A Thesis

entitled

The effects of fatigue on plantar pressure distribution in subjects with chronic ankle instability after jump-landing task.

by

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

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An Abstract of
The effects of fatigue on plantar pressure distribution in subjects with chronic ankle instability after jump-landing task.

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Objective: The purpose of this study is to examine the relationship of fatigue on plantar pressure distribution on subjects with chronic ankle instability after a jump-landing task.

Setting: Two separate 2-within (condition, time), repeated measures ANOVAs were performed for the dependant variables of Forefoot Medial:Lateral pressure ratio, Midfoot Medial:Lateral pressure ratio, Rearfoot Medial:Lateral pressure ratio, and Total Foot Medial:Lateral pressure ratio. Significance was set at p<.05. All data was recorded within the research laboratory. Subjects: Twenty physically active subjects were recruited from the University of Toledo community voluntarily. The individuals consisted of both Males and females between the ages of 18 and 30. Ten of the subjects were healthy subjects and had no previous lower extremity injuries. The other ten subjects had chronic ankle instability. Measurements: Subjects participated in one testing session that consisted of a jump-landing task with the use of plantar pressure insoles before and after a fatigue protocol. Three trials of a jump-landing task were performed under each condition. The jump-landing task consisted of a single-leg landing from a jump height equivalent to 50% of the subjects maximum jump height. (50% Vert\textsubscript{max}). The functional
fatigue task consisted of three stations: Southeast Missouri (SEMO) agility drill, forward lunges and quick hops at 50% $V_{t,max}$. Subjects performed the fatigue task until the time to finish increased by 50% compared to their fastest time. Post-Testing took place immediately after fatigue. **Results:** There were no statistically significant findings for Group, Time and Group by Time interactions for each of the variables: Forefoot Medial:Lateral pressure ratio, Midfoot Medial:Lateral pressure ratio, Rearfoot Medial:Lateral pressure ratio, and Total Foot Medial:Lateral pressure ratio. **Conclusion:** Previous work with plantar pressure systems demonstrated a pattern of increased lateral pressure during gait in CAI subjects that is theorized to contribute to increased risk of injury mechanism, plantar pressure distributions during a more dynamic task such as landing from a jump had not been conducted. Contradictory to previous studies and our hypotheses we did not find an increase in lateral plantar pressure distribution during a jump-landing task. Further research is needed with a larger sample size to make a better decision regarding the effects of fatigue and plantar pressure distribution within a jump-landing task.
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Chapter 1

Introduction

Lateral ankle sprains are one of the most common forms of injury in physical activity; especially in sports that involve dynamic jump landing tasks. Once lateral ankle sprains occur individuals are more susceptible to future sprains and can eventually lead to chronic ankle instability. Nearly 40% to 75% of individuals who have lateral ankle sprains will eventually develop chronic ankle instability.\textsuperscript{18, 35} Chronic ankle instability consists of two components, mechanical and functional instability. Mechanical instability consists of joint laxity whereas functional instability is associated with deficits in balance and neuromuscular control.\textsuperscript{31} With the combination of these components, fatigue can play an important factor in the reoccurrence of ankle sprains in those with chronic ankle instability.\textsuperscript{19} Ankle sprains typically occur within the latter portion of a bout of physical activity.\textsuperscript{8} This suggests that fatigue may play an important role in injury incidence and specifically in repeated ankle injuries. Neuromuscular control of a joint will decrease when the muscles surrounded are fatigued.\textsuperscript{8, 13, 16} Therefore, neuromuscular fatigue may be a factor that may influence lower extremity injuries. With a decrease in neuromuscular feedback, this puts the ankle in a more susceptible state for injury.\textsuperscript{23}
Fatigue has been shown to cause greater neuromuscular deficits in subjects with chronic ankle instability measured through dynamic postural control using the Star Excursion Balance Test.\textsuperscript{10} Additionally, multiple authors have observed a reduced level of dynamic stability when landing from a jump in subjects with CAI,\textsuperscript{10,29,32,33} as well as when fatigue was introduced\textsuperscript{10,24}. However, a recent investigation examined the effects of fatigue on persons with and without CAI.\textsuperscript{4,12} Consistent with previous work, fatigue created a decline in dynamic stability measured with Time to Stabilization. However, there was not a difference in the response to fatigue between those with and without CAI. To understand the mechanisms of recurrent injury among individuals with CAI, it may be important to examine the effects of fatigue during landing using other measures and indices.

Plantar pressure distribution may play a major role in individuals that have CAI. Plantar pressure systems have been able to demonstrate a increased lateral pressure distribution in those with CAI during gait analysis.\textsuperscript{27} This was consistent with Nyska et al.\textsuperscript{25} who reported that during a simple walking gait those with CAI demonstrated more pressure on the lateral forefoot causing a shift of the center of pressure. Additionally, previous studies have focused on plantar pressure distribution after augmented low-dye tape jobs and the effects the tape has on pronation of the foot.\textsuperscript{6,21,30} O’Sullivan et al\textsuperscript{21} and Vincenzino et al\textsuperscript{3} both concluded that the effect of augmented low-dye taping reduces both pronation and supination in the rearfoot. Plantar pressures recorded found that the use of the augmented low dye taping may be effective for reducing medial forefoot and rearfoot plantar pressures. The use of a plantar pressure system may help to
illustrate altered pressure distributions which could be useful in determining factors that may influence the reoccurrence of ankle sprains in those with CAI.

While previous work with plantar pressure systems have demonstrated a pattern of increased lateral pressure during gait in CAI subjects that is theorized to contribute to increased risk of injury mechanism, plantar pressure distributions during a more dynamic task such as landing from a jump has not been conducted. Additionally, since fatigue threatens dynamic stability, it is important to understand how fatigue may influence plantar pressure distributions during landing. Therefore the purpose of this study is to examine the relationship of fatigue on plantar pressure distribution on subjects with chronic ankle instability after a jump-landing task.

**Statement of the Problem and Purpose:**

The relationship between plantar pressure distribution, fatigue and chronic ankle instability has not been researched thoroughly. Fatigue has been proven to show neuromuscular deficits in subjects with CAI with postural control and dynamic control. It is not known if individuals with CAI have different peak plantar pressure distribution during landing and after fatigued conditions. The purpose of this study is to examine the relationship of fatigue on plantar pressure distribution among subjects with chronic ankle instability after a jump-landing task.

**Specific Aims and Hypothesis:**

Specific Aim #1: To compare the plantar pressure distributions during landing between those with and without CAI.
Hypothesis 1: CAI subjects will have increased lateral plantar pressure displacement when compared to healthy subjects.

Specific Aim #2: To examine the effect of fatigue on plantar pressure during landing.

Hypothesis 2a: Fatigue will increase lateral plantar pressure in subjects with and without CAI.

Hypothesis 2b: CAI subjects will experience a greater increase in lateral plantar pressure with fatigue than the Healthy subjects.

Limitations

Subjects will self report their past lower extremity injury history, which may alter subjects validity of having self reported CAI. Fatigue will not be measured by EMG and it can only be assumed that subjects are always giving their maximal effort during fatigue protocol. Each subject will bring his or her own shoes, which may alter plantar, pressure displacement.

Significance of the Study

Fatigue and CAI are two common issues that plague most athletes. This study may help clinicians determine if fatigue affects CAI peak plantar pressures. This in turn will help clinicians determine the appropriate interventions for reducing risk factors for ankle injuries.
Chapter 2

Chronic Ankle Instability

Once lateral ankle sprains occur, individuals are more susceptible to future sprains and can eventually lead to chronic ankle instability. Nearly 40% to 75% of individuals who have lateral ankle sprains will eventually develop chronic ankle instability.\textsuperscript{18,35} Chronic ankle instability has been described by Hertel \textsuperscript{17} as the occurrence of repetitive amounts of lateral ankle instability which results in numerous ankle sprains. Chronic ankle instability may consist of two components, mechanical and functional instability or the combination of both.

\textit{Mechanical Ankle Instability}

Mechanical instability is defined as joint laxity after an ankle ligament injury. Mechanical instability alters the mechanics within the ankle joint complex after initial ankle sprain, which in turn will lead to insufficiencies. With altered mechanics this can lead to laxity, impaired arthrokinematics, inflammation, impingement, and degenerative changes.\textsuperscript{17} Within mechanical instability lateral ligamentous laxity can occur. Through interruptions to appropriate and thorough ligament healing.\textsuperscript{18}

The amount of laxity present is determined on the amount of damage to the lateral ligaments that had occurred during the time of injury. Laxity is seen within the talocrual
and subtalar joints. Laxity within the talocrural joint is seen with injury to the ATFL and CFL. 22

Arthrokinematic changes within the ankle joint complex have been seen in subjects with CAI. It is suggested that subjects with CAI have an anteriorly and inferior displaced fibula. This allows the ATFL to have more slack within a resting position (17) This in turn allows the talus to go through a greater ROM before the ATFL even becomes taut.

It is also shown that subjects with CAI may have restricted dorsiflexion. 26 With a lack of range of motion this makes those with CAI more susceptible to a lateral ankle sprain. If the talocrural joint is not able to reach full dorsiflexion the joint is unable to reach a closed pack position during stance phase and will be able to invert and internally rotate more easily. 17,18 This in turn will predispose the subject to reoccurring ankle sprains. Other potential contributions to mechanical ankle instability also include synovial inflammation, impingement and degenerative changes to the ankle joint. 17

Functional Ankle Instability

Functional ankle instability is defined by alterations in one of more of the following: proprioception, neuromuscular control, postural control, and strength. 17 When a joint becomes injured the athlete’s sense of joint position becomes hindered. This decreases their ability to properly stabilize the joint and to prevent further injury. A loss in proprioception has been shown to influence the increase in reoccurring ankle sprains. 17,34 Lentell et al. looked at how proprioception, muscle activity and laxity contribute to functional instability. By having the subjects recreate joint positions, the subjects with
functional ankle instability demonstrated that their joint position sense was reduced significantly. They concluded that trauma and loss of function does occur to mechanoreceptors that normally fire in response to joint movement.

Deficiencies in postural control are often seen in individuals suffering from both acute ankle sprains and CAI. These deficits are linked to deficits in both impaired proprioception and neuromuscular control. \textsuperscript{16} Postural control deficiencies are often seen in the use of a single leg stance in those with acute ankle sprains and in those with CAI. During a single-leg stance the foot pronates and supinates in order to maintain the body’s center of gravity, this is called the “ankle strategy.” Due to changes in central neural control that occurs, individuals with CAI use the “hip strategy” to maintain balance.\textsuperscript{17} The hip strategy is less efficient. An assessment protocol that measures multiple insufficiencies with chronic ankle instability is the star excursion balance test. In a study by Gribble et al \textsuperscript{10} by using the star excursion balance test. They found that individuals with CAI had reached significantly less in all three directions measured on their involved leg when compared to that of their uninjured side. These results demonstrate that there are alterations in neuromuscular control that occur after an ankle sprain. This suggests that further rehabilitation needs to continue after an initial ankle sprain. By using a rehabilitation program that focuses on proprioception, neuromuscular control and balance training it will reduce the risk of recurrent ankle sprains. \textsuperscript{17}

\textbf{Fatigue}

Fatigue can play an important factor in the reoccurrence of ankle sprains in those with chronic ankle instability. \textsuperscript{19} Muscle fatigue has been shown to alter biomechanics
even in healthy subjects during sporting activities that include cutting and sprinting. \(^2\)

Ankle sprains typically occur within the latter portion of physical activity. \(^2\,8\) This may play a major role in repeated ankle injuries. Any changes in muscle performance that is caused by fatigue will affect the body in preventing injury. \(^23\) Fatigue occurs both at the central and peripheral levels. Peripheral fatigue occurs at the muscle or muscle group. \(^16\) Peripheral refers to the reduced activity of the muscle spindles. Conversely, central fatigue occurs from a lack of drive or motivation.

Previous studies have used isokinetic protocols to induce fatigue to simulate neuromuscular deficits that may take place within the ankle joint musculature. Isokinetic fatigue is defined commonly a force production decrease below 50% of the peak force. \(^19\) In a study done by Jackson et. al\(^{19}\) the use of inversion perturbations of the peroneals after fatigue was used to study the stretch reflex response in the ankle musculature. When looking at the stretch reflex response in ankle inversion injuries, they are caused by an inability of the peroneal muscles to eccentrically resist the inversion movement. The results of this particular study showed that there was a decrease in the reflex amplitude of the peroneals, suggesting that fatigue may impair an individual’s ability to correct for ankle inversion after the inducement of fatigue. Several studies looking at isokinetic fatigue suggest using functional fatigue protocols, which in turn will help utilize peripheral fatigue and involve central fatigue as well, that is experienced within sporting activities. \(^14,19,26\)

Fatigue alters postural control due to the decreased activity of the muscle spindles, which play an important role in stability. \(^16\) Studies looking at altered postural control often used simple postural or static measures after fatigue protocols. The use of
these static protocols fail to recognize the deficits that may occur in sport specific activities. In a study done by Gribble et al.\textsuperscript{10} the Star Excursion Balance Test (SEBT) was used to determine how dynamic postural control is affected by fatigue and CAI. Within the study they were able to find that after the onset of fatigue, the injured side of the CAI group demonstrated a greater reduction in maximum reach distances when compared to the control subjects. This demonstrates that although after fatigue the athlete may be able to complete the motor task, the method may be less efficient and create a possible threat of injury, suggesting that they may have altered neuromuscular control.

Fatigue also has a negative influence during more dynamic, functional tasks. Several studies looked at a single hop landing and the biomechanical changes that take place after the onset of fatigue upon landing. Augustsson et al.\textsuperscript{2} looked at hip movements and ground reaction forces during a single let hop take off and landing following the inducement of fatigue. After fatigue, subjects showed less Anterior Posterior GRF during take off and had a significantly less ability to generate power and decreased joint movements at all hip, knee and ankle joints. The fatigued subjects also jumped a lesser distance, which resulted in a lower GRF during landing and decreased hip movements. Orshimo and Kremenic\textsuperscript{26} also looked at the effects of fatigue on a single leg hop. By utilizing a step up fatigue protocol they were able to find that subjects took more time in the deceleration of their center of mass, which resulted in a significant increase in knee flexion at landing after the inducement of fatigue. After fatigue the ankle also remained within a dorsiflexed position throughout landing. From the results they found the ankle to be the main contributor to the maximal total support moment increase after fatigue.
Because fatigue was occurring within the proximal musculature of the ankle, the ankle was forced to slow the progression of the center of mass to prevent a lower extremity collapse. 26 By having a dorsiflexed position upon landing, the ankle length tension relationships have changed, which allows the plantar flexors to absorb more energy and provide support. These results suggest that muscle fatigue does alter biomechanics and may help to identify compensatory mechanisms in those with pathologies such as CAI.

**Plantar Pressure**

Plantar pressure systems measure the amount of mass or force being distributed across the plantar surface of the foot using. 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. Studies have found that the F-Scan has fair to good reliability 1. Plantar pressure systems may play a major role in individuals that have chronic ankle instability by looking at peak plantar pressure distribution within sport specific activities such as a jump landing task. The use of this instrumentation in those with CAI may play a role in the prevention of future injuries. The plantar pressure system has been used predominantly with gait analysis but with little research conducted on with those with chronic ankle instability. Previous studies have focused on plantar pressure distribution after augmented low-dye tape jobs and the effects the tape has on pronation of the foot.6, 21 O’Sullivan et al 21 and Vincenzino et al 3 both concluded that the effect of augmented low-dye taping reduces both pronation and supination in the rearfoot. Plantar pressures recorded in each found that the use of the augmented low dye taping may be effective if
wanting to reduce medial forefoot and rearfoot plantar pressures. Vincenzino et al.\textsuperscript{30} also looked at the augmented low dye taping technique, like the previous two studies, they found that the augmented tape job technique not only altered pronation but also supination as well in the rearfoot. Unlike the other two studies, they looked at the effectiveness of the tape job after walking and jogging. The concluded that after the application of ALD plantar pressures were altered, showing increases in peak and mean maximum pressures in the lateral midfoot in both walking and jogging. There has been very limited research conducted with individuals with CAI. Nyska et al. looked at subjects with CAI within a walking protocol. Within a simple walking gait those with CAI demonstrated more pressure on the lateral forefoot causing a shift of the center of pressure.\textsuperscript{25} Schmidt et al.\textsuperscript{28} looked at plantar pressure distribution and forces with an in shoe plantar pressure system during jogging in those with CAI. This is the first study conducted with the use of an in shoe plantar pressure system to study those with CAI. Each subject was asked to jog on a treadmill at a set pace for three trials where 10 consecutive steps were recorded. From the three trials they looked at plantar pressure time integrals, maximum force, time to maximum force and forced time integral in all the lateral rear foot, midfoot and forefoot. With the data recorded they concluded that those with CAI had greater plantar pressures and forces demonstrated on the lateral rearfoot, midfoot and forefoot in comparison to the control group.\textsuperscript{27} Morrison et. al\textsuperscript{20} also looked at CAI subjects within a barefoot running protocol. Subjects were asked to perform a running protocol across a Tekscan plantar pressure floor mat. Rearfoot medial/lateral ratio, foot strike and center of pressure trajectory were recorded. They concluded that CAI subjects have more lateral foot positioning and loading pattern during barefoot
running when compared to healthy subjects, which was demonstrated in the center of pressure trajectories and pressure distributions. Because those with CAI in the previous study demonstrated greater forces on the lateral aspect of the foot within a jogging state, this could be a factor in the reoccurrence of ankle sprains in those with CAI. As mentioned in the studies above those with CAI demonstrate greater lateral forces and lateral plantar pressure distributions within both a walking and jogging protocol. Not much research has been done with the effects of fatigue and plantar pressure distribution in those with CAI. The effects of the inducement of fatigue may alter peak plantar pressure forces that are distributed; this may be seen after a jump-landing task. This puts the subject in a more sport specific like environment and can give insight to clinicians

**Summary**

Fatigue has been proven to show negative effects on neuromuscular deficits in subjects with CAI with postural control and dynamic control.\(^9,10\) Until recently, plantar pressure systems in the past have only looked at plantar pressure distributions within a walking gait in those with CAI.\(^25\) It has been observed that those with CAI demonstrate greater lateral plantar pressure distribution within both walking and jogging protocols.\(^25,27\) Not much research has been done looking at the effects of fatigue and plantar pressure distribution in subjects with CAI after a jump-landing task.
Chapter 3

Subjects

Twenty physically active subjects were recruited from the University of Toledo community voluntarily. The individuals consisted of both males and females between the ages of 18 and 30. Ten of the subjects were healthy subjects and had no previous lower extremity injuries. The other ten subjects had chronic ankle instability. The subjects were matched by age, sex, height, mass and the injured leg (Table 1).

Table 1. Subject Demographics.

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>Age</th>
<th>Height</th>
<th>Mass</th>
<th>FADI</th>
<th>FADI Sport</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAI (n=10)</td>
<td>M=6</td>
<td>F=4</td>
<td>21.2 +/- 1.72</td>
<td>68.6 +/- 3.60</td>
<td>167 +/- 23.93</td>
<td>76.44 +/- 3.47</td>
</tr>
<tr>
<td>Control (n=10)</td>
<td>M=6</td>
<td>F=4</td>
<td>22.2 +/- 2.16</td>
<td>69.9 +/- 3.72</td>
<td>179.9 +/- 21.57</td>
<td>99 +/- 2.65</td>
</tr>
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</table>

CAI within this study was defined as if the individual has a history of at least one ankle acute ankle sprain which led to swelling, pain and loss of function. The individuals also had a history of more than once having the sensation of “giving way” within the past 6 months. Each subject was given a specific questionnaire regarding previous ankle injuries. Subjects with reported CAI also had to fill out the Foot and Ankle Disability Index (FADI) and the FADI Sport Scale. These questionnaires were used to determine CAI group. These instruments have been used to determine CAI group inclusion using
cut-off scores of <90% on the FADI and <80% on the FADI Sport Scale. Subjects will also then read and sign an informed consent form that was approved by the University Institutional Review Board.

**Instrumentation**

To measure the subjects’ standing maximum and 50% vertical jump height a Vertec vertical jump tester (Sports Imports, Columbus, OH) was used. A plantar pressure F-Scan was used to determine the plantar pressure distribution. The insole was divided in a 6-area grid that will represent the plantar surface of the foot. The following areas were looked at: medial forefoot, lateral forefoot, medial midfoot, lateral midfoot, medial rearfoot, and lateral rearfoot. From these foot regions, ratios of medial:lateral pressure distribution will be calculated and serve as the dependant variables as follows: 1) Forefoot Medial:Lateral ratio, 2) Midfoot Medial:Lateral ratio, 3) Rearfoot Medial:Lateral ratio and 4) Total Medial:Lateral ratio. Tekscan Software was used to analyze the data. During the functional fatigue protocol an A Monark Ergomedic 828E ergometer (Monark Exercise AB; Vansbro, Sweden) was used. A Seiko DM50L Metronome (Seiko Corp., Mahwah, NJ) was used to standardize the lunge cycles during the fatigue protocol.

**Independent Variables**

**Repeated Measures**

1. Group
   a. Healthy
b. CAI

2. Time
   a. Pre-fatigue
   b. Post-fatigue

**Dependent Variables**

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

**Procedures**

Each subject was asked to report to the research laboratory for one testing session. Subjects was asked to wear comfortable athletic shoes and athletic clothing for each testing session and requested to bring a second pair of athletic shoes and pair of socks. Upon arrival for the session, the subject was asked to complete paperwork (informed consent, injury history, FADI instruments), Also, a recording of height and mass, establishing the maximum vertical jump height. During the session, subjects completed a single-leg jump-landing task before and after the completion of the functional fatigue protocol.
Each subject’s maximum vertical jump height was determined using the Vertec vertical jump tester. Initially, the subjects’ standing reach height was measured. This was done 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, subject’s maximum vertical jump height was measured. The subject was instructed to jump off both feet and reach up to touch the highest point possible on the Vertec. Each subject will complete three trials of the vertical jump 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 trial.

After a 5-minute rest, calibration of plantar system was established at the end of this testing session. Insoles were inserted into the subjects’ shoes and the subject was instructed to “load” each insole with full body weight for 1 second.

The subjects completed the fatigue protocol. Each subject ran through the protocol until the time to finish each of the stations had increased to 50%. The fatigue protocol consisted of a five minute warm up on a stationary bike, lower extremity stretching, and the following exercises in the order as follows:

1. *The Southeast Missouri (SEMO) Agility Drill.* The SEMO agility drill is a series of a forward sprints, diagonal backpedaling, and side shuffling. This was completed in a rectangle of 12 x 12 feet.

2. *Stationary lunges.* This consisted of five forward lunges per leg from the starting position of the SEMO agility drill. Subjects lunged forward to a distance equal to their individual leg length. Pieces of tape on the floor served as the point of
origin and the target reaching distance. Lunges performed at a rate of one lunge per two seconds. A metronome was used to establish the rate of performance for the subjects. A lunge cycle was defined as having the subject reach to the target, achieve approximately 90° of hip and knee flexion in the lunging leg while maintaining an upright trunk, and returning the reaching leg back to the point of origin.

3. **Quick jumps done at 50% of each subject’s Vert\textsubscript{max}.** This will be done near a wall and will consist of ten quick, two-footed jumps with both arms above the head reaching for a mark on the wall equal to 50% of the previously measured maximum jump height.

Each of the components of the fatigue protocol were completed as fast as possible in the order listed above.

Once fatigue is induced, the subject then changed socks and shoes with the plantar pressure insoles attached and go back to the jump-testing point and perform three post fatigue trials of the single-leg jump-landing task.

During the pre and post-test, subjects completed the single-leg jump-landing task. The jump-landing task consists of a jump at 50% of their Vert\textsubscript{max} and a single leg landing. The subject group with CAI landed on their injured leg, while healthy subjects landed on the same leg as their CAI matched subject. Each subject will be given instructions and demonstrations of the jump-landing task and will be given four practice trials prior to their test trials.

The jump landing task begins with the subject standing 70 cm away from the force platform, jumping with both feet and reach up to touch the indicated marker on the
Vertec, which will be 50% of their \( \text{Vert}_{\text{max}} \). The subject then landed on a single leg onto the force plate. They were instructed to land on their test leg, while stabilizing as quickly as possible and placing both hands on their hips. They were given four practice trials at the beginning of the second testing sessions to become accustomed to the task and minimize a learning effect. During the testing, three trials will be completed both before and after the fatigue protocol. The mean of these three trials were recorded. If during the three trials the subject lost their balance or touched down with the non-test leg, it was considered a failed trial and was repeated until three successful trials are completed.

During the fatigue protocol, the pressure insoles that were calibrated stayed inserted within the shoes and subjects were asked to complete the fatigue protocol in another pair. Immediately after completing the fatigue protocol, the subject was asked to change socks and the shoes with the insoles will be put on and the post-test landing trials will be performed. It is estimated that the post-test trials were commenced in less than 3 minutes after the targeted level of fatigue is achieved.

**Data Processing**

**Statistical Analysis**

The four plantar pressure ratios from the pre- and post-test trials will be used in the statistical analysis. Each plantar pressure distribution was divided into six sections of the foot, medial, lateral forefoot, midfoot and rearfoot. Each division peak PSI was found using the Tekscan software. With each peak PSI, a ratio was interpreted by taking each of the medial peak pressures and lateral pressures within each section of the foot. A ratio of greater than 1 indicated more medial pressure was distributed within that section of the
foot; while a ratio of less than one indicated that more lateral pressure was distributed in that region. This was done for each the forefoot, midfoot, rearfoot and total foot. For each of these four dependant variables, a separate 1-within (Time), 1-between (Group) repeated measures ANOVA were performed. Statistical significance was set a priori at p<.05. All statistical analysis was performed using SPSS 17.0 (SPSS, Inc. Chicago, IL.).

**Potential Health Risks**

Subjects were given verbal and visual instructions and adequate practice time for the jump-landing task and fatigue protocols in order to minimize the risk of injury. Subjects were monitored during this time to make sure proper technique was being performed.

Subjects may also have experience muscle soreness upon the completion of the functional fatigue protocol. If subjects experience any problems due to testing, they may drop out at any time.
Chapter 4

Results

Forefoot Medial/Lateral Ratio

The Group by Time interaction was not statistically significant ($F_{1,18}=3.086; p=.096$). While not significantly different, a strong effect size ($d=0.80; 95\% CI: -0.15,1.67$) indicated that subjects in the CAI group demonstrated greater medial forefoot pressure than those in the healthy group prior to fatigue (Table 2). Additionally, subjects within the healthy group demonstrated greater medial forefoot pressure following fatigue ($d=0.53; 95\% CI: -1.40,0.39$). All other comparisons had weak associated effect sizes.

The main effect for Group was not statistically significant ($F_{1,18}= 1.86 p= 0.193$; $d=0.46; 95\% CI: -0.35, 1.43$) (Table 2). Finally, the main effect for Fatigue was not statistically significant ($F_{1,18}= .000 \ p=.990; d=0.00; 95\% CI: -0.62, 0.62$) (Table 2).

Midfoot Medial/Lateral Ratio

The Group by Time interaction was not statistically significant ($F_{1,18}=0.001\ p=.981$) with both groups demonstrating similar plantar pressure distribution of the midfoot prior and after the fatigue condition. (Table 3) All other comparisons had weaker associated effect sizes.
The main effect for Group was not statistically significant (F_{1,18} = 0.013; p = 0.911; d=0.45; 95%CI: -0.91, 0.84) (Table 3). Finally, the main effect for Fatigue was not statistically significant (F_{1,18} = 1.296, p = 0.270; d=0.32; 95%CI: -0.31, 0.94) (Table 3).

**Rearfoot Medial/Lateral Ratio**

The Group by Time interaction was not statistically significant (F_{1,18} = 0.900; p = 0.355). Although not significantly different, a moderate to strong effect size (d = 0.77; 95% CI: -0.17, 1.64) indicated that subjects in the CAI group demonstrated greater medial rearfoot pressure than those in the healthy group prior to fatigue (Table 4). All other comparisons had weaker associated effect sizes.

The main effect for Group was not statistically significant (F_{1,18} = 0.845; p = 0.370; d=0.45; 95%CI: -0.54, 1.23) (Table 4). Finally, the main effect for Fatigue was not statistically significant (F_{1,18} = 0.504; p = 0.229; d=0.15; 95%CI: 0.77, 0.47) (Table 4).

**Total Foot Medial/Lateral Ratio**

The Group by Time interaction was not statistically significant (F_{1,18} = 0.131; p = 0.722). Although not significantly different, a moderately strong effect size (d = 0.73; 95% CI: -0.20, 1.60) indicated that subjects in the CAI group demonstrated greater medial total foot pressure than those in the healthy group prior to fatigue (Table 5). All other comparisons had weaker associated effect sizes.

The main effect for Group was not statistically significant (F_{1,18} = 1.853; p = 0.190; d=0.45; 95%CI: -0.42, 1.35) (Table 5). Finally, the main effect for Fatigue was not statistically significant (F_{1,18} = 1.550; p = 0.229; d=0.10; 95%CI: -0.52, 0.72) (Table 5).
Table 2. Forefoot Ratio

<table>
<thead>
<tr>
<th>Group Main Effect</th>
<th>Fatigue Main Effect</th>
<th>Group Interaction</th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{1.18} = 1.82, p=0.193$</td>
<td>$F_{1.18} = 3.08, p=0.096$</td>
<td>Pre-Fatigue</td>
<td>Fatigue</td>
<td>Pre-Fatigue</td>
</tr>
<tr>
<td>Power = 1.00</td>
<td>Power = 0.050</td>
<td>Power = 0.383</td>
<td>1.669 +/- 0.885</td>
<td>1.474 +/- 0.2557</td>
</tr>
<tr>
<td>ES = 0.46 95% CI (-0.35, 1.43)</td>
<td>ES = 0.0 95% CI (-0.62, 0.62)</td>
<td>ES:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Pre Fatigue - CAI vs Control: 0.80 (-0.15, 1.67)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>2. Post Fatigue - CAI vs Control: 0.25 (-0.64, 1.12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. CAI Pre vs. Post: 0.26, (-0.63, 1.13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Control Pre vs. Post: 0.53 (-1.40, 0.39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Midfoot Ratio

<table>
<thead>
<tr>
<th>Group Main Effect</th>
<th>Fatigue Main Effect</th>
<th>Group Interaction</th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{1:18} = .01, p = .911$</td>
<td>$F_{1:18} = 1.296, p = .270$</td>
<td>$F_{1:18} = .001, p = .981$</td>
<td>Pre-Fatigue</td>
<td>Fatigue</td>
</tr>
<tr>
<td>Power=1.00</td>
<td>Power=.190</td>
<td>Power=.05</td>
<td>1.118 +/- .853</td>
<td>.861 +/- .447</td>
</tr>
</tbody>
</table>

ES= 0.45 95% CI (-0.91, 0.84)  
ES= 0.32 95% CI (-0.31, .94)  
ES:  
1. Pre Fatigue - CAI vs Control: 0.03 (-0.90, .85)  
2. Post Fatigue – CAI vs. Control: 0.06 (-.94, 0.82)  
3. CAI Pre vs. Post: 0.38 (-0.52, 1.24)  
4. Control Pre vs. Post: 0.27 (-0.62, 1.14)
### Table 4. Rearfoot Ratio

<table>
<thead>
<tr>
<th>Group Main Effect</th>
<th>Fatigue Main Effect</th>
<th>Group Interaction</th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>F$_{1:18}$ = .845, p=.370</td>
<td>F$_{1:18}$ = .504, p=.487</td>
<td>F$_{1:18}$ = .900, p=.355</td>
<td>Pre-Fatigue</td>
<td>Pre-Fatigue</td>
</tr>
<tr>
<td>Power= .140</td>
<td>Power= 0.103</td>
<td>Power= .146</td>
<td>1.068 +/- .189</td>
<td>1.060 +/- .152</td>
</tr>
<tr>
<td>ES=0.45 95% CI (-0.54, 1.23)</td>
<td>ES= 0.15(-0.77, 0.47) 95% CI (-0.62, 0.62)</td>
<td>ES:</td>
<td>1.036 +/- .132</td>
<td></td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>1. Pre Fatigue - CAI vs Control: 0.77 (-0.17, 1.64)</td>
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<td></td>
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</tr>
<tr>
<td>2. Post Fatigue – CAI vs Control: 0.17(-0.72, 1.04)</td>
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<tr>
<td>3. CAI Pre vs. Post: 0.05 (-0.83, 0.92)</td>
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<tr>
<td>4. Control Pre vs. Post: 0.41 (-1.28,0.49)</td>
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</tbody>
</table>
### Table 5. Total Ratio

<table>
<thead>
<tr>
<th>Group Main Effect</th>
<th>Fatigue Main Effect</th>
<th>Group Interaction</th>
<th>CAI</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{1,18} = 1.82, p=193$</td>
<td>$F_{1,18} = 1.550, p=.229$</td>
<td>Pre-Fatigue</td>
<td>Fatigue</td>
<td>Pre-Fatigue</td>
</tr>
<tr>
<td>Power=1.00</td>
<td>Power=.218</td>
<td>1.196 +/- .306</td>
<td>1.09 +/- .1485</td>
<td>1.003 +/- .216</td>
</tr>
<tr>
<td>ES=0.45 95% CI (-0.42, 1.35)</td>
<td>ES= 0.10 95% CI (-0.52, 0.72)</td>
<td>ES:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Pre Fatigue – CAI vs Control: 0.73 (-0.20, 1.60)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2. Post Fatigue – CAI vs Control: 0.14 (-0.74, 1.01)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. CAI Pre vs. Post: 0.44 (-0.46, 1.31)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Control Pre vs. Post: 0.26 (-1.13, 0.72)</td>
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</tbody>
</table>
Chapter 5

Discussion

The overall purpose of this study was to examine the relationship of fatigue on plantar pressure distribution on subjects with chronic ankle instability after a jump-landing task. We first hypothesized that CAI subjects will have increased lateral pressure displacement when compared to healthy subjects. Previous research by Nyska et al.\textsuperscript{25} examined plantar pressure among subjects with CAI during a walking protocol. Within this simple walking gait task, those with CAI demonstrated more pressure on the lateral forefoot causing a shift of the center of pressure. Similarly Schmidt et al.\textsuperscript{28} looked at plantar pressure distribution and forces with an in shoe plantar pressure system during jogging in those with CAI. Consistent with the Nyska et al.\textsuperscript{20,28} study, the CAI subjects had greater plantar pressures and forces demonstrated on the lateral rearfoot, midfoot and forefoot in comparison to the control group.\textsuperscript{27} Similar findings were also found with CAI subjects when asked to perform a barefoot running protocol.\textsuperscript{20} The results within our study are not in agreement with the previous studies, refuting our hypothesis that there would be increased lateral plantar pressure among the CAI subjects.

The previous studies\textsuperscript{20,27} found a greater rearfoot inversion in those with CAI, which would place more load and contact at the lateral rearfoot, creating greater lateral
plantar pressure values. It has been suggested that an increased inversion at the rearfoot will increase the potential of injuries during a dynamic activity such as running or a jump-landing. Unlike the previous studies, the CAI subjects in our study demonstrated more medial pressure distributions, but this could be attributed to the task differences. The previous studies looked at a walking gait and running pattern, while our study measured the plantar pressure distribution at impact during a jump landing task. Although with differences in medial lateral distributions, the medial distribution within the jump-landing task could be a potential factor to ankle injury; unlike a simple walking task, which demonstrated more lateral pressure. Potentially, during the jump-landing task, CAI subjects were landing with more medial pressure and possibly leading to a more rapid time to reach these peak medial pressures, which in turn could lead to an increased external inversion moments from the associated medial ground reaction forces, which could cause an inversion ankle sprain.

Secondly, we hypothesized that fatigue will increase lateral plantar pressure in both healthy and CAI subjects. Since no plantar pressure studies have been conducted looking at the effects of fatigue and plantar pressure distribution in either healthy or CAI subjects we based our hypothesis on previous studies that muscle fatigue does alter dynamic and postural control. Muscle fatigue has been shown to alter biomechanics even in healthy subjects. Therefore, we felt that fatigue would create a more lateral plantar pressure distribution, potentially creating a more injurious position for the ankle. However, our data does not support our hypotheses. Instead, both groups demonstrated greater medial plantar pressure ratios both before and after the fatigue condition. Therefore, fatigue may not have an affect on the plantar pressure distribution in those
with or without CAI. Not only may this may give insight into altered neuromuscular control and altered proximal joint kinematics within landing in subjects with CAI, but also after the inducement of fatigue in both healthy and those with CAI.

Fatigue has been shown to have a negative influence during more dynamic, functional tasks. Augustsson et al.\(^2\) looked at hip movements and ground reaction forces during a single leg hop take off and landing following the inducement of fatigue. After fatigue, subjects showed less Anterior Posterior GRF during take off and had a significantly less ability to generate power and decreased joint movements at all hip, knee and ankle joints. The fatigued subjects also jumped a lesser distance, which resulted in a lower GRF during landing and decreased hip movements. Results by Orshimo and Kremenic\(^26\) also looked at the effects of fatigue on a single leg hop, reporting a significant increase in knee flexion at landing after the inducement of fatigue, suggesting that the ankle also remained in a dorsiflexed position throughout landing. These results suggest that muscle fatigue does alter biomechanics and might help to identify compensatory mechanisms in those with pathologies such as CAI, and specifically why CAI groups demonstrated greater medial pressure upon landing. In a study done by Wikstrom et. al\(^7\) when looking at a landing in both subjects healthy and those with CAI the GRF demonstrated upon landing showed differences between the two groups. Like Orshimo and Kremenic, the CAI subjects demonstrated a more dorsiflexed position and demonstrated increased GRF.

These differences may be a factor for compensated or altered neuromuscular control in their ankle, which may be due to utilizing other compensatory mechanisms upon landing as mentioned above (ie. Hip strategy). An increased medial pressure
distribution could be indicative of a more dorsiflexed position of the ankle. Subtalar eversion and external rotation is coupled with dorsiflexion, which could help to explain the increased ground surface contact by the medial side of the foot. While we can only speculate, perhaps the induced fatigued led to compensation of increased knee and hip flexion, which would create more dorsiflexion. Coupling this phenomenon with the increased medial pressure distribution of the CAI group may be suggesting there is a compensatory pattern in the proximal joints designed to create more stability in the ankle (ie more dorsiflexion). The literature is inconsistent on this issue as Caulfield et al 5 reported increased knee flexion in CAI subjects during landing, while Gribble and Robinson 11 observed decreased knee flexion in CAI subjects during landing. More research will be needed to determine how the ankle, knee and hip are interacting during landing in those with CAI and in response to fatigue to better understand the consequences for ankle injury.

Although our hypotheses were not supported, there are still some clinical implications that can be taken from this study. One possible reason for lack of significant results could be from the small sample size. Due to limited availability, there were only 10 subjects recruited within each group. We feel it is important that research continues to further address the hypotheses we have presented in this study

There are several interesting relationships that are associated with moderate to strong effect sizes, mostly associated with Group main effects. This goes back to our first hypotheses that CAI subjects would demonstrate greater lateral plantar pressure distribution than that of the control group. The CAI group demonstrated greater medial pressure prior to fatigue both in the forefoot and rearfoot than the healthy subjects as
mentioned before. This could be linked to the altered proximal joint kinematics or protective mechanisms to prevent future inversion of the ankle. The main effect for group and fatigue had low effect sizes for rearfoot and midfoot. Low effect sizes were not expected for fatigue, because fatigue has shown to increase dynamic and postural instability. Although fatigue may not influence plantar pressure, the data recorded was within the first second of initial contact within the landing task. This shows us that fatigue may not be a factor in the plantar pressure distribution in those with CAI but altered neuromuscular control and proximal joint kinematics may be more important to look at in prevention.

Limitations

There are several limitations that could have possibly altered the results of our study. The first possible limitation is the large number of failed trials after the inducement of fatigue. With each failed trial a subject was able to rest and have more time in-between the recorded trials. This would have caused changes in the post-fatigue peak plantar pressure distributions. Also, the subjects after completing the fatigue protocol were asked to change socks and switch shoes. This like the failed trials may have allowed the subjects time to rest before recorded trials were done. Every effort was made to progress the participants through the post-testing trials as quickly and as safely as possible

Each fatigue protocol was based on the subjects’ performance time and was not recorded by EMG. This could have caused subjects to quit before fatigued and cause the
post fatigue trials to be altered. The lack of familiarity with the plantar pressure insoles and equipment could have influenced both the pre and post fatigue trials. The presence of the plantar pressure equipment could have caused the subjects to concentrate more on the insoles and the equipment itself then on the jump landing task. Perhaps future research should afford a period of familiarization with the insoles.

**Future Directions**

Although, our study did not provide statistically significant findings regarding the effects of fatigue on plantar pressure distribution we feel our study may have identified some important observations that should lead to continued research. Significant results may be seen with a larger sample size. Previous studies also looked at center of pressure trajectory, which may show different results than what was demonstrated within our study. The use of a force plate in conjunction with the plantar pressure system may show an increase in Medial lateral ground reaction forces upon landing that may in turn give more insight to compensatory mechanisms CAI subjects are producing at the proximal joint.

**Conclusion**

The study was conducted to examine the relationship of fatigue on plantar pressure distribution on subjects with chronic ankle instability after a jump-landing task. Previous work with plantar pressure systems demonstrated a pattern of increased lateral pressure during gait in CAI subjects that is theorized to contribute to increased risk of injury mechanism, plantar pressure distributions during a more dynamic task such as
landing from a jump had not been conducted. Contradictory to previous studies and our hypotheses we did not find an increase in lateral plantar pressure distribution during a jump-landing task. Although, fatigue threatens dynamic stability, fatigue did not influence plantar pressure distributions during landing. Further research is needed with a larger sample size to make a better decision regarding the effects of fatigue and plantar pressure distribution within a jump-landing task.
References


Damien Nolan NK. Effects of low-day taping on plantar pressure pre and post exercise: an exploratory study. BMC Musculoskeletal Disorders. 2009;10(40).


Nyska M, Shabat S, Simkin A, Neeb M, Matan Y, Mann G. Dynamic


