of landing from a jump. It was hypothesized that the CAI group would have a greater plantar pressure distribution under the lateral portion of the foot compared with the Healthy group based on findings from previous studies.\textsuperscript{14,29} However, this was not found to be the case; but this may be attributed to differences in task demands, as well as a low sample size.

In the forefoot and total foot ratios there were no statistical differences found between the CAI and Healthy groups in the medial to lateral pressure ratios, however moderate to strong effect sizes indicated that the CAI group displayed more medial forefoot pressure compared to the Control group. In the midfoot and rearfoot, there was little difference in between the groups, with both having slightly more medial pressure under the no brace condition. This seems to contradict the previous studies that reported more lateral plantar pressure among CAI subjects during gait.\textsuperscript{14,29} Perhaps landing creates a different landing pattern of plantar pressure, that may be amplified with a history of ankle sprain. When the foot makes contact with the ground from a vertical
landing, there is initial contact with the forefoot, and from our results, apparently more medial pressure distribution in the forefoot region. This is in contrast with gait in which initial ground contacts are more lateral in the rearfoot.

It is possible that the increases in medial pressure in the CAI group may be evident of a potential for ground reaction forces to create increased inversion moments, thus increasing potential injury risk. Another aspect that was not quantified in this analysis, but could have an influence, is that we do not know how rapid the peak pressures were achieved. It is possible that peak pressures may have been achieved more rapidly during this task, which may have a large influence on how and to what extent resultant ground reaction forces may be creating influence on stability during landing. Future investigations may need to consider this. So, it is possible that the higher medial pressures, along with the unknown influence of time to reach peak pressure could be contributing to recurrent instability in CAI subjects. While no subjects actually suffered an injury during testing, this may be an important piece in understanding the consequence of previous ankle injury on subsequent injury risk.

A secondary purpose was to explore the potential changes in pressure during a dynamic task while wearing a prophylactic ankle brace. We hypothesized that the application of the ankle brace would increase medial plantar pressure distribution in the CAI and Healthy groups. While we did not find strong statistical support, the bracing effect actually created more lateral distribution, thus refuting our hypotheses.

Statistical significance was found when comparing the braced to non-braced trials for the midfoot, as indicated by a greater ratio of medial midfoot pressure in the non-
braced trials. The associated effect size was not strong, but could be attributed to the relatively small sample size. These findings suggest that after the application of a brace there is a shift in plantar pressure to the lateral aspect of the foot, irregardless of the presence of CAI. This reveals that the brace may actually be decreasing the amount of pronation allowed at the subtalar during jump landing, keeping the foot in a more neutral position. Previous theories suggested that a more lateral pressure distribution would be indicative of a more supinated foot position, and therefore a greater potential for injury. But, as discussed above, we are not sure about the speed at which peak pressures were achieved. It is possible that the lateral shifting of plantar pressure could result in an increased resultant eversion moment to the ankle, creating more stability, during the more dynamic task of landing from a vertical jump. Again, future research will need to consider this factor further.

In the rearfoot, the statistical significant main effect for Brace and associated strong effect sizes indicated that the CAI and control groups both experienced a decrease in medial rearfoot pressure after the application of a brace. This data correlates with the findings from the midfoot that indicate that the brace is decreasing the amount of medial rearfoot pressure during jump landing.

Finally, the total foot pressure ratios produced statistical significance that indicated an overall shift in pressure from more medial to more lateral after the application of a brace. This also confirms the finding from the other regions of the foot that show a lateral change in pressure. Within the Group by Brace interaction, there was a strong effect size that indicated more medial pressure in the CAI group than in the control
group before the application of a brace. Although this was not statistically significant, with a larger sample size this may become a significant finding.

These findings suggest that there was an unexpected, but possibly important, effect of the ankle brace that created increased, rather than decreased lateral plantar pressure. It was initially hypothesized that the CAI group would demonstrate greater lateral pressure during a jump landing task, and that after the application of a prophylactic ankle brace both subject groups would experience a medial shift in pressure. What was found from this study was the opposite. The CAI and control group demonstrated very little differences in the non-braced condition, with the CAI group actually having slightly more medial pressure. Additionally, the application of a brace caused both groups to have an increase in lateral pressure.

Germanowski et al.\textsuperscript{29} found that taping and ankle bracing did not diminish lateral plantar pressure during walking, but did tend to increase peak medial pressure during jogging. There is no current literature that has examined plantar pressure during jumping and landing, so walking and jogging studies have to be used for comparison. Shmidt et al.\textsuperscript{14} found that there was more time spent and pressure on the lateral aspect of the foot in a chronic ankle instability group. One explanation for the differences in findings is that during walking the foot is loaded gradually, allowing the medial longitudinal arch to maintain its rigid position, where as during jump landing the foot is loaded quickly, taking away the ability to attenuate the force. As mentioned before, one reason for this could be that the ankle brace is keeping the sub-talar joint in a more neutral position, not allowing for pronation during the jump landing. Trials without the ankle brace allowed
the subjects to go past neutral into a more pronated position upon landing. This finding is consistent with the results from Robbins and Waked\textsuperscript{27} who found that the ankle brace kept the foot in a more neutral position upon landing to reduce the risk of injury and promote proper foot positioning.

So, overall it appears that increased lateral, rather than medial, plantar pressure may be indicative of a more stable distribution during landing. The CAI subjects demonstrated slightly more medial pressure distributions, and the introduction of an ankle brace encouraged more lateral pressure distribution. If we assume that a brace creates more stability, and CAI subjects should be more unstable, then this lateral pressure distribution during landing may be important to consider for future investigations.

A major limitation to this study is that the sample size was small. Due to time constraints, we were only able to enroll 10 subjects in each group. It is the intent of the research group to continue building this sample size to adequately address the hypotheses.

Another limitation of the project is that the brace conditions were not randomized. This project was part of a larger project that involved additional testing with the brace applied; and subsequently, the pressure sensors needed to be calibrated for the second phase of the larger project once the brace was applied. Subsequently, within the larger experimental design, the brace conditions were not randomized and always was the second condition. Future investigations should consider this factor.
Finally, a limitation to this study is that it is difficult to determine if the increase in lateral plantar pressure is due to the actual biomechanics of the jump landing, or the application of the brace, which adds pressure. When the ankle brace is applied, it could be increasing the pressure on the sensors due to the plastic and rigid nature of the brace. More research is needed to determine to what extent the brace application has on redistribution of plantar pressure during a variety of functional tasks to understand the potential benefits of the brace applications.

**Conclusion**

This study attempted to determine the effects that CAI and ankle bracing have on plantar pressure distributions during a dynamic task, such as jump landing. The evidence from this study suggests that ankle braces causes an increase in lateral foot pressure, which may be due to the rigid nature of the brace keeping the foot in a more neutral position during landing. This may be important to understanding how a brace application may be beneficial to preventing additional ankle injury. Additionally, we can draw a cautious conclusion that CAI subjects demonstrate more medial plantar pressure distributions during landing, especially in the forefoot; which also may provide insight on injury mechanisms during this task. To our knowledge, this research is the first step in utilizing the F-scan plantar pressure system to analyze plantar pressure during a jump landing. Future research should be done utilizing larger sample sizes as well as variations of ankle braces.
References


