A Thesis

entitled

Effects of Hip Rehabilitation Intervention on Dynamic Postural Control and Self-Reported Ankle Impairment in Patients with Chronic Ankle Instability

by

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

Master of Science Degree in Exercise Science

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An Abstract of

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Objective: The objective of this study was to determine the effectiveness of two intervention programs focusing on proximal alterations or distal alterations on improving dynamic postural control and self-reported disability in patients with chronic ankle instability (CAI). Design and Setting: A double blinded, randomized control trial was conducted in a laboratory setting. Subjects: Twelve patients with CAI were randomly assigned to an Ankle intervention group (4 males, 2 females; 21.5±2.81 years; 176.74±10.91 cm; 83.14±20.85 kg), or to an Ankle/Glut intervention group (2 males, 4 females; 19.5±1.52 years; 168.48±7.82 cm; 80.74±27.63 kg). Procedure: Experimental measures were measured pre- and post-intervention period. All participants filled out the Foot and Ankle Ability Measure (FAAM) and FAAM Sport during pre- and post-testing to test for improvement in self-reported function following the intervention. The Star Excursion Balance Test (SEBT) and Time to Stabilization (TTS) were tools used to assess dynamic postural control. Lastly, the participant’s hip abduction strength (HABD) and external rotation strength (ER) were determined using a hand-held dynamometer. Hip ER was tested in a seated position, while HABD was tested in a sidelying position. Participants were randomly assigned to the Ankle or Ankle/Glut intervention group and
took part in a four-week exercise program. The Ankle intervention group participated in traditional ankle rehabilitation of four directional therabands, wobbleboard, and single-leg balance exercises, whereas the Ankle/Glut intervention group took part in the same traditional ankle rehabilitation along with gluteal exercises of rotational lunges and rotational squats. Both groups met twice a week, for approximately 20 minute sessions, with the first exercise intervention occurring immediately following pre-testing of outcome measures and the day prior to post-testing after four-weeks. During the first week, the gluteal exercises were performed with no resistance. During the 2-4 weeks of the intervention, participants wore a weight vest to which 5% of body mass was added each week, resulting in resistances of 5%, 10%, and 15% of body mass during weeks 2, 3, and 4, respectively, of the intervention. Significance was determined using dependent t-tests between pre and post values (p<0.05). Cohen’s $d$ effect sizes with corresponding 95% confidence intervals (CI) were calculated. Results: The pre-post intervention difference for the FAAM was significantly different between groups ($p=0.02$), with the Ankle group reporting a greater improvement in self-reported disability after the intervention period. All other pre-post comparisons were not statistically significant between groups. Moderate effect sizes showed greater improvement in the Ankle/Glut rehabilitation group compared to the Ankle group for resultant vector TTS ($d=0.57$), HABD ($d=0.60$), ER ($d=-0.75$) and posteriorlateral SEBT ($d=-0.65$); however the 95% CI for these comparisons all crossed zero. Conclusion: This study provides support that the Ankle rehabilitation was more effective at increasing self-reported function when compared to Ankle/Glut rehabilitation. There is limited support that the Ankle/Glut intervention may reduce functional instability associated with CAI, as well as strengthen
the hip musculature. We believe this study will be instrumental in creating a
rehabilitation paradigm shift that incorporates interventions that alleviate proximal joint
alterations that are commonly seen in those with CAI.
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Chapter One

Introduction

1.1 Introduction

Lateral ankle sprains are the most common injuries in sport, representing up to 15% of all injuries in the athletic population.\(^1\,\text{\textsuperscript{2}}\) After a lateral ankle sprain residual symptoms may affect 55% to 72% of patients\(^3\) with reoccurrence rate as high as 80%.\(^4\) Repetitive events of lateral ankle instability are referred to as chronic ankle instability (CAI). Patients with CAI present with functional deficits including contributions from both subjective and objective assessments, such as self-reporting of disability and giving way, ligamentous laxity, impaired proprioception, and deficits in neuromuscular control.\(^5\,\text{\textsuperscript{\textendash}8}\)

Commonly, neuromuscular control deficits have been investigated distally at the ankle joint;\(^9\) however disruption of proximal joint neuromuscular activation, strength and movement patterns are factors that have gained increased attention as possibly contributing to functional impairments and recurrent injury rates in those with CAI.\(^10\,\text{\textendash}17\) A growing body of work that presents altered proximal joint neuromuscular control in
CAI patients suggests this may be a point of focus for innovative interventions.

Specifically, there is consistent data to suggest that hip muscle activation is inhibited in CAI patients, but there is little research on exercise interventions that target this particular alteration. Recent work from our laboratory suggests that rehabilitation exercises, such as rotational lunges and rotational squats, are able to elicit activation of the gluteus medius and maximus; and individuals with CAI exhibit declined muscle activation patterns compared with healthy control participants when performing these tasks. These deficits in proximal muscle strength and activation, along with alterations in kinematic patterns simultaneously appear to negatively influence measures of dynamic postural control.

Dynamic postural control can be described as the ability to maintain a stable base of support while performing a prescribed movement. The star excursion balance test (SEBT) and time to stabilization (TTS) are tools used to assess dynamic postural control. The SEBT has the ability to show diminished performance in individuals with CAI as evidenced by reduced reaching distances; while TTS is a more dynamic single-leg jump landing/stability task. Both TTS and SEBT assessments have been used consistently to differentiate groups with and without CAI; however, the contribution of altered hip joint neuromuscular control during these tasks has not been completely defined. While patients with CAI have been shown to present with diminished postural control, it is also important to address subjective feelings of the ankle impairment during daily and physical activity. This has previously been measured subjectively with the Foot and Ankle Disability Index (FADI) and new patient orientated outcome
measure the Foot and Ankle Ability Measure (FAAM),\textsuperscript{31,32} as well as the Ankle Instability Index (AII)\textsuperscript{33,34}. But, as with measures of dynamic postural control, it is not known to what extent deficits in hip neuromuscular control influence self-reported disability in individuals with CAI. Therefore, it is of critical need to determine the effects of interventions for altered hip neuromuscular control on measures of dynamic postural control and self-reported disability in order to develop the most effective outcomes for CAI.

1.2 Statement of the Problem

Alteration in proximal neuromuscular control at the hip continues to be documented in those with CAI when compared to healthy patients. Patients with CAI demonstrate a difference in posterior lateral hip musculature during closed chain functional tasks compared to healthy patients. The body of work that presents altered proximal joint neuromuscular control in CAI patients suggests this may be a point of focus for innovative interventions. There is consistent data to suggest that hip muscle activation is inhibited in CAI patients,\textsuperscript{14-16,18-20} but there is little research on exercise interventions that target this particular alteration.

1.3 Statement of Purpose

The objective of this study was to determine the effectiveness of two intervention programs focusing on proximal alterations or distal alterations on improving dynamic
postural control and self-reported disability in patients with CAI. This is of critical importance in the development of effective intervention strategies for CAI.

1.4 Research Hypotheses

1. Participants in the Ankle/Glut intervention group will have a significantly increased pre-post intervention reach distance performance on the SEBT compared to the Ankle intervention group.

2. Participants in the Ankle/Glut intervention group will have a significantly decreased pre-post intervention TTS score compared to the Ankle intervention group.

3. The participants in the Ankle/Glut intervention group will have a significant pre-post intervention increase in the FADI scores compared to the Ankle intervention group.

4. The participants in the Ankle/Glut intervention group will have significantly increased pre-post intervention in hip abduction strength (HABD) and external rotator strength (ER) compared to the Ankle intervention group.

1.5 Specific Aims

1) To examine the effect of a four-week proximal rehabilitation intervention on the improvement of dynamic postural control in those with CAI.
• This aim was accomplished by measuring dynamic postural with two different established and reliable measurements: time to stabilization (TTS) and the star excursion balance test (SEBT).

2) To examine the effect of a four-week proximal rehabilitation intervention on the improvement of self-reported outcomes in those with CAI.
• This aim was accomplished by administering the Foot and Ankle Ability Measure (FAAM) and Ankle Instability Index (AII) before and after the intervention.

3) To examine the effect of a four-week proximal rehabilitation intervention on the improvement of hip strength in those with CAI.
• This aim was accomplished by measuring hip abduction strength (HABD) and external rotator strength (ER) with a hand-held dynamometer.

1.6 Operational Definitions
Chronic Ankle Instability (CAI): a condition characterized by the residual symptoms that persist after an ankle sprain. Symptoms include pain, swelling, and decreased function. Individuals report a sensation of the ankle “giving way”.  

Functional Instability (FI): another subset of CAI that has been proposed as a method of explaining the persistent symptoms of CAI among individuals who do not experience the increased joint motion that characterizes mechanical instability.
Neuromuscular Control: unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring functional joint stability.

Dynamic Postural Control: the ability to maintain a stable base of support while purposefully moving multiple body segments. 35

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

Time to Stabilization (TTS): a dynamic single-leg jump landing/stability task used to assess dynamic postural control.

Foot and Ankle Ability Measure (FAAM/FAAM Sport): Questionnaire used to determine degree of disability in subjects. The FAAM consists of questions regarding activities of daily living; while the FAAM Sport is comprised of more functional activities primarily used during sports.

Ankle Instability Instrument (AII): Questionnaire used to categorize participants ankle instability.

Hand-held Dynamometer (HHD): Device used to assess muscle strength that has been shown to be valid and reliable method. 36-38

1.7 Potential Limitations

1. Individuals who have previously sustained ankle sprains and are currently experiencing CAI were included in this study, thus having a retrospective nature. Therefore,
confidently using the information from this study to predict injury mechanisms in the future was limited.

2. The SEBT is dynamic in nature but was not necessarily a good representation of movements demanded during all athletic participation. However, this task was demonstrated as reliable and sensitive to detecting performance deficits in CAI participants.

3. A potential problem we could have encountered in this study was participant drop out. There was a potential for participant dropout with a four-week intervention; therefore we attempted to over sample to account for subject drop out and a grant was submitted in hopes to give participants financial compensation for participation.

4. Sample size was a limitation in this study.

1.8 Significance

Alteration in proximal neuromuscular control at the hip continues to be documented in those with CAI when compared to healthy patients. Patients with CAI demonstrate a difference in posterior lateral hip musculature during closed chain functional tasks compared to healthy patients. The proposed research will help clinicians determine what exercises to implement for rehabilitation to improve dynamic postural control and decrease self-reported disability for patients with CAI. This may help in designing a rehabilitation program which assists in preventing future ankle injuries for those with CAI. We expect this intervention will improve outcomes for traditional ankle
joint injury management as well as spark advancement in the study of new rehabilitation paradigms for CAI.
Chapter Two

Literature Review

2.1 Lateral Ankle Sprains

Lateral ankle sprains (LAS) are the most common injuries in sport, representing up to 30% of all injuries in the athletic population.\(^1\)\(^2\) Garrick\(^3\) was one of the first authors to conclude that the lateral ligament complex of the ankle is the most commonly injured structure in athletes, with recent literature finding lateral ankle sprains to account for 85% of all ankle sprains.\(^5\) Lateral ankle instability refers to the existence of an unstable ankle due to lateral ligamentous damage. This damage to the lateral ligaments can be caused by excessive supination or inversion of the rearfoot. The high rates of reoccurrence after the initial injury are of great concern. After a LAS, residual symptoms may affect 55% to 72% of patients\(^3\) with reoccurrence rate as high as 80%.\(^4\)

2.2 Chronic Ankle Instability
Chronic ankle instability (CAI) is the occurrence of repetitive events of lateral ankle instability, resulting in numerous ankle sprains. In basketball, reoccurrence rates have been reported to exceed 70%. Typical symptoms include pain during activity, weakness, recurrent swelling, and feeling of giving way. Osteoarthritis and articular degeneration at the ankle has also been linked to repetitive sprains and is a driving force for further research on prevention.

Chronic ankle instability has been attributed to two potential categories of contributing factors: functional ankle instability (FAI) and mechanical ankle instability (MAI). Functional instability is a subjectively reported occurrence by the athlete that is defined as a tendency during normal activity for the ankle to give way. Athletes with FAI could experience one or more of the following: neuromuscular, proprioceptive, and/or strength deficits, as well as impaired postural control. Mechanical instability is often referred to as laxity and can be defined as ankle movement beyond the physiological limit of the ankle’s range of motion that predisposes the ankle to further episodes of instability. Recently, Hertel has described MAI as pathological laxity of the ankle secondary to anatomical damage of the lateral ligamentous tissues that support the ankle joint. He also concluded that individuals with MAI had associated contributing factors such as: arthokinematic restrictions, degenerative changes and synovial changes. Studies have provided evidence that FAI can exist separate to MAI however; other studies have demonstrated that the two may also coexist.
2.3 Postural Control

Postural control may be classified as either static or dynamic. Maintenance of postural control both in static and dynamic situations requires factors such as preprogrammed reactions, nerve-conduction velocity, joint range of motion, and muscle strength.\(^22\) Static postural control is the ability to remain as still as possible while maintaining balance over a stable base of support.\(^10,22\) Impairments of static postural control due to CAI are thought to be caused by impaired proprioception and neuromuscular control.\(^22\) When ligaments are torn, articular receptors may be damaged which in turn will contribute to the observed postural deficits.\(^22\) Maintenance of balance during dynamic movements, such as those involved in performing the Star Excursion Balance Test (SEBT), is very important. Dynamic postural control involves the ability to keep the center of gravity over the stable base of support while maintaining balance throughout a prescribed movement.\(^10,22\) During single-leg stance, control of posture is accomplished through corrective movements, with some occurring through reflexive ankle muscle contractions, which may be inhibited in CAI subjects.\(^39\) Impairments of dynamic postural control due to CAI are thought to be caused by impaired proprioception and neuromuscular control. Although dynamic postural impairments may be influenced by altered proprioception and neuromuscular control, other factors may contribute to this condition, including deficits in strength and range of motion.\(^22\)

2.4 Proximal Joint Alterations
There is evidence to suggest that, among healthy individuals, proximal joint neuromuscular control is altered in the presence of localized fatigue to proximal muscle groups, which may be similar to the type of fatigue athlete’s experience during longer duration exercises.\textsuperscript{11} It has also been shown, that proximal joint alterations during measures of postural control following fatigue seem to be amplified in the presence of CAI.\textsuperscript{11} Chronic ankle instability is an injury that disrupts joint integrity, which is theorized to impair afferent-efferent pathways that allow for maintenance of proprioception, kinesthesia, and ultimately neuromuscular control.\textsuperscript{10} Disruptions at one joint, such as the ankle, may create altered neural activity and compensatory muscle recruitment at other joint complexes, like the hip and knee, resulting in disrupted movement patterns.\textsuperscript{10} Gribble et al\textsuperscript{11} examined the relationship between CAI and fatigue on proximal joint alterations using the SEBT. Their results revealed that CAI and fatigue affect proximal joint kinematics and dynamic postural control.\textsuperscript{11}

In another study examining proximal joint alterations, Beckman and Buchanan\textsuperscript{14} had subjects stand on a platform that instantaneously inverted the foot and ankle. Experiments were performed on 10 normal or mobile subjects, and 10 hypermobile subjects, defined as subjects with a minimum of 10° of excessive foot inversion. Their results showed an altered proximal muscle recruitment pattern in hip musculature in response to instantaneous ankle inversion in the presence of ankle hypermobility. Specifically, they found that when a hypermobile ankle was forced into unexpected inversion, the contralateral gluteus medius was recruited before the ipsilateral gluteus
medius. They discovered that both recruitments occurred more rapidly in the hypermobile subjects compared to the healthy subjects. The authors attributed this muscle recruitment pattern to the use of a hip strategy in maintaining an upright posture. This strategy is less efficient and may result in recurrence of ankle sprains.

Bullock-Saxton had subjects performed prone hip extensions, a non-weight-bearing open chain task, which is a completely different task when compared to the SEBT. However, the trend of alterations in neuromuscular control in the proximal joints of subjects with lateral ankle sprain is consistent across these investigations. Their results showed alterations in electromyographic activity of hamstrings, gluteus maximus, and erector spinae in subjects who have suffered a severe LAS. It is thought that although an injured athlete may be able to complete a gross motor task, the method of completion may be altered and less than efficient, creating the potential threat of reinjury.

Aspects of neuromuscular control may be quantified through measures of postural control. Gribble et al examined 30 physically active subjects during five individual sessions at least one week apart. They looked at the reach distances and kinematic measures of the ankle, knee and hip during performance of the SEBT under various fatigue conditions in participants with and without CAI. They found that CAI and fatigue to the lower extremity adversely affected dynamic postural control when assessing SEBT. The results demonstrated reduced maximum reach, reduced knee joint angles, and reduced hip joint angles for the involved limb of the CAI group, when compared to the uninjured limb and healthy control group. The outcome indicates a relationship between
performance on the SEBT and altered neuromuscular control at the knee and hip due to ankle injury.\textsuperscript{10} It is a possibility that neuromuscular deficits associated with CAI result in similar changes in proximal neuromuscular control at the knee and hip.\textsuperscript{10} Changes in movement patterns may be caused by altered neural activity and compensatory muscle recruitment at other joint complexes due to injury to the ankle joint.\textsuperscript{11} A significant amount of the variance in dynamic postural control may be related to altered neuromuscular control from CAI and fatigue.\textsuperscript{11}

In a follow-up study, Gribble and Hertel\textsuperscript{41} examined the effect of fatigue at the hip and ankle on postural control. Thirteen subjects had fatigue induced to either the frontal plane movers of the hip or ankle. Immediately after fatigue, subjects’ postural control was tested on a forceplate. Results of the study showed that while fatigue to both muscle groups led to deficits in postural control, fatigue to hip abductors and adductors created significantly increased postural deficits compared to fatigue of the ankle invertors and evertors.\textsuperscript{41} Results in both studies seem to show that fatigue to proximal musculature negatively affects postural control more than fatigue to distal musculature. Therefore there appears to be a greater reliance on proximal joint control since as the hip is fatigued, it results in diminished postural control.\textsuperscript{10,41} This ultimately may be detrimental to CAI subjects.

\textbf{2.5 Intervention Studies}
Neuromuscular control deficits have been investigated distally at the ankle joint; however disruption of proximal joint neuromuscular activation, strength and movement patterns are factors that have gained increased attention as possibly contributing to functional impairments and recurrent injury rates in those with CAI. There is consistent data to suggest that hip muscle activation is inhibited in CAI patients. Hale et al30 studied the effect of a 4-week intervention on postural control in individuals with CAI. The intervention included a combination of stretching, Theraband strengthening in multiple directions, neuromuscular control, jumping and running drills. Participants with CAI demonstrated deficits in postural control and SEBT reach distance of the involved limb when compared to the uninvolved limb. The rehabilitation group resulted in improvements in measurements of dynamic postural control (SEBT) and self-reported disability (FADI and FADI Sport).

Balance is maintained by strategies at the hip, knee, and ankle, but may be disturbed when joint positions cannot be properly sensed, which occurs after injury, or when corrective movements are not executed in a coordinated fashion. Subjects with FAI have been shown to lack ankle strategy, during a single-leg stance, and instead adopt a less efficient hip strategy which potentially increases the chance of ankle inversion. Literature also shows that fatigue to proximal musculature impairs postural control which may adversely affect the hip strategy that CAI subjects rely on in order to maintain balance. In the end, the fatigue of the musculature will make it more likely for them to have reoccurrence of an ankle sprain. McKeon et al42 studied the effect of a balance
training program on postural control in individuals with CAI. The intervention included a balance training program with multidirectional hop landing and progressions of single-leg stances. The balance training group showed significant improvements in reach distances in SEBT, and decreased self-reported disability on the FADI, and FADI Sport instruments.

Alteration in proximal neuromuscular control at the hip continues to be documented in those with CAI when compared to healthy patients. A study performed by Webster and Gribble investigated how hip muscle activation, specifically the gluteus medius and gluteus maximus, trigger during functional closed-chain rehabilitation exercises in those with and without CAI. Their results showed that gluteus maximus activation was lower in the CAI group compared to those with healthy ankles during the rotational squat exercise. This study supports the use of these novel tasks to elicit activation of the proximal hip musculature in CAI patients and therefore should be considered during rehabilitation.

Dynamic postural control is the ability to maintain a stable base of support through corrective movements which may be inhibited in ankle muscle contractions. Gribble and Shinohara compared two rehabilitation protocols for improving dynamic postural control and self-reported impairments using the SEBT performance and Foot and Ankle Disability Index (FADI), respectively. A protocol using exercises focused on knee and hip strengthening produced the largest improvements in both of the outcome measures. Both of the rehabilitation groups produced significant pre-to-post
improvements; but the proximal rehabilitation groups showed significantly larger improvements compared to the ankle rehabilitation group.

2.6 Star Excursion Balance Test (SEBT)

The SEBT is a reliable tool that has the ability to show diminished dynamic postural performance in individuals with CAI as evidenced by reduced reaching distances.\textsuperscript{22} For the SEBT, dynamic postural stability is defined as the point to which a person can reach without moving the stance leg and still maintain balance.\textsuperscript{22} The SEBT has demonstrated consistency in detecting deficits in dynamic balance in individuals with CAI,\textsuperscript{44} as well as proximal joint alterations in CAI populations.\textsuperscript{10,11} Additionally, the SEBT has been used to demonstrate positive effects from rehabilitation interventions.\textsuperscript{30,42,43} The SEBT is sensitive enough to detect proximal joint alterations.\textsuperscript{11,22}

The SEBT consists of eight separate reaching directions and subjects perform the test while standing in the middle of a grid formed by the eight lines. The eight lines are named anteriolateral (AL), anterior (A), anteriormedial (AM), medial (M), posteriormedial (PM), posterior (P), posteriolarateral (PL), and lateral (L), in relation to the stance leg.\textsuperscript{45} Hertel et al\textsuperscript{28} determined the A, PM, and PL directions have been shown to be the most effective in assessing dynamic balance in those with CAI.

As a subject attempts to accomplish maximum reach during the SEBT, the stance leg is free to undergo coupled movements at the ankle, knee, and hip. Maintaining single-leg stance while performing maximum reach with the opposite leg requires the stance leg
to have sufficient ankle, knee, and hip motion. As a subject attempts to achieve maximum reach, his or her center of gravity is lowered as the closed kinetic chain motions of ankle dorsiflexion, knee flexion, and hip flexion occur on the stance leg. In order for optimal performance of the SEBT to be obtained there must be no restrictions to range of motion or neuromuscular control at the ankle, knee and hip joints. Trunk motion and hip rotation during the SEBT are also permitted.

2.7 Time to Stabilization

Time to stabilization (TTS) is a more dynamic measure of stability and is performed during a single-limb jump-landing task. Consistency at detecting dynamic stability in individuals with CAI deficits has been shown with TTS. TTS determines the length of time it takes a participant to stabilize their ground reaction forces during a jump-landing task from a height of 50% of their maximum vertical jumping ability.

The assessment of TTS forces subjects to maintain balance through a transition from a dynamic to a static state. Dynamic postural stability is defined as the time it takes for the peak ground reaction force of a jump landing to become similar to the A/P and M/L ground reaction forces in a stabilized single-leg stance. Gribble et al examined the TTS and contributions of lower extremity kinematics in participants with CAI. The CAI group showed a diminished ability to stabilize on the injured limb when compared to the uninjured side of the CAI group or both limbs of the control group. During the single-
leg jump landing, CAI participants also demonstrated altered knee position and diminished dynamic stability. In a similar study, Brown et al\textsuperscript{21} investigated differences in movement variability in the lower extremity joints between individuals with FAI, MAI, ankle copers, and healthy controls during a TTS task. The MAI and FAI individuals demonstrated less variability at the hip and knee compared to controls during the jump landing task. The authors\textsuperscript{21} interpreted these results by suggesting that less variability at the proximal joints may cause reduced stability demands on the injured ankle.

Factors that cause functionally unstable ankles may cause individuals to land from a jump differently than individuals with stable ankles. Ross et al\textsuperscript{24} determined TTS differences during single-leg jump landings between stable and unstable ankles and concluded that TTS was longer for subjects with FAI than subjects with stable ankles. Similarly, Ross and Guskiewicz\textsuperscript{23} examined the differences in static and dynamic stabilization times between individuals with FAI and those without. The FAI individuals took significantly longer to stabilize during the dynamic stability task but there was no difference in the static stability task when comparing groups.

2.8 Self-Reported Disability

Another aspect used when investigating CAI is assessment of patient reported disability and function through the use of established questionnaires. The FADI and FADI Sport questionnaires have been employed as a measure of self-reported disability in patients with previous ankle sprains.\textsuperscript{29} The FADI is a subjective report of function that
assesses activities of daily living. The FADI scores are recorded as a percentage of 104 points. The FADI Sport is designed to detect deficits in higher functioning subjects by assessing more difficult tasks that are essential to sport participation. The FADI Sport scores are recorded as a percentage of 32 points. Participants are instructed to respond to every question with the closest description of their condition within the past week. Hale and Hertel\textsuperscript{29} studied fifty recreationally active subjects, including both healthy and CAI individuals. A subgroup of the CAI individuals participated in a 4-week ankle rehabilitation program. Subjects scored significantly higher on the FADI and FADI Sport after the rehabilitation program, compared to baseline. The authors concluded that the FADI and FADI Sport are reliable in detecting functional limitations in subjects with CAI. The self-reported functional tests were responsive to improvements in function after rehabilitation in participants with CAI. The FADI and FADI Sport were shown to be sensitive enough to detect differences between healthy participants and participants with CAI.\textsuperscript{29}

More recently, the FADI and FADI Sport have been improved and modified into the FAAM and FAAM Sport. Investigators discovered that the questions asking about difficulty during sleeping as well as questions that rated ankle pain did not contribute significantly to the depiction of patient disability, and therefore were removed from the questionnaire.\textsuperscript{31,32} The FAAM and FAAM Sport have similarly used cut-off scores to the FADI instruments, but have been deemed more sensitive to discriminate patients with self-reported disability related to previous ankle injury.\textsuperscript{31,32}
2.9 Hand-held Dynamometer

A hand-held dynamometer is a clinically applicable device that is used to assess muscle strength. It has been shown to be valid and reliable method in assessing muscle strength.\textsuperscript{36-38} Wadsworth et al\textsuperscript{38} found the HHD to be more sensitive at detecting smaller differences in muscle strength compared to manual muscle tests. Wikholm and Bohannon\textsuperscript{48} found that tester strength caused unreliable results with higher force production by a participant. Studies done in our laboratory have shown the HHD to have reliable and valid results when using a strap to assess HADB and ER.\textsuperscript{49,50}

2.10 Summary

Alteration in proximal neuromuscular control at the hip continues to be documented in those with CAI when compared to healthy patients. Patients with CAI demonstrate a difference in posterior lateral hip musculature during closed chain functional tasks compared to healthy patients. The proposed research will help clinicians determine what exercises to implement for rehabilitation to improve dynamic postural control and decrease self-reported disability for patients with CAI. This may help in designing a rehabilitation program to assist in preventing future ankle injuries in those with CAI.
Chapter Three

Methods

3.1 Study Design

This study was a randomized control trial using block randomization to allocate participants to one of two groups: Ankle Intervention or Ankle/Glut Intervention.

3.2 Dependent Variables

1) Star Excursion Balance Test (SEBT)
   - The reach distances for the anterior (ASEBT), posteriormedial (PMSEBT), and posteriorlateral (PLSEBT) test were used.

2) Time to Stabilization (TTS) measured by MotionMonitor software
   - The anterior/posterior (APTTS) and medial/lateral (MLTTS) were calculated from the anterior/posterior and medial/lateral ground reaction forces collected during the 5 second post-landing period at 200 Hz.

3) Foot and Ankle Ability Measure (FAAM/FAAM Sport)
   - Self-reported questionnaires
4) Hip Strength

- The hip abduction strength (HABD) and external rotator strength (ER) were collected using a hand-held dynamometer (HHD) and converted from foot-pounds to Newton-meters (Nm).

3.3 Independent Variables

1) Group

- Ankle/Glut Intervention = participants receiving ankle and hip intervention
  
  o Six participants were randomly assigned to the Ankle/Glut intervention group and participated in a four-week traditional ankle exercise program along with rotational lunges and rotational squats.

- Ankle Intervention = participants receiving only ankle exercise intervention

  o Six participants were randomly assigned to the Ankle group and participated in a traditional ankle exercise program of four directional therabands, wobbleboard, and single-leg balance.

2) Time

- Pre = measurements taken just prior to the intervention

- Post = measurements taken immediately after the intervention

3.4 Participants
A recently completed study evaluating the effect of a proximal joint intervention protocol in CAI patients was used to calculate sample size. The power analysis calculation estimated that 16 patients were needed per group for a total of 32 patients. Participants were randomly allocated to 2 groups: Ankle/Glut Intervention or Ankle Intervention. (Table 3.1) There was no statistical significant difference between groups. (Table 3.2)

<table>
<thead>
<tr>
<th>Group</th>
<th>Male</th>
<th>Female</th>
<th>Age</th>
<th>Height</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle</td>
<td>4</td>
<td>2</td>
<td>21.5</td>
<td>176.74</td>
<td>83.14</td>
</tr>
<tr>
<td>Ankle/Glut</td>
<td>2</td>
<td>4</td>
<td>19.5</td>
<td>168.49</td>
<td>80.74</td>
</tr>
</tbody>
</table>

Table 3.1: Participant numbers for the ankle and ankle/glut groups.

<table>
<thead>
<tr>
<th></th>
<th>Ankle</th>
<th>Ankle/Glut</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>176.74±10.91</td>
<td>168.48±7.82</td>
<td>1.51</td>
<td>0.16</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>83.14±20.85</td>
<td>80.74±27.63</td>
<td>0.17</td>
<td>0.868</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>21.5±2.81</td>
<td>19.5±1.52</td>
<td>1.53</td>
<td>0.156</td>
</tr>
</tbody>
</table>

Table 3.2: Mean, standard deviations, t-value, and p-value for the ankle and ankle/glut groups.

At the time of the writing of this document, only 12 participants were enrolled. Participants were recruited from the University of Toledo community. This study was approved by the Institutional Review Board at the University of Toledo (IRB#107972). After enrolling in the study, on the initial day of pre-testing, an opaque envelope containing group membership was opened by the examiner immediately prior to starting the intervention to determine group assignment.

All participants exhibited CAI, defined as 1) a history of at least one acute ankle sprain which caused swelling, pain, and temporary loss of function; but no significant injury to the ankle in the past six months and 2) a history of at least two repeated episodes
of “giving way” in the last three months. In addition, all participants completed two questionnaires to further define CAI: (1) the Ankle Instability Instrument (AII) and (2) the FAAM including the FAAM Sports Subscale. To be included in the CAI group, participants will be required to answer yes to at least four other symptom questions on the AII, as well as self-report functional disability on a score of ≤ 90% on the FAAM and ≤ 80% on the FAAM Sports Scale.

All potential participants with a current lower extremity injury other than to the ankle or history of a major knee or hip injury, lower extremity surgical procedure, or are pregnant were excluded in this study. We excluded individuals with a history of: concussion or head injury, or any other lower extremity injury in the past 6 months that may have altered their muscle activity and movement patterns. All participants provided written informed consent approved by the institutional review board at the University of Toledo prior to performing any of these proposed experiments.

3.5 Instrumentation

Time to stabilization (TTS) data was collected using a force plate (Bertec 4060-NC, Bertec, Inc.; Columbus, OH) integrated with the MotionMonitor software (version 8.0; Innsport Inc, Chicago, IL) at a sampling rate of 200 Hz. A Vertec vertical jump tester (Sports Imports, Columbus, OH) was used to determine 50% of the maximum jump height. In order to standardize timing, the intervention exercises were performed with a Wittner MT-50 Quartz metronome (New Market, VA) at a rate of 72 bpm.
3.6 Procedures

Upon arrival in the laboratory, all participants were provided a standardized explanation of the study and completed the injury history questionnaire.

3.7 Outcome Measures

All participants filled out the FAAM, FAAM Sport and AII instruments before any other further testing was to begin. During post-testing participants filled out another FAAM and FAAM Sport to test for improvement in self-reported function following the intervention. After reviewing the history and questionnaire information, a testing limb was selected for the testing procedures. If a participant had bilateral ankle instability, the ankle with the lowest FAAM scores and highest AII scores was used. During the initial testing session, the limb length of the selected testing limb was measured with the participant supine from the anterior superior iliac spine to the inferior portion of the medial malleolus on the tibia. This was used to normalize SEBT reach distances and rotational lunge performance distance in the Ankle/Glut intervention group.

During the initial testing session, the subjects’ age, height, mass and sex, and maximal vertical jump height was recorded. They were asked to stand next to a Vertec vertical jump tester, reach up and touch the highest point possible while maintaining both feet flat on the ground. This measurement was recorded as their standing reach height. Next, the subject was asked to perform a maximum jump off both feet and touch the highest point possible on the Vertec. There were three trials and the maximum vertical height of those three was recorded as the maximum jump height. During the testing
trials, participants jumped to a height equivalent to 50% of their maximum vertical height, determined as the difference between the maximum height reached during the jump and the standing-reach height.\textsuperscript{23}

Time to stabilization (TTS) began with the subjects standing 70 cm away from the force plate. They began the jump landing task with both feet on the ground, jumped towards the force plate, reached up and touched the indicated marker on the Vertec and landed on the designated testing limb on the force plate. Each subject was given at least 4 practice trials with as much rest as they would like between trials.\textsuperscript{52} The subjects were instructed to stabilize as quickly as possible on the single testing leg and put both hands on their hips while facing forward, holding this position for 5 seconds. If the subject hopped or touched down the non-testing limb during a trial, then the trial was eliminated, recorded, and repeated.\textsuperscript{23}

In recent applications of the SEBT in rehabilitation intervention studies for CAI patients, the anterior, the posteriormedial, and the posteriorlateral have been used.\textsuperscript{42,43} The lines were made with measuring tapes secured to the floor with clear packing tape. For anterior reach performance, the toes of the stance leg were placed at the 0 position of the grid line; and for the posteriormedial and posteriorlateral reach performances, the heel of the stance limb was placed at the 0 position of those grid lines.\textsuperscript{44} While standing on the testing limb, the participant was instructed to reach as far as possible along the line with the most distal part of the reaching foot, make a light touch on the line, and return to a double-leg stance without compromising their base of support. Subjects were instructed
to hold their hands on their hips at all times and to maintain contact of the heel of the stance leg with the ground during the trials. \cite{10,11,22,39,45}

Lastly, the participant’s HABD and ER hip strength were determined using a hand-held dynamometer. Hip ER strength was tested in a seated position, while HABD strength was tested in a sidelying position. The proximal joints were secured via straps to avoid compensatory mechanisms. For the ER seated position the torso and quadriceps were secured with straps. The HHD was consistently placed 5.08cm from the medial malleoli and lateral joint line for the ER and HABD positions. For the HABD sidelying position a proximal strap over the waist of the participant was used. Since participant’s hip abduction strength may exceed the tester’s strength, \cite{48} HABD was tested using a strap placed 5.08cm proximal to lateral joint line to allow for valid results. Participants were instructed to give maximal effort during all trials. If maximal effort of the participant was doubted by the investigator the trial was discarded and repeated.

3.8 Intervention

Participants were randomly assigned to the Ankle intervention or Ankle/Glut intervention group and took part in a four-week exercise program. The Ankle group participated in traditional ankle rehabilitation, whereas the Ankle/Glut group took part in the same traditional ankle rehabilitation along with gluteal exercises of rotational lunges and rotational squats. Both groups met twice a week, for approximately 20 minute sessions, with the first exercise intervention occurring immediately following pre-testing of outcome measures and the last session occurring at least 24 hours prior to post-testing.
There was a total of eight rehabilitation sessions in four-weeks. All exercises were performed in a randomized order each session. During each intervention session, the Ankle/Glut group performed three sets of ten repetitions of the rotational squats and lunges with a two-minute break for optimal rest between sets. During the first week, the gluteal exercises were performed with no resistance. During the 2\textsuperscript{nd} through 4\textsuperscript{th} week of the intervention, participants wore a weight vest to which 5% of body mass was added each week, resulting in resistances of 5\%, 10\%, and 15\% of body mass during weeks 2, 3, and 4, respectively, of the intervention.

A lunging distance using the previously measured leg length was designated with a mark on the floor for the rotational lunge. Participants began facing forward with both feet on the ground. To determine the positioning for the task, prior to performing repetitions, participants lifted and externally rotated the involved limb 90\°, and lunge laterally towards the mark on the floor. With the toes on this mark, participants lowered themselves until 60\° of knee flexion was achieved (measured with a goniometer) and a tape measure was used to give the subject point of reference for consistency in repeating the lunges. The participant then returned to the original starting position with two feet on the ground.

Participants began the rotational squat by standing on the involved limb with arms together and shoulders flexed to 90\°, then squatting down and rotating laterally, placing the stance hip in internal rotation, to reach a marker on the tape measure with both hands and then returning to the original single-leg stance. The height from the floor to the subjects’ lateral femoral condyle was used to determine the height of the marker. The
distance of the pole placement away from the subjects was determined using their arm length measured from the acromion process to the distal third phalanx.\textsuperscript{19}

Both exercises were completed in four beats of the metronome. For the rotational lunge, participants started on two feet, pick up and rotate the test leg externally $90^\circ$ and achieve the target position in two beats, and return to the beginning position in two beats.\textsuperscript{19} For the rotational squat, the participants’ started on the stance leg with arms outstretched anteriorly. They were asked to flex the knee and hip on the first beat, externally rotate the torso to touch the marker on the second beat, then return to the starting position within two beats of the metronome.\textsuperscript{19} The participants were permitted to briefly stabilize with a toe touch or hand if necessary.

The traditional ankle exercises included four directional therabands, wobbleboard exercises, and single-leg balance exercises. All of the traditional exercises were progressed during the four weeks. (Table 3.3)
<table>
<thead>
<tr>
<th>Week</th>
<th>Day</th>
<th>Theraband</th>
<th>Wobble Board</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Red (3x10)</td>
<td>15 CW, 15 CCW Opposite foot on floor</td>
<td>EO/stable (3x30)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Red (3x10)</td>
<td>15 CW, 15 CCW Opposite foot on floor</td>
<td>EO/stable (3x30)</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Green (3x10)</td>
<td>10 CW, 10 CCW Opposite foot on board</td>
<td>EO/unstable (3x30)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Green (3x10)</td>
<td>10 CW, 10 CCW Opposite foot on board</td>
<td>EO/unstable (3x30)</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Blue (3x10)</td>
<td>15 CW, 15 CCW Opposite foot on board</td>
<td>EC/stable (3x30)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Blue (3x10)</td>
<td>15 CW, 15 CCW Opposite foot on board</td>
<td>EC/stable (3x30)</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Black (3x10)</td>
<td>10 CW, 10 CCW no opposite foot</td>
<td>EC/unstable (3x30)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Black (3x10)</td>
<td>10 CW, 10 CCW no opposite foot</td>
<td>EC/unstable (3x30)</td>
</tr>
</tbody>
</table>

Table 3.3 Progression of traditional ankle rehabilitation.

3.9 Data Analysis

After TTS testing, the anterior/posterior (APTTS) and medial/lateral (MLTTS) were calculated from the anterior/posterior and medial/lateral ground reaction forces that were collected during the 5 second period at 200 Hz. A Labview custom software file was used to convert the AP and ML ground reaction forces into the TTS variables. The APTTS and MLTTS were combined to determine the resultant vector of the time to stabilization (RVTTS) which provides a single stability assessment of both planes of movement. After testing, the reach distances for the ASEBT, PMSEBT, and PLSEBT were normalized to leg length. The means and standard deviations from the testing trials were used to create a pre and post intervention scores. The dependent variable was the pre-post change in the RVTTS and the four selected measures of the SEBT.
The FAAM and FAAM Sport scores were represented as percentage scores. Participants filled out the FAAM and FAAM Sport instruments during the pre-testing and post-testing. The HABD and ER strength measurements were collected during the pre and post testing and converted from foot-pounds into Newton-meters. Dependent variables were represented as the pre-post intervention change in the FAAM, FAAM Sport, HABD, and ER.

3.10 Statistical Analysis

For each dependent variable (RVTTS, SEBT, PMSEBT, PLSEBT, FAAM, FAAM Sport, HABD, ER), independent t-tests were used to compare the pre-post intervention change between the Ankle/Glut and Ankle groups. Cohen’s d effect sizes using the pooled standard deviations were calculated, along with 95% confidence intervals (CIs) to assess clinical significance for dependent variables. The strength of effect sizes was interpreted as weak (d ≤ 0.4), moderate (0.40 < d ≤ 0.8), and strong (d > 0.8). Alpha levels were set a priori at P≤0.05 for all inferential statistics, which were evaluated using SPSS 17.0 statistical software.
Chapter Four

Results

Means and standard deviations for all variables at pre-test and post-test time intervals are found in Table 4.1. The raw data means were the same at baseline for all measures. Significance and Cohen’s $d$ within-group effect sizes with respective 95% confidence intervals are also in Table 4.1.

The change score for the FAAM was significantly different between groups ($p=0.02$), with the Ankle group reporting a greater improvement in self-reported disability after the intervention period. (Table 4.1) All other pre-post comparisons were not statistically significant between groups (Table 4.1).

A strong effect size with a 95% confidence interval (CI) that did not cross zero was found for the FAAM, with the Ankle rehabilitation group reporting a larger pre-post change compared to the Ankle/Glut rehabilitation group ($d=1.56, 95\% \text{ CI: (0.17, 2.71)}$). Conversely, moderate effect sizes showed greater improvement in the Ankle/Glut rehabilitation group compared to the Ankle group for RVTTS ($d=0.57, 95\% \text{ CI: -0.62, 1.68}$), HABD ($d=0.60, 95\% \text{ CI: -1.71, 0.60}$), ER ($d=-0.75, 95\% \text{ CI: -1.86, 0.47}$) and
PLSEBT \( (d=-0.65, 95\% \text{ CI: } -1.76, 0.55) \); however the 95\% CI for these comparisons all crossed zero (Table 4.1). All other effect sizes were small (Table 4.1).

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Group</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>T-value</th>
<th>P-value</th>
<th>Effect size (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVTTSchange</td>
<td>Ankle</td>
<td>0.0404</td>
<td>0.18556</td>
<td>0.988</td>
<td>0.347</td>
<td>0.57 ((-0.62, 1.68))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>-0.044</td>
<td>0.09659</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HABDchange</td>
<td>Ankle</td>
<td>-0.4351</td>
<td>12.85977</td>
<td>-1.043</td>
<td>0.322</td>
<td>-0.6 ((-1.71, 0.6))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>5.1372</td>
<td>2.44145</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERchange</td>
<td>Ankle</td>
<td>1.1803</td>
<td>11.04661</td>
<td>-1.307</td>
<td>0.22</td>
<td>-0.75 ((-1.86, 0.47))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>9.127</td>
<td>9.98178</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAAMchange</td>
<td>Ankle</td>
<td>0.0913</td>
<td>0.0418</td>
<td>2.705</td>
<td>0.022</td>
<td>1.56 ((0.17, 2.71))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>0.0114</td>
<td>0.05908</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAAMSportchange</td>
<td>Ankle</td>
<td>0.047</td>
<td>0.08064</td>
<td>0.048</td>
<td>0.963</td>
<td>0.03 ((-1.11, 1.16))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>0.0433</td>
<td>0.17419</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASEBTchange</td>
<td>Ankle</td>
<td>-1.5862</td>
<td>7.21091</td>
<td>-0.62</td>
<td>0.549</td>
<td>-0.36 ((-1.47, 0.81))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>0.523</td>
<td>4.18745</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMSEBTchange</td>
<td>Ankle</td>
<td>4.8583</td>
<td>8.08046</td>
<td>0.378</td>
<td>0.713</td>
<td>0.22 ((-0.93, 1.34))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>3.1846</td>
<td>7.23041</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLSEBTchange</td>
<td>Ankle</td>
<td>1.371</td>
<td>5.44028</td>
<td>-1.132</td>
<td>0.284</td>
<td>-0.65 ((-1.76, 0.55))</td>
</tr>
<tr>
<td></td>
<td>Ankle/Glut</td>
<td>5.2649</td>
<td>6.43194</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1: Pre and post intervention means, standard deviations, t-value, p-value, and effect sizes for the ankle and ankle/glut groups.
Chapter Five

Discussion

5.1 Discussion

The objective of this study was to determine the effectiveness of improving dynamic postural control and self-reported disability in patients with CAI through an intervention program that targeted gluteal muscles. Neuromuscular control deficits have been investigated distally at the ankle joint;\textsuperscript{9,13,14,25,26} however disruptions of proximal joint neuromuscular activation, strength and movement patterns are factors that have gained increased attention as possible contributors to functional impairments and recurrent injury rates in those with CAI.\textsuperscript{10-17} There is consistent data to suggest that hip muscle activation is inhibited in CAI patients,\textsuperscript{14-16,18-20} but there is little research on exercise interventions that target this particular alteration.

Statistical significance and a strong effect size with a 95\% CI that did not cross zero supported the finding that the Ankle rehab group had more improvements in self-reported disability compared to the Ankle/Glut exercise group. Previous studies have shown the FAAM to be reliable in detecting improvements in function after rehabilitation.
in participants with CAI. Our data showed that both groups had improvements in FAAM scores, but the Ankle group had a 9% improvement in self-reported disability, while the Ankle/Glut group only had a 1% improvement. This contradicts previous work in our laboratory that found that a rehabilitation protocol of knee and hip exercises produced greater improvements in self-reported disability during physically demanding activities using the FADI Sport (13%) compared to a protocol group using ankle exercises (9%) and a control group (no change). In the previous and current study, interventions lasted for four weeks, but the previous study had twice as many participants than our current study has enrolled. It will be important to continue increasing the enrollment in the current study to continue examining this outcome.

Though the pre-post changes in RVTTS were not statistically different between groups (p=0.35), a moderate effect size (d=0.57, 95% CI: -0.62, 1.68) may indicate a clinically significant improvement in functional landing in the Ankle/Glut group compared to the Ankle group. The Ankle/Glut rehabilitation group exhibited a decrease in RVTTS (-0.04±0.10), while the Ankle group increased their RVTTS (0.04±0.19). This could indicate that the gluteal exercises allowed for better functional landing patterns in those with CAI. However, the clinical importance of a 4 ms improvement in dynamic stability and whether or not this is enough to reduce ankle injury rate, remains unknown. These relationships are consistent with previous work from our laboratory that showed a knee/hip rehabilitation protocol improved RVTTS (-35 ms) to a greater extent than an ankle rehabilitation protocol (-16 ms) in CAI subjects. However, the improvements in
RVTTs from the previous work were larger than we have observed in our sample, and are of a magnitude that may have implications for reducing injury risk. Again, increasing our enrollment in this RCT will be vital to understanding these relationships.

Although ER and HABD were not statistically significant (p=0.22, p=0.322), both variables produced moderate effect sizes ($d=-0.75$ 95% CI: -1.86, 0.47, $d=0.60$, 95% CI: -1.71, 0.60) implying a potentially clinically relevant increase in hip strength if a larger sample size was acquired. The Ankle/Glut rehabilitation group increased their HABD (5.14±2.44) and ER (9.13±9.98) relative to the Ankle rehabilitation group which showed a decrease in HABD (-0.44±12.86) and an increase in ER (1.1803±11.05). These results support the claims made by Webster and Gribble\textsuperscript{19} that rotational lunges and rotational squats increase hip strength in participants with CAI and therefore should be considered during rehabilitation. It is not surprising that these outcomes were improved in the group performing the additional gluteal exercises. Previous studies by Bullock-Saxton\textsuperscript{15,40} and Beckman and Buchanan\textsuperscript{14} have shown alterations in activation level of the gluteus medius and gluteus maximus during both open chained and closed chained activities. Gribble et al\textsuperscript{41} found that fatigue to hip abductors and adductors led to increased postural deficits compared to fatigue of the ankle invertors and evertors. Therefore there appears to be a greater reliance on proximal joint control at the hip in the presence of fatigue to maintain postural control.\textsuperscript{10,41} These alterations in activation level and diminished postural control may be detrimental to injury reoccurrence in CAI participants. Therefore, strengthening of the hip musculature, specifically the gluteus maximus and medius, may
lead to increased activation and postural control which ultimately leads to clinical improvements in CAI participants.

While the Ankle/Glut group showed physical performance outcome improvement, the patients only reported a 1% improvement in self-reported function. In other words, the Ankle/Glut group reported their disability changed very little at the end of four weeks, but improved in hip strength as well as function during a jump landing task. Our study and previous research\textsuperscript{8,57} shows that multiple subjective and objective factors should be evaluated in CAI participants because they are affected by several impairments associated with this multi-factorial pathology.

The SEBT has demonstrated consistency in detecting deficits in dynamic balance in individuals with CAI,\textsuperscript{44} as well as proximal joint alterations in CAI populations.\textsuperscript{10,11} Results of the study showed that the difference between groups pre to post intervention for the ASEBT, PMSEBT and PLSEBT were not statistically significant. Moderate effect sizes with 95% CI crossing zero was found for the PLSEBT ($d=-0.65$, 95% CI: -1.76, 0.55) which may indicate a clinically significant improvement in reach distance in the Ankle/Glut group compared to the Ankle group, especially if enrollment was increased for the study. These results seem to be consistent with previous research from our laboratory where statistically significant pre-post SEBT improvements were seen with the proximal rehabilitation groups showing significantly larger improvements compared to the ankle rehabilitation group.\textsuperscript{43}
5.2 Limitations

Currently, this study is substantially under-powered statistically; therefore our conclusions are based on effect sizes rather than inferential statistics. Even though we did not have enough subjects to produce statistical significance in the objective measurements, our changes in RVTTS, HABD, ER, and PLSEBT did produce moderate effect sizes. However, the respective 95% CI were wide and crossed zero, thus limiting the clinical applicability. All of the other variables were not statistically significant and revealed only small effect sizes.

The four weeks between the pre and post-testing can be seen as a limitation of the study. Rehabilitation studies range not only in the length of time between pre and post-testing but also the frequency in rehabilitation sessions during a period of a week. It is possible that the rehabilitation exercises may take longer than four weeks to create successful outcomes. Previous studies have shown increases in ankle musculature activation after eight weeks,\textsuperscript{58} increases in isokinetic testing after eight weeks,\textsuperscript{59} and improvements in postural sway after six weeks.\textsuperscript{60} On the other hand, Ross and Guskiewicz\textsuperscript{61} showed that coordination training improved APTTS after two weeks and MLTTS after four weeks. We based our study design on multiple studies\textsuperscript{30,42,61} that provide support for using a four week rehabilitation protocol. Current research has shown proximal neuromuscular control deficits at the hip in those with CAI, therefore future intervention research should focus on using rehabilitation targeting these proximal joint alterations, including what is the optimal time period of the intervention.
Most participants managed their CAI therefore it could take other intensive rehabilitation to see more dramatic changes. On the other hand, not all individuals with CAI may respond to a hip rehabilitation strategy so this may be a reason why there were limited results to report.

5.3 Clinical Implications

CAI is an intricate problem that can be comprised of many functional and mechanical disruptions of the neuromuscular system. Patients with CAI present with functional deficits including contributions from both subjective and objective assessments, such as self-reporting of disability and giving way, ligamentous laxity, impaired proprioception, and deficits in neuromuscular control. Due to this, CAI must be evaluated comprehensively through subjective and objective measurements. CAI is a multifaceted injury and therefore must be studied in the same approach through the development of methods to more accurately measure the functional and mechanical disruptions at the ankle. With reoccurrence rates as high as 80%, evolution of ankle rehabilitation is needed to address the different factors that comprise CAI. In turn, a comprehensive evaluation is needed to assess outcomes in order to evaluate the effectiveness of the intervention.

5.4 Conclusion
In conclusion, our study found that the Ankle rehabilitation was more effective at increasing self-reported function when compared to Ankle/Glut rehabilitation. On the other hand, the Ankle/Glut intervention may reduce functional instability associated with CAI, as well as strengthen the hip musculature. We expect this study, using a four-week rehabilitation program, to be fundamental for justifying the use of rotational squats and rotational lunges in an attempt to regain strength and increased activation of the gluteus maximus and gluteus medius in CAI patients. We were severely limited in our ability to recruit, but believe that with more participants many of our objective measurements would become clinically significant due to moderate effect sizes. Even with the current limitations to this investigation, we expect that rehabilitation exercises specifically targeting proximal joint alterations will prove to be a clinically effective method of reducing reoccurrence rates and subjective impairment in CAI patients. We believe this study will be instrumental in creating a rehabilitation paradigm shift that incorporates interventions that alleviate proximal joint alterations that are commonly seen in those with CAI.
References


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


Appendix A

Consent Form

<Enter Heading (Title) of Appendix A here>
ADULT RESEARCH SUBJECT INFORMATION AND CONSENT FORM

REHABILITATION INTERVENTION IN CHRONIC ANKLE INSTABILITY INDIVIDUALS

Principal Investigator: Phillip Gribble, Ph.D., ATC
Other Staff (identified by role): Samantha Boland, ATC, Co-Investigator
Hayley Erickson, MS, ATC, Co-Investigators

Contact Phone number(s): Dr. Phillip Gribble: (419) 530-2691
Samantha Boland: (808) 792-4609
Hayley Erickson:

What you should know about this research study:

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

- Routine clinical care is based upon the best-known treatment and is provided with the main goal of helping the individual patient. The main goal of research studies is to gain knowledge that may help future patients.

- We cannot promise that this research will benefit you. Just like routine care, this research can have side effects that can be serious or minor.

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

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

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

- Your participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)

You are being asked to take part in a research study that examines neuromuscular characteristics in the lower extremity associated with chronic ankle instability (CAI) during dynamic postural control balance tests. Once an individual has sustained an ankle sprain, the likelihood for re-occurrence is very high, potentially leading to CAI. The purposes of the study are (1) to examine the effect of a four-week rehabilitation intervention on the improvement of dynamic postural control in those with CAI, (2) to examine the effect of a four-week rehabilitation intervention on the improvement in self-reported outcomes in those with CAI, and (3) to compare two rehabilitation protocols. This study may help
Illustrate the link between proximal and distal segments of the lower extremity and specifically what factors may be contributing to repetitive ankle instability.

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

You will be in an intervention group if you:
- Would like to voluntarily participate in this study
- Are between the ages 18 and 35 years
- Are free of any diagnosed balance or vestibular disorders and head injury
- Have
  (1) A previous history of at least one acute lateral ankle sprain which caused swelling, pain, and temporary loss of function
  (2) A history of at least two repeated episodes of "giving way" in the past 6 months
  (3) No history of any musculoskeletal or neurovascular injury in the lower extremity other than the ankle in the previous two years, and (4) no previous fractures or surgery in the lower extremity.
- Report a score of ≤ 90% on the Functional Ankle Disability Index (FADI) and ≤ 80% on the FADI Sport Subscale and answered yes to at least four questions on the Ankle Instability Instrument (Alli).

We will be enrolling a total of 40 participants. This research study will be conducted in the Athletic Training Research Laboratory and Motion Analysis Laboratory in the Health Sciences and Human Services building at the University of Toledo.

DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR INVOLVEMENT

If you decide to take part in this study, you will be asked to complete eight testing sessions over a period of four weeks. Each participant will meet twice a week, for approximately 20 minute sessions, with the first exercise intervention occurring immediately following pre-testing of outcome measures and preceding the post-testing after four-weeks. Pre-testing and post-testing of the outcome measures will take 1 hour. Therefore, the total duration of involvement of each participant in the study will be approximately 4 hours and 40 minutes.

After reading and signing the informed consent, you will be asked to complete a health history questionnaire and three ankle questionnaires, called Ankle Instability Index (Alli), Functional Ankle Disability Index (FADI), and FADI Sport. The questionnaires include daily activity and sport sections to allow us to better understand the history of your lower extremity injury. Following completion of the questionnaires, your leg length, height, weight, and hip (gluteus maximus, gluteus medius) strength will be assessed.

In order to assess your maximum vertical jump height you will be asked to stand next to a Vertec vertical jump tester, reach up and touch the highest point possible while maintaining both feet flat on the ground. This measurement will be recorded as your standing reach height. Next, you will be asked to perform a maximum jump off both feet and touch the highest point possible on the Vertec. There will be three trials and the maximum vertical height of those three will be recorded as the maximum jump height. During the testing trials, you will jump to a height equivalent to 50% of their maximum vertical height, determined as the difference between the maximum height reached during the jump and the standing-reach height.
You will begin the jump landing task, time to stabilization, with both feet on the ground, jump towards the force plate, reach up and touch the indicated marker on the Vertec and land on the designated testing limb on the force plate. You will be given at least 4 practice trials with as much rest as you would like between trials. You will be instructed to stabilize as quickly as possible on the single testing leg and put both hands on their hips while facing forward, holding this position for 5 seconds. If you hop or touch down the non-testing limb during a trial, then the trial will be thrown out and repeated.

The Star Excursion Balance Test (SEBT) consists of three separate reaching directions that you will perform while standing in the middle of the lines. While standing on the testing limb, you will be instructed to reach as far as possible along the line with your toe of the reaching foot, make a light touch on the line, and return to a double-leg stance without losing balance. You will be instructed to hold your hands on their hips at all times and to maintain contact of the heel of the stance leg with the ground during the trials.

After the pre-testing is finished you will be placed in a rehabilitation group. You will be given specific exercises that will be supervised by one of the investigators. You will meet twice a week for four weeks in order to progress through the exercises each week. During the final session of week four the hip strengthening, SEBT, and TTS tests will be performed again.

RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH
When participating in any research study, you may encounter some risks. Although the risk for taking part in this study is very low, you may experience one or more of the following:

1. Because you are performing functional activities, there is a slight chance of falling. However, you will be given instruction on how to perform the task and as much practice as you need to become comfortable with the task. Finally, an investigator will be standing nearby in the unlikely event that you need assistance.
2. You may experience minor muscle soreness following the study as you would after exercising. To minimize this risk, you will be given rest periods between test trials to make sure you don’t get tired.

If you are pregnant, it is advised that you remove yourself from the study during your pregnancy. While there are no known risks for pregnant women taking part in this study, because of the mild risk of falling, we would advise you to consider not participating if you are pregnant.

POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH
We cannot and do not guarantee or promise that you will receive any benefits from this research. The benefit of participating in this study is to help further research regarding chronic ankle instability.

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

No compensation including money, free treatment, free medications, or free transportation will be provided for this study.

PAYMENT OR OTHER COMPENSATION TO THE RESEARCH SITE
The University of Toledo is not receiving money or other benefits from the sponsor of this research as reimbursement for conducting the research.
ALTERNATIVE(S) TO TAKING PART IN THIS RESEARCH
There is no alternative to taking part in this research. Exclusion from the study, however, will not affect the quality of care you may receive at the sports medicine/physical therapy facility, doctor’s office, or other medical facilities.

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

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

In the event of an injury, contact Phillip Gribble, PhD, ATC (419) 530-2691.

VOLUNTARY PARTICIPATION
Taking part in this study is voluntary. You may refuse to participate or discontinue participation at any time without penalty or a loss of benefits to which you are otherwise entitled. If you decide not to participate or to discontinue participation, your decision will not affect your future relations with the University of Toledo or The University of Toledo Medical Center.

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

OTHER IMPORTANT INFORMATION
There is no additional information

ADDITIONAL ELEMENTS
There are no additional elements to the study.

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

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-383-6796.

SIGNATURE SECTION (Please read carefully)

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

BY SIGNING THIS DOCUMENT YOU AUTHORIZE US TO USE OR DISCLOSE YOUR PROTECTED HEALTH INFORMATION AS DESCRIBED IN THIS FORM.

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

<table>
<thead>
<tr>
<th>Name of Subject (please print)</th>
<th>Signature of Subject or Person Authorized to Consent</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to the Subject (Healthcare Power of Attorney authority or Legal Guardian)</td>
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<td>a.m.</td>
</tr>
<tr>
<td>Name of Person Obtaining Consent (please print)</td>
<td>Signature of Person Obtaining Consent</td>
<td>Date</td>
</tr>
<tr>
<td>Name of Witness to Consent Process (when required by ICH Guidelines) (please print)</td>
<td>Signature of Witness to Consent Process (when required by ICH Guidelines)</td>
<td>Date</td>
</tr>
</tbody>
</table>

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

Foot and Ankle Disability Index (FADI) and FADI Sport Instruments
Foot and Ankle Disability Index (FADI)

Please answer **every question** with one response that most closely describes your condition within the past week.

If the activity in question is limited by something other than your foot or ankle mark **not applicable (N/A)**.

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
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<tr>
<td>Walking on even ground</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Walking on even ground</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Walking on even ground</td>
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<td></td>
<td></td>
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<tr>
<td>Walking up hills</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Walking down hills</td>
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<td></td>
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<tr>
<td>Going up stairs</td>
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<tr>
<td>Going down stairs</td>
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<tr>
<td>Walking on uneven ground</td>
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<tr>
<td>Stepping up and down curbs</td>
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<tr>
<td>Squatting</td>
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<tr>
<td>Sleeping</td>
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<tr>
<td>Coming up on your toes</td>
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<tr>
<td>Walking initially</td>
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<tr>
<td>Walking 5 minutes or less</td>
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<tr>
<td>Walking approximately 10 minutes</td>
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<tr>
<td>Walking 15 minutes or greater</td>
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</tbody>
</table>

1999 FADI Interim 1/2
Because of your foot and ankle how much difficulty do you have with:

<table>
<thead>
<tr>
<th>Activities</th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home responsibilities</td>
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<tr>
<td>Activities of daily living</td>
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<tr>
<td>Personal care</td>
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<tr>
<td>Light to moderate work (standing, walking)</td>
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<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
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<td></td>
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<tr>
<td>Recreational Activities</td>
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</tr>
</tbody>
</table>

Please rate your pain level as it relates to your foot and ankle:

<table>
<thead>
<tr>
<th>Pain level</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Unbearable</th>
</tr>
</thead>
<tbody>
<tr>
<td>General level of pain</td>
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<tr>
<td>At rest</td>
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<tr>
<td>During your normal activity</td>
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<tr>
<td>First thing in the morning</td>
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</tbody>
</table>

FADI Sports Scale

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

<table>
<thead>
<tr>
<th>Activity</th>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running</td>
<td></td>
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<tr>
<td>Jumping</td>
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<tr>
<td>Landing</td>
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<td>Starting and stopping quickly</td>
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<tr>
<td>Cutting lateral movements</td>
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<tr>
<td>Low impact activities</td>
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<tr>
<td>Ability to perform activity with your normal technique</td>
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<tr>
<td>Ability to participate in your desired sport as long as you would like</td>
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</tbody>
</table>

1999 FADI Interim 2/2
Appendix C

Ankle Instability Instrument (AII)

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

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

1. Have you ever sprained an ankle?  
   - Yes ☐  No ☐

2. Have you ever seen a doctor for an ankle sprain?  
   - Yes ☐  No ☐
   
   If yes,
   2a. How did the doctor categorize your most serious ankle sprain?  
      - Mild (grade 1) ☐  Moderate (grade 2) ☐  Severe (grade 3) ☐

3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?  
   - Yes ☐  No ☐
   
   If yes,
   3a. In the most serious case, how long did you need to use the device?  
      - 1-3 days ☐  4-7 days ☐  1-2 weeks ☐  2-3 weeks ☐  >3 weeks ☐

4. Have you ever experienced a sensation of your ankle "giving way"?  
   - Yes ☐  No ☐
   
   If yes,
   4a. When was the last time your ankle "gave way"?  
      - <1 month ☐  1-6 months ago ☐  6-12 months ago ☐  1-2 years ago ☐  >2 years ☐

5. Does your ankle ever feel unstable while walking on a flat surface?  
   - Yes ☐  No ☐

6. Does your ankle ever feel unstable while walking on uneven ground?  
   - Yes ☐  No ☐

7. Does your ankle ever feel unstable during recreational or sport activity?  
   - Yes ☐  No ☐  N/A ☐

8. Does your ankle ever feel unstable while going up stairs?  
   - Yes ☐  No ☐

9. Does your ankle ever feel unstable while going down stairs?  
   - Yes ☐  No ☐
Appendix D

Data Collection Pictures

Jumping to 50% of maximum vertical jumping height

Landing on stabilizing on the testing limb

Figure D-1: Time to Stabilization Procedure
Figure D-2: Reaching distances for the Star Excursion Balance Test

Left-leg stance

Right-leg

Figure D-3: Anterior, posteriorlateral and postiormedial reach distances for the SEBT
Figure D-4: Hip Strength

Hip Abduction

Hip External Rotation
Figure D-5: Rotational Lunge

Figure D-6: Rotational Squat
Figure D-7: Traditional Ankle Exercises

Four directional Therabands  Wobbleboard  Single-leg balance