This thesis titled
Neurocognitive Ability in Individuals with Chronic Ankle Instability

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Abstract

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Neurocognitive Ability in Individuals with Chronic Ankle Instability

Director of Thesis: Dustin Grooms

**Background:** Chronic ankle instability (CAI) occurs following repetitive lateral ankle sprains. Studies suggest that brain regulation may be altered resulting in impaired motor control, translating to poor postural control and motor planning. Limited studies are available to identify etiology and suggest neurocognitive changes. **Purpose:** To determine if functional deficits are present in individuals with self-reported symptoms associated with CAI when compared to a control group. **Methods:** Participants completed the Identification of Functional Ankle Instability measure (IdFAI), the Foot and Ankle Ability Measure (FAAM) including the FAAM-Activities of Daily Living, and FAAM-Sport. In addition, a medical questionnaire identified individuals with CAI. Dynamic postural control was assessed using the Y-Balance Test. Participants then completed a protocol on the Bertec Vision Trainer (Bertec Inc, Columbus. OH), to identify neurocognitive deficits. **Main outcome measures:** Y-Balance, reaction time (wide and narrow), visual memory (wide and narrow), and random targets. **Results:** Comparing between groups, no functional or neurocognitive deficits were noted even though participants self-identified with CAI. **Conclusion:** Regardless of self-reported symptoms, participants in the CAI group were functioning with no neurocognitive or postural control deficits. The high activity level of this cohort or heterogeneity of CAI may contribute to the inability of the Y-Balance or neurocognitive function to discriminate between controls and participants with CAI.
Preface

Chapter 3 contained within the thesis document serves as a prepublication manuscript. This manuscript has been formatted to meet the guidelines set forth by the *Journal of Athletic Training* and Thesis and Dissertation Services at Ohio University. The heading style and reference citation style follow the guidelines of the AMA Manual of Style (10th ed., 2007).
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Chapter 1: Introduction

Ankle sprains are a common musculoskeletal injury in the active and general population. Each day approximately 23,000 ankle sprains occur in the United States, at a rate of 1 ankle sprain per 10,000 people. Of those reported, lateral ankle sprains account for 80% of all ankle sprains. Lateral ankle sprains can potentially cause damage to ligaments, muscles, nerves, and mechanoreceptors that innervate the lateral aspect of the ankle. Sprains can also result in decreased performance, removal from structured physical activity, and athletes’ loss of identity due to decreased participation.

CHRONIC ANKLE INSTABILITY

Repetitive occurrences of lateral ankle sprains may result in long-term functional impairments and residual symptoms. Of individuals who reported an initial ankle sprain, 73% have subsequently suffered an additional ankle sprain, and 59% of those cases report continued symptoms and related disabilities. Disabilities with associated symptoms following an initial ankle sprain, lasting a year or longer, has been classified as chronic ankle instability (CAI). CAI is an umbrella term that is used to encompass both functional ankle instability (FAI) and mechanical ankle instability (MAI). FAI refers to subjective symptoms that are reported by the individual that the ankle is repeatedly “giving way,” while MAI is the true measurement of ligament laxity.

SENSORIMOTOR SYSTEM

Riemann and Lephart defined the sensorimotor system as the “subcomponent of the comprehensive motor control system of the body” that describes the “sensory, motor,
and central integration and processing components involved in maintaining joint homeostasis during bodily movements. Sensorimotor control regulates feedback and feed-forward responses through obtained afferent information. Feedback responses, or corrective movements, are constantly processing incoming afferent information to provide reflexive reactions.

Postinjury, alterations in somatosensory function is disrupted by alterations in mechanoreceptors, proprioceptors, and joint receptors, inherently affecting feedback responses. An altered relay of afferent information through the ascending pathway may increase reliance on visual information and previous experiences to achieve and maintain dynamic stability.

POSTURAL CONTROL

Balance, muscle coordination, kinesthesia, and associated mechanoreceptor function are all components that comprise postural control. Postural control is the ability to maintain, achieve, and restore a state of balance during any activity. As previously stated, postural control is reliant on the somatosensory component of the sensorimotor system. Postural control depends on feedback and feedforward systems, which is altered with CAI. Decreased feedback responses lead to a weakened perception of joint position sense affecting the ability to make corrective movements. Again this altered relay of afferent information increases central nervous system (CNS) reliance on vision, previous experiences and learned responses.

NEUROMUSCULAR ADAPTATIONS

Neuromuscular function is never fully regained following injury resulting in prolonged alterations in neuromuscular function and extremity movement.
changes are reflective of the dysfunction in afferent signals at the spinal level of the CNS. CAI can cause prolonged degraded performance\textsuperscript{35–39} and proprioception\textsuperscript{14,40–42} noted during single-limb functional testing\textsuperscript{20,43} and delayed proprioceptive feedback and peroneal dysfunction\textsuperscript{44,45} during unanticipated movements.\textsuperscript{46} Deficits are measured during single-limb hop,\textsuperscript{43} figure-of-8 hop test, side-hop test,\textsuperscript{20} and trapdoor angular displacement\textsuperscript{46} recording reaction time\textsuperscript{43,46} and patient-reported “feelings of giving way.”\textsuperscript{20,43} Therefore, the purpose of this study was to determine if individuals with CAI have deficits in neurocognitive function when compared to individuals without CAI.

**RESEARCH QUESTION AND HYPOTHESES**

1. Do individuals with CAI have deficits in neurocognitive function when compared to the non-CAI (control) group.
   a. Individuals with CAI will have decreased performance in reaction time (seconds) when compared to the non-CAI (control) group.
   b. Individuals with CAI have decreased performance in eye-hand coordination protocol when compared to the non-CAI (control) group.
   c. Individuals with CAI have decreased performance in narrow vs wide visual processing (split attention) protocol when compared to the non-CAI (control) group.
   d. Individuals with CAI have decreased performance in the Y-Balance Test (FunctionalMovement.com, Danville, VA) when compared to the non-CAI (control) group.

**INDEPENDENT VARIABLES**

1. Individuals with CAI (experimental group).
2. Non-CAI (control) group.

**DEPENDENT VARIABLES**

1. Y-Balance Test (FunctionalMovement.com, Danville, VA) – measured in maximum reach distance, normalized to leg length.

2. Reaction time (seconds) compared between groups.
   a. Narrow Visual Processing
   b. Wide Visual Processing

3. Visual Memory (score) compared between groups.
   a. Narrow visual processing
   b. Wide visual processing

4. Random targets (score) compared between groups.

**ASSUMPTIONS**

1. Participants will answer the IdFAI truthfully.

2. Participants will answer the Foot and Ankle Ability Measure-Activities of Daily Living (FAAM-ADL) and Foot and Ankle Ability Measure-Sport (FAAM-S) truthfully.

3. Participants will give their maximum effort and attention when participating in the study.

4. Participants will be truthful when asked about previous history of injury and possess no unknown conditions that will influence the results.

5. The Bertec Vision Trainer (Bertec Inc, Columbus, OH) will be accurate and reliable throughout the study.
6. Participants will be well rested before they are tested and are getting an adequate amount of sleep.

7. Participants will be properly hydrated and nourished before they are tested.

LIMITATIONS

1. Lack of neurocognitive data and performance scores prior to injury.

2. The use of the Bertec Vision Trainer (Bertec Inc, Columbus, OH) as an assessment tool.

DELIMITATIONS

1. Individuals who do not fit the inclusion criteria.

2. Individuals who do classify as a control.

3. Participants do not answer the IdFAI honestly.

4. Participants do not answer the FAAM-ADL honestly.

5. Participants do not answer the FAAM-S honestly.
Chapter 2: Literature Review

Ankle sprains are one of the most prevalent injuries among the general and athletic populations.\textsuperscript{1,7} Evidence has been building to suggest that injuries, such as anterior cruciate ligaments tears and ankle sprains, can be linked to delays in individuals’ ability to detect and adjust to unanticipated forces.\textsuperscript{33,47} As clinicians, it is crucial to be aware of these delays in neurocognitive function and visual acuity. Understanding causation of these delays can lead to more advanced practices and utilization of neurocognition training as a rehabilitation tool.\textsuperscript{33} It is known that CAI exhibits differences in spatiotemporal variables during dynamic stability tasks\textsuperscript{48,49}; however, the underlying cause of these changes remain unknown. This literature review will focus on the complications resulting from CAI, primarily focusing on the static and dynamic ankle stabilizers, and current research regarding neurocognitive changes to the sensorimotor system, vision, and postural control.

ANKLE SPRAINS

Prevalence

Ankle sprains are a common musculoskeletal injury that occurs in both athletes\textsuperscript{4,7,50} and the general population.\textsuperscript{1} In the United States, an estimated 23,000 ankle sprains are reported each day,\textsuperscript{2–4,6} 80% of which are lateral ankle sprains.\textsuperscript{8,10} Ankle sprains can result in damage to ligaments, muscles, nerves, and mechanoreceptors that supply and cross the lateral ankle.\textsuperscript{9} Sprains result in decreased performance, removal from structured physical activity, and athletes’ loss of identity due to an inability to perform.\textsuperscript{8,10–12} Of individuals who reported an initial lateral ankle sprain, 73% reported an additional ankle sprain, and 59% of these reported cases had subsequent symptoms and
related disabilities. Following repetitive ankle sprains, there is a potential for individuals to develop CAI. The reasons behind such high reoccurrence rates and associated disabilities continue to be studied.

**Static Stabilizers**

A sprain is a common musculoskeletal injury in which the ligaments are partially or completely ruptured due to sudden overstretching in the absence of an associated fracture or dislocation. When ligaments are repetitively overstretched, a plastic change is produced, meaning the ligament remains elongated after the tensile force is removed. This deformation may present with increased laxity and a patient-reported feeling of instability.

Ligaments that stabilize the ankle are the anterior talofibular ligament (ATFL), calcaneofibular (CFL), posterior talofibular ligament (PTFL), and the deltoid ligament, which is comprised of four subjunctive ligaments. The ATFL, CFL, and PTFL primarily stabilize the lateral aspect of the ankle, in conjunction with the talus, fibula, and tibia.

The ATFL is the most commonly injured ligament during a lateral ankle sprain, accounting for 85% of reported cases. It is commonly injured because it is the smallest and weakest of the lateral stabilizers and demonstrates lower maximal load and energy to failure values under tensile stress. The role of the ATFL is to prevent anterior translation of the talus from the mortise, and excessive inversion and internal rotation of the talus on the tibia.

The second most commonly injured ligament is the CFL. The CFL is rarely injured in isolation and occurs simultaneously with injuries to other structures, causing it to have the second highest injury rate. It is also uncommon for the CFL to be damaged
in isolation because damage occurs during maximal loading when the ankle is placed in dorsiflexion and pronation. The primary function of the CFL is to prevent inversion of the calcaneus.

Of the lateral ankle stabilizers, the PTFL is the least commonly injured ligament. The primary function of the PTFL is to prevent posterior translation of the talus on the calcaneous. The PTFL is least commonly injured due to the ligament’s broad insertion on the talus and fibula. The PTFL provides a strong base of support against tensile forces. These ligaments provide stability against eversion, abduction, and pronation at the talocrural and subtalar joint. The ligamentous structures work congruently with the boney stabilizers of the ankle. The boney static stabilizers are the calcaneus, talus, and tibia.

**Dynamic Stabilizers**

Static stabilizers are coupled with dynamic stabilizers, such as muscles and tendons. Dynamic stabilizers are damaged when the force produced is greater than the tensile strength of the tendon and/or muscle and microtearing results. The 4 major categories of dynamic stabilizers produce inversion, eversion, dorsiflexion, and plantarflexion at the ankle. The invertor muscles consist of the tibialis anterior, tibialis posterior, flexor hallucis longus, flexor digitorum longus, and extensor hallucis longus. Evertors consists of the peroneus longus and brevis muscles. The dorsiflexor muscle group is more effective when the talocrural joint is placed in a closed-pack stable position, often referred to as subtalar neutral. The muscles that provide support in this position are the tibialis anterior, extensor digitorum longus, and the extensor hallucis longis. Lastly, the plantarflexor group consists of the tibialis
posterior, flexor hallucis longus, flexor digitorum longus, extensor hallucis longus, and triceps surae group; gastrocnemius and soleus. Literature focuses on each muscle group affecting the prevalence of ankle sprains, especially following repetitive damage. However, the invertors and evertors are the primary focus due to forced inversion being the common mechanism of injury. However, the aforementioned dorsiflexors and plantarflexors are also important for those with CAI, FAI specifically, because ankle support requires cocontraction of all dynamic stabilizers.

**CHRONIC ANKLE INSTABILITY**

Repetitive occurrences of lateral ankle sprains may result in long-term functional impairments, and residual symptoms. The presence of these deformations is referred to as CAI. CAI is defined as having residual symptoms directly resulting from a previous injury lasting for at least 1 year postinjury. Residual symptoms include but are not limited to pain, swelling, and a general feeling of instability. CAI is an umbrella term that is used to encompass both FAI and MAI. Identification of CAI is imperative to patient health. This includes proper rehabilitation techniques and overall prevention. Doherty et al found that the inability for individuals to complete a jump-landing task within the first 2 weeks of the first occurrence of a lateral ankle sprain could be a determinant in the development of CAI. A rehabilitation plan that does not implement such activity could result in a compromised talar articular surface and posttraumatic osteoarthritis, resulting in life-long impairments.

**Mechanical Ankle Instability**

MAI is determined through objective measurements of ligament laxity through selective tissue tests and devices such as arthrometers. Individuals who exhibit
anatomical changes such as joint restrictions, pathological laxity, or degenerative changes are at a higher risk for developing MAI following initial or repetitive ankle sprains.¹⁷

**Functional Ankle Instability**

FAI refers to subjective symptoms that are reported by the individual that the ankle is repeatedly “giving way.”⁸,¹³,¹⁴,¹⁷ Some studies have suggested that individuals with FAI may also have associated MAI,¹⁴,⁷⁴,⁷⁵ resulting in conflicting evidence with other studies that suggest there is no relationship between FAI and MAI.¹⁷,⁴²,⁷⁶ FAI predisposes an individual to dynamic changes, changes in functional performance,³⁵–³⁹ proprioception,¹⁴,⁴⁰–⁴² neuromuscular and sensorimotor control,²²,⁴⁷,⁴⁹,⁷⁷–⁸⁰ and strength deficits.¹³,¹⁴,⁴¹

**Assessing Functional Ankle Instability.** Since Freeman’s initial definition of FAI¹³ in 1965, much research has been done regarding FAI. The most common inclusion criteria for FAI have been disabilities with associated symptoms following an initial ankle sprain, lasting at least a year¹⁰,¹⁶ and recurrent patient reports of giving way¹⁴,³⁶,⁶⁰,⁶²,⁶³,⁷⁴,⁸¹–⁸⁴ during activity. There are 6 assessment tools that have been used to identify the presence of CAI: Foot and Ankle Outcome Score (FAOS), Ankle Instability Instrument (AII), Foot and Ankle Ability Measure (FAAM), Foot and Ankle Disability Index (FADI), Functional Ankle Instability Questionnaire (FAIQ), Chronic Ankle Instability Scale (CAIS), and the Identification of Functional Ankle Instability (IdFAI). Each tool’s reliability has been evaluated in past literature⁸⁵–⁸⁹ and the IdFAI have proven the most reliable with an ICC₂,₁ = 0.959 in individuals aged 20-60.⁹⁰
The Foot and Ankle Ability Measure (FAAM) is another outcome measure that has proved to be reliable in supporting a diagnosis of CAI, as well as general ankle dysfunction. The FAAM is a self-reported assessment tool that consists of 2 surveys, the 21-item FAAM-Activities of Daily Living (FAAM-ADL) and 8-item FAAM-Sport (FAAM-S). These surveys are scored separately on a 5-point Likert scale. Options range from 4 (no difficulty at all) to 0 (unable to do). The FAAM-ADL ranges from 0-84 and the FAAM-Sport from 0-32. The sum is taken from each survey and then converted into percentages. Participants scoring 100% are identifying themselves as having no functional deficits. Carcia et al found that the FAAM is an appropriate self-reported outcome measure to identify individuals with CAI. Houston et al and others report that individuals with CAI describe a state of decreased function when compared to healthy individuals. This finding suggests that individual quality of life should be catered to during the rehabilitation process.

**Relevant Functional Performance Deficits with Chronic Ankle Instability**

Some studies have been conducted and determined that individuals with FAI have deficits in functional performance by comparing the FAI group to healthy stable ankles. From these experiments clinicians have been able to determine that individuals with FAI perform with functional deficits in the following functional performance tests: single leg hop for distance, a 6-m timed hop, agility hop, up-and-down hop, side hop and several others that require dynamic movements. When performing these tests, individuals with FAI placed greater stress on the lateral structures of the ankle leading to the significant deficits, as recorded by force-plate data. Greater functional deficits were noted when participants self-reported more significant
sensations of “giving way.” While several studies placed great significance on self-reported “giving-way,” many have shown none. Perceived differences could still be experienced if a questionnaire had been used to determine performance levels. FAI is defined as the sensation of “giving way,” which is a subjective symptom. Questionnaires are an effective way to determine performance when administered in conjunction with the functional tests listed above.

SENSORIMOTOR SYSTEM

As defined by Riemann and Leaphart the sensorimotor system is a “subcomponent of the comprehensive motor control system of the body” that describes the “sensory, motor, and central integration and processing components involved in maintaining joint homeostasis during bodily movements.” The sensorimotor system utilizes feed-forward and feedback information. Feed-forward incorporates somatosensory and visual stimuli with motor memory patterns to prepare the body while the feedback mechanism is continually processing afferent information to provide reactions following the event. Studies have determined that CAI affects both feedback and feed-forward responses.

Sources of afferent information include somatosensory, visual, and vestibular inputs. These components received input from efferent reflex responses, which receives input from mechanoreceptors.

CAI NEUROPHYSIOLOGY

CAI is an injury-induced sensory-motor adaptation that fundamentally alters ligament laxity and postural stability. After injury, the somatosensory system, which is comprised of proprioception, joint stability, and all sensory input, is disrupted. The
disruption results from alterations in mechanoreceptors, proprioceptors, and joint receptor function, which innately affect the feedback responses. When this afferent input is altered, the CNS adapts to rely more heavily on other sources of afferent information. Other sources include vision, previous experiences, and learned motor patterns. This reorganization may influence movement and muscle activation patterns during functional activities, these altered movement patterns potentially lead to a predisposition for further injuries.

McLeod et al also found that individuals with FAI have increased cortical excitability. The exact location of the disrupted signal is unknown but means that individuals with FAI need to generate more corticospinal excitability to overcome insufficiencies and achieve similar movement patterns.

Neurophysiologic evidence indicates that the CNS is fundamentally altered in those with CAI. This may extend beyond the motor cortex and ankle motor control but may induce changes in brain function more generally, specifically related to visual-motor integration. As visual processing is vital to athletic performance and maintaining neuromuscular control, the changes in brain function after injury may comprise neurocognitive abilities.

**BALANCE DEFICITS**

FAI has been linked to postural instability due to reported center of pressure being more anteriolaterally positioned and altered central mechanics of motor control. Research suggests adding balance training to the rehabilitation protocol to improve the resulting deficits in proprioception.
Postural sway can be reliably assessed in a variety of methods including the Rhomberg Test, Balance Error Scoring System (BESS), Star Excursion Balance Test (SEBT), and force plates. The most widely researched method for assessing for postural sway in individuals with FAI is the SEBT.\textsuperscript{101–103} The SEBT is a highly functional dynamic balancing task that incorporates a single-leg stance while attempting to obtain a maximum reach on the nonplanted leg to 8 lines.\textsuperscript{104} Due to the dynamic nature of this test, it is adequate in determining functional performance and return-to-play standards by stimulating actions of running and cutting.\textsuperscript{105}

Significantly less reach distance was noted in the CAI group when compared to a stable group.\textsuperscript{104} A notable disadvantage to the SEBT is the amount of time required to complete the 8 directions, but studies have determined that all lines are not necessary\textsuperscript{106} and that the lines that were anterior, posteromedial, and posterolateral were sufficient.\textsuperscript{107,108} The Y-Balance Test Kit, a component of the SEBT, has shown an improvement in reliability.\textsuperscript{109} The Y-Balance Test is performed in anterior, posteromedial, and posterolateral reach directions\textsuperscript{110} by sliding a plate to a maximum reach distance that has been normalized to leg-length. The instrument has been found to have greater reliability than the SEBT by controlling the limitations.\textsuperscript{109} While more recent studies suggest that these clinically oriented postural control outcomes may be limited in detecting the presence of CAI.\textsuperscript{67,69–71}

Individuals with CAI have a disruption in dynamic postural control, which is due to a decreased maximum voluntary contraction of the dynamic stabilizers.\textsuperscript{98,102} CAI individuals also have decreased postural control due to adaptations within neuromuscular control, specifically proximal to the ankle as previously mentioned. These adaptations
present as decreased force production, changes in kinematic patterns, and deficits in muscle activation patterns.\textsuperscript{8}

Muscle control and movement patterns are controlled by the CNS through spinal reflexive and corticospinal pathways.\textsuperscript{8} McLeod et al\textsuperscript{8} suggested that individuals with ankle instability have decreased spinal reflexive excitability, specifically of the fibularis longus and soleus muscles, which both aid in plantarflexion of the ankle.

**Clinical Balance Measures**

Methods that have been used to assess for deficits in postural control include Balance Error Scoring System (BESS), Star Excursion Balance Test (SEBT), and Y-Balance Test, which is a component of the SEBT. Y-Balance Test was found to be reliable (composite ICC = .89)\textsuperscript{109} and is effective for determining balance deficits in patients with FAI. Studies have suggested that subjects with CAI, either MAI or FAI, demonstrated poor postural control and used a more anteriorly and laterally positioned center of pressure (COP) during a single-limb static balance task when standing on a force plate.\textsuperscript{111} Following a 4-week balance training protocol, Bowman et al\textsuperscript{111} suggested that when using the SEBT, COP was shifted from anterolateral to posterolateral position. While this study did not exhibit the desired results of a more central pressure it did suggest that change is possible when training with the SEBT. Other studies also imply that by training the stable ankle using the SEBT may result in improvement in balance and lower extremity function in the unstable ankle.\textsuperscript{112}

**NEUROCOGNITIVE FUNCTION ALTERATIONS**

Neurocognitive function appears to be a good indicator of elevated risk for sprains.\textsuperscript{113} Individuals with CAI are known to be more at risk for dysfunctional gait and
poor kinematic patterns\textsuperscript{47,77} due to poor postural control.\textsuperscript{114} Poor balance control correlates to an increased reliance on visual-motor interaction to maintain a homeostatic position.\textsuperscript{27} Postural control is often assessed using a stable force plate. When standing on a force plate, individuals with CAI present with greater plantarflexion strength and weaker dorsiflexion strength, and an unbalanced coupling leads to an increased incidence of ankle sprains.\textsuperscript{115} Invertor strength deficits have also been displayed in FAI subjects\textsuperscript{61,81} but this is in contradiction to other studies that show no significant invertor deficits in FAI subjects.\textsuperscript{30,41,60,62,115} The contradictory information regarding muscle weakness as a risk factor for individuals with FAI can likely be attributed to inconsistencies in technology and varying testing procedures.\textsuperscript{116}

**VISUAL MOTOR CONTROL IMPLICATIONS FOR POSTURAL CONTROL**

A suggested key component to maintaining balance is vision.\textsuperscript{117} The visual system can be divided into 3 components, central, ambient and retinal slip. The central system is primarily responsible for motion perception and recognition. Ambient dominates perception of movement and postural control and retinal slip specializes in afferent motion perception and is used for feedback for compensatory movements.\textsuperscript{117,118}

Visual information integrates with somatosensory and vestibular systems\textsuperscript{119} to maintain a homeostatic position. In an eye-closed situation, postural sway is increased,\textsuperscript{120,121} suggesting that postural control is partially reliant on vision.

**BERTEC VISION TRAINER**

Sensorimotor skills are an integral part of performing efficiently in an athletic setting.\textsuperscript{122} Clinicians and researchers alike are currently striving to create the most optimal training device to create a protocol that places an increased demand on visual
perception and oculomotor tasks in hopes of improving vision, creating more efficient motor movements, and ultimately improving overall athletic performance while potentially reducing the risk of injury.  

This technological approach toward improving healthcare is classified as the Bertec Vision Trainer (Bertec Inc, Columbus, OH) and has yielded mixed results. Some studies such as those by Bressan and others have suggested that training-related improvements are possible, while other studies suggest that there are no improvements to be gained by training with sensory station. Most of these studies occurred in previous years prior to advancements that have been made in technology.

**Reaction Time**

Visual-motor response speeds are critical to performance. Reaction time is defined as the elapsed time between the onset of a visual stimulus and the initiation of a motor response. Response time, in contrast, is the total time required for the stimulus to be processed by the visual system, as well as the time that is required to complete the motor response.

**Wide vs Narrow Visual Processing**

The aim of these training exercises is to improve individuals’ ability to rapidly shift visual attention between near and far distances. The protocol also improves recognition accuracy by measuring speed and span of recognition. Some studies reported that athletes can evaluate information pertaining to sports more rapidly than inexperienced observers, while other studies report no significant differences in athletes when compared to nonathletes.
Chapter 3: Neurocognitive Ability in Individuals with Chronic Ankle Instability

Context: Chronic ankle instability (CAI) results from repetitive lateral ankle sprains and results in self-reported “giving way.” Altered brain regulation of muscle tone and mechanical stability is associated with CAI. However, evidence to support neurocognitive changes are inconclusive.

Objective: To determine if individuals with CAI display neurocognitive deficits.

Design: Cross-sectional.

Setting: Research laboratory.

Participants: Forty-three participants (20.16 ± 1.62 years, 1.77 ± 0.09m, 79.19 ± 11.53kg) were enrolled (control N = 21; CAI N = 22). Group placement was dependent on scores from the Identification of Functional Ankle Instability (IdFAI: CAI: 18.5 ± 4.18, CON:0 ± 0).

Data Collection: Participants completed the Identification of Functional Ankle Instability measure (IdFAI), the Foot and Ankle Ability Measure (FAAM)-Activities of Daily Living, the FAAM-Sport, and a medical questionnaire to identify individuals with CAI. Dynamic postural control was assessed using the Y-Balance Test. Participants completed a protocol on the Bertec Vision Trainer (Bertec Inc, Columbus. OH) to identify neurocognitive deficits.

1 This chapter represents a prepublication manuscript to be submitted to the Journal of Athletic Training (August, 2017). Authors are: Allison N. Jackson, AT (School of Applied health Sciences and Wellness, Ohio University, Athens), Janet Simon, PhD, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens); Bentley Krause, PhD, AT (School of Applied Health Sciences and Wellness, Ohio University, Athens) and, Dustin Grooms, PhD, AT, CSCS (School of Applied Health Sciences and Wellness, Ohio University, Athens).
**Data Analysis:** A MANOVA was calculated with the independent variables (groups) on all dependent variables. Alpha level was set at $P < 0.05$ for all analyses.

**Results:** There were no between-group differences on any neurocognitive, visual-motor variable, or functional performance measure (reaction time narrow: CAI: 0.32 ± 0.05, CON: 0.35 ± 0.07; reaction time wide: CAI: 0.54 ± 0.09, CON: 0.47 ± 0.07; narrow visual memory: CAI: 7.12 ± 2.01, CON: 8.12 ± 3.14; wide visual memory: CAI: 6.68 ± 1.99, CON:7.40 ± 2.24; targets: CAI:28.44 ± 1.89, CON:27.76 ± 2.11; reach composite sum: CAI:2.66 ± 0.19, CON:2.70 ± 0.22).

**Conclusions:** CAI may not cause sufficient insult to produce functional deficits, or the body creates compensatory adaptations to overcome deficits.

**Key Words:** chronic ankle instability, foot and ankle ability measure, identification of functional ankle ability

**Word Count:** 291

**Key Points**

- Participants self-reported functional deficits.
- Participants did not exhibit any functional deficits during clinical postural control measures or the Bertec Vision Trainer (Bertec Inc., Columbus, OH).
Ankle sprains are a common musculoskeletal injury in the active and general population.\textsuperscript{1} Each day, approximately 23,000 ankle sprains occur in the United States,\textsuperscript{3} a rate of 1 ankle sprain per 10,000 people.\textsuperscript{4–6} Of those reported, lateral ankle sprains account for 80% of all ankle sprains.\textsuperscript{7,8} Lateral ankle sprains can potentially cause damage to ligaments, muscles, nerves, and mechanoreceptors that innervate the lateral aspect of the ankle.\textsuperscript{9} Sprains can also result in decreased performance, removal from structured physical activity, and athletes’ loss of identity due to decreased participation.\textsuperscript{8,10–12} Repetitive occurrences of lateral ankle sprains may result in long-term functional impairments\textsuperscript{8,13–15} and residual symptoms.\textsuperscript{7} These deficits resulting from repetitive ankle sprains has been deemed chronic ankle instability (CAI).

Evidence has been building to suggest that injuries, such as anterior cruciate ligaments tears and ankle sprains, can be linked to delays in an individual’s ability to detect and adjust to unanticipated forces.\textsuperscript{33,47} These deficits in motor control may be due to delays in neurocognitive function and visual acuity. Understanding causation of these delays can lead to more advanced interventions and utilization of neurocognition training as a rehabilitation tool.\textsuperscript{33}

When compared to a control group, individuals with CAI exhibit differences in spatiotemporal variables, especially during dynamic stability tasks.\textsuperscript{22,48,49} These spatiotemporal variables relate to time and space and include a multitude of parameters. Gribble et al\textsuperscript{22} compared resultant vector time to stabilization during 10 single-limb jump landing tasks and found that individuals with CAI prepare to land with significantly less knee flexion when compared to a control group. This deceased knee flexion may contribute to diminished dynamic stability during jump-landing tasks. During similar
jump-landing tasks, individual with CAI also exhibit disordered force patterns\textsuperscript{48} and a longer time to stabilize.\textsuperscript{49} It is speculated that these changes, ground reaction force and increased time to stabilize, result from deficits in feed-forward motor control,\textsuperscript{48} but the exact cause remains unknown. Therefore, the purpose of this study was to determine if individuals with CAI have deficits in neurocognitive function when compared to individuals without CAI.

**METHODS**

**Design**

This cross-sectional study used original data collected from 6 Ohio University Club Sports teams.

**Participants**

Forty-three physically active participants between the ages of 18-22 volunteered to be part of this study following an information session at the beginning of a practice during the Fall semester. Participants were placed in either the CAI or control group based on demographic information that can be found in Table 1.

The CAI group consisted of 22 participants who had suffered at least 1 ankle sprain that resulted in inflammatory processes prior to enrollment in the study, self-reported at least 2 instances of the ankle “giving way” in the past 6 months, as identified by the IdFAI measure (18.77 ± 4.04), and scored greater than 11 on the IdFAI.\textsuperscript{16} CAI participants could not have sustained a lower extremity injury within the last 3 months, no previous history of lower-extremity surgery, were free of balance or neurological disorders (such as multiple sclerosis) and had not sustained a head injury within the last 3 months. The control group consisted of 21 participants who self-reported no history of
lower extremity surgery, no history of ankle sprain, no head injury within the last 3 months, and scored 0 on the IdFAI (0 ± 0).

Table 1. Demographic Information, IdFAI, FAAM-Activities of Daily Living, FAAM-Sport scores for CAI and Control Group Means ± Standard Deviations

<table>
<thead>
<tr>
<th></th>
<th>Control (No. 21)</th>
<th>CAI (No. 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>19.90 ± 1.79</td>
<td>20.36 ± 1.47</td>
</tr>
<tr>
<td>Height (M)</td>
<td>1.79 ± 0.10</td>
<td>1.75 ± 0.09</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>79.16 ± 12.74</td>
<td>78.88 ± 11.07</td>
</tr>
<tr>
<td>IdFAI</td>
<td>0 ± 0</td>
<td>18.77 ± 4.04</td>
</tr>
<tr>
<td>FAAM-ADL</td>
<td>83.67 ± .91</td>
<td>82.05 ± 2.42</td>
</tr>
<tr>
<td>FAAM-ADL%</td>
<td>99.6 ± 1.1</td>
<td>97.67 ± 2.88</td>
</tr>
<tr>
<td>FAAM-S</td>
<td>31.19 ± 2.40</td>
<td>28.18 ± 3.69</td>
</tr>
<tr>
<td>FAAM-S%</td>
<td>97.47 ± 7.50</td>
<td>88.07 ± 11.51</td>
</tr>
</tbody>
</table>

Abbreviations: IdFAI, Identification of Functional Ankle Instability; FAAM, Foot and Ankle Ability Measure; CAI, chronic ankle instability.

Participants were excluded from the CAI or control group if they had a history of any surgery to the musculoskeletal structure to either extremity, a history of fracture in either lower extremity that required realignment, an acute injury to the musculoskeletal structure of either lower extremity in the previous 3 months, prior to enrollment, and any diagnosis of a neuromuscular dysfunction, this includes but is not limited to head injuries, prolonged neurocognitive deficits. Participants could also not have sustained a concussion 3 months prior to enrollment. Inclusion and exclusion criteria were determined used the following instruments.
Procedures

**Instruments.** Several instruments were used to determine group placement and suggest how participants would perform during the neurocognitive protocol. The IdFAI\textsuperscript{138} was used to separate eligible participants into the CAI group or the control non-CAI group. The FAAM-ADL and FAAM-S were used to validate the findings from the IdFAI. General demographic information was also collected from eligible participants and was used to determine any exclusionary details as well as potentially provide more detailed information about individuals who suffer from CAI.

**Outcome Variables.** Following group placement, participants arranged individual times to complete a one-time assessment that consisted of the Y-Balance Test\textsuperscript{104} and the Bertec Vision Trainer (Bertec Inc, Columbus, OH). Participants in the CAI group stood on the leg they self-identified as having more dysfunction, as determined by the IdFAI, while the control group stood on their nondominant leg, as determined by the medical questionnaire. Participants were all instructed to keep their heel flat when completing the 3 directions, anterior, posteromedial, and posterolateral. Participants completed 3 practice trials and 3 measured trials, in each direction. Reach distance was normalized to participants’ leg length, which was measured from the anterior superior iliac spine to the distal tip of the medial malleolus. Participants received 3 practice trials in each direction; 3 instances were recorded for this study. Reach distance was recorded in centimeters. Composite findings can be found in Table 2 reported as Mean ± Standard Deviation for all dependent variables, between groups.
Following a brief rest period, participants completed a set protocol on the Bertec Vision Trainer. Participants completed 5 protocols to assess neurocognitive function; narrow and wide reaction time, narrow and wide visual memory, and random targets.

**Reaction Time.** Reaction time required participants to respond to visual stimuli. Four rings were displayed in a “plus sign” pattern on the 55-in screen. Participants were asked to place the index finger of their dominant hand in the “starting” ring that corresponded with the side of the dominant hand. Participants stood facing the “landing” ring, which was displayed on the adjacent side of the dominant hand; see Bertec-Narrow Reaction Time Setup in Figure 2 and Bertec-Wide Reaction Time Setup in Figure 3. The “landing” ring then turned red and the participant removed the dominant hand from the “starting” ring to touch the “landing” ring as quickly and accurately as possible. Narrow visual processing speed used the minimal static grid size; there were a total of 5 trials; score was measured as the time it took to make contact with the “landing” dot. The same procedure was followed for wide visual processing speed; the static grid size was set to
the maximum size, and 5 trials were performed and resulting scores were recorded.

Dominant hand was determined using the medical questionnaire.

**Figure 2.** Bertec-Narrow reaction time setup.
Visual Memory. Participants completed 2 visual memory protocols on the Bertec Station. The first protocol displayed 9 dots on 55-in screen in the minimum static grid size for narrow visual processing. The Bertec Vision Trainer randomly generated a pattern sequence at the start of each trial. Following a target dot turning red the participant would touch the dot. Each stage progressed by 1 additional target dot after each correctly answered pattern. Scores were recorded for each of the 3 trials, each using a different programmed pattern. An additional 3 trials were completed with the static grid size set to maximal setting for wide visual processing.
Random Targets. Participants completed the random targets protocol on the Bertec Station. Participants had 30 seconds to make contact with as many red dots displayed on the 55-in screen as possible, using only the dominant hand. One dot would appear at a time and a subsequent dot would not appear until the previous dot was
Targets appeared in a randomly arranged pattern, as designed by the Bertec Vision Trainer. Five trials were completed and the resulting scores were recorded for each trial.

**Figure 6.** Bertec-Random target setup.

**Statistical Analysis**

Descriptive statistics were calculated for each dependent variable. A MANOVA was calculated with the independent variable group (CAI and Control) on dependent variables (Composite Y-Balance Test, averages for all Bertec Protocols variables, narrow reaction time, wide reaction time, narrow visual memory, wide visual memory and random targets). If the overall MANOVA was significant for group, follow-up univariate ANOVAs were conducted for each dependent variable. The alpha level was set at $P < 0.05$ for all analyses.
RESULTS

The overall MANOVA was not significant between groups $F_{(10,32)} = 1.57$, $P = 0.17$, $1-\beta = 0.635$. No follow-up univariate ANOVAs were conducted because of the nonsignificant finding for the multivariate ANOVA. Means and standard deviations between groups for dependent variables are located in Table 2.

Table 2. Data Reported as Mean ± Standard Deviation for All Dependent Variables Between Groups.

<table>
<thead>
<tr>
<th></th>
<th>Control (No. 21)</th>
<th>CAI (No. 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-Balance Composite Reach (%) of LL</td>
<td>2.76 ± 0.24</td>
<td>2.66 ± 0.19</td>
</tr>
<tr>
<td>Reaction Time-Narrow Average (sec)</td>
<td>.34 ± 0.08</td>
<td>.32 ± 0.06</td>
</tr>
<tr>
<td>Reaction Time-Wide Average (sec)</td>
<td>.51 ± 0.1</td>
<td>.47 ± 0.09</td>
</tr>
<tr>
<td>Visual Memory-Narrow Average (score)</td>
<td>7.25 ± 2.29</td>
<td>8.12 ± 3.14</td>
</tr>
<tr>
<td>Visual Memory-Wide Average (score)</td>
<td>6.44 ± 2.01</td>
<td>7.41 ± 2.25</td>
</tr>
<tr>
<td>Random Targets (score)</td>
<td>28.29 ± 3.53</td>
<td>28.44 ± 2.93</td>
</tr>
</tbody>
</table>

Abbreviations: LL, leg length.

DISCUSSION

It is known that CAI develops following repetitive occurrences of lateral ankle sprains $^{1-4}$ but the subsequent joint stability has many mechanisms encompassing mechanical and neural factors. $^{5}$ One of the strongest indicators of CAI is decreased functionality during dynamic stability tasks, as measured by the Y-Balance Test. $^{6}$
Typically, individuals with CAI have a submaximal reach distance when compared to healthy individuals due to an inhibition in postural control and an inability to achieve maximal contraction.\textsuperscript{7,8} The dynamic nature of these postural outcome measures, such as performance on the Y-Balance Test was believed to be adequate to determine functional performance deficits because it simulates actions of running and cutting.\textsuperscript{9} While other studies suggest that CAI individuals only show deficits during functional tests like the single leg hop for distance,\textsuperscript{10,11} and agility hop,\textsuperscript{11,12} while overall lower extremity function is not affected.\textsuperscript{12} The idea that CAI individuals only display deficits during activities like hopping is congruent with the findings from the present study and with a recent study by Wikstrom et al,\textsuperscript{13} who found that the research on the ability of clinically oriented postural control outcomes, such as the Y-Balance Test, are limited in determining the presence of CAI.\textsuperscript{7,14–16} The results from this study and that of Wikstrom\textsuperscript{13} suggest that these previously established norms are not sensitive enough to assess for CAI-induced postural control impairments, due to no differences being noted. A reason for this discrepancy could be biases in the literature or a trivial point such as not controlling for activity level. For example, Olmsted et al\textsuperscript{97} and others\textsuperscript{99,132} did note a specific activity level. Perhaps the absence of deficits can be attributed to our inclusion of highly active participants. In the present study, all club sports individuals participate in practices 3-5 times a week, with several outside activities.

Administration of the Y-Balance Test could also explain the differences between results. Wikstrom et al\textsuperscript{13} recently found that individuals with CAI had a significant increase in foot lifts when performing an eye-closed single-leg stance. It has been noted that individuals with CAI have weaker dorsiflexion strength,\textsuperscript{19} possibility contributing to
Y-balance deficits. During the present study individuals kept their heel flat on the Y-Balance Test indicating dorsiflexion may be challenged as well as postural control capability. Other studies suggest that functional deficits were only noted in individuals who self-reported more sensations of “giving way.” While all participants in the present study reported a sensation of the ankle “giving way” at least twice in a period of 6 months, perhaps this is not a frequent enough sensation to result in functional deficits.

The IdFAI has proven to be reliable in detecting the presence of FAI in individuals aged 20-60 with an ICC\textsubscript{2,1} = 0.959\textsuperscript{21} if the participant meets the minimum requirements set by the IdFAI. In the present study, all individual met the specific requirements and no individuals were copers (no measurable ankle instability or repetitive occurs of ankle injury).\textsuperscript{22}

Clinicians and researchers are constantly striving to improve healthcare options and incorporating technology into the rehabilitation process is thought to be key to motivating patients and staying current. The use of vision trainers, like that of the Bertec Vision Trainer is relatively new and has yielded mixed results regarding the clinical relevance and potential for improvement.\textsuperscript{23–29} While the majority of vision trainer studies occurred prior to recent technological advancements, the findings from these studies do not suggest that tools such as these are imperative to the rehabilitation process, or lack clinical relevance in determining the presence of CAI. Of the dependent variables tested, no findings were statistically significant between groups; however, CAI individuals performed more efficiently during memory tasks.

These null findings regarding neurocognitive changes are congruent with Needle et al.\textsuperscript{5} Needle et al\textsuperscript{5} found the relationship between brain function and ankle laxity were
different between participants with unstable ankles and healthy individuals, suggesting that individuals with CAI have developed compensatory strategies to cope with these changes in joint proprioception. These compensatory mechanisms translate to increased cortical excitability of muscles used to counteract for increased laxity. They also found that this increased excitability translated to increased muscle stiffness, which increased the ability to resist perturbations, like those experienced during the Y-Balance Test. The null findings during the Y-Balance Test and efficiency in the Bertec Vision Trainer in relation to previous literature supports the idea that regardless of self-reported symptoms, individuals with CAI are not performing with functional neurocognitive deficits. Instead, the body is creating compensatory reactions to overcome laxity and maintain homeostasis during functional activities.

**Limitations**

Limitations in this study include that when reading through the variously cited articles activity levels are not mentioned, as well as the specifics for completing the Y-Balance Test. It is unknown if participants completed the Y-Balance Test with heel-up or heel-down. Also the use of the Bertec Vision Trainer is fairly new and has not been used frequently in studies. An additional limitation is that The Bertec Vision Trainer requires only upper extremity motions to complete the designated tasks when assessing for neurocognitive function. When assessing for a local CNS change perhaps more lower extremity movements are essential for proper assessment.

**Clinical Implications**

The lack of significant differences among groups with postural control, or visual and neurocognitive function suggests that clinically oriented assessments, like the Y-
Balance Test, are not sensitive enough to detect impairments associated with CAI. The lack of meaningful correlations suggests that there may not be a valid way to determine if an individual has CAI or is at risk, but the Y-Balance Test and the SEBT may continue to indicate risk of lower-extremity injuries. Research into the underlying cause for the development of residual symptoms following repetitive ankle sprains should continue. Future knowledge and understanding of CAI will contribute to better treatment and prevention options.

Doherty et al\textsuperscript{30} recently found that the inability to complete a jump landing task within the first 2 weeks of the first occurrence of a lateral ankle sprain could be a predictor for the development of CAI and aid in maintaining the integrity of talar articular surface. This is important because CAI is a leading cause of a compromised talar articular surface\textsuperscript{13,31} and posttraumatic osteoarthritis.\textsuperscript{13,32} These exercise combined with neuromuscular training, focusing on lower extremity strength, has proven to improve performance on the SEBT.\textsuperscript{33}

**Future Research**

Future research should focus on highly active participants to determine if correlations can be found between poor postural control and visual and neurocognitive function. Future research is also needed to create more sensitive clinically oriented postural control outcome measures capable of detecting CAI deficits. Future knowledge of CAI could improve treatment and reduce the risk of future injuries.

**CONCLUSION**

CAI should be a concern for clinicians due to the unknown cause of prolonged symptoms, and the unknown nature of why some individuals will develop CAI while
others will not. This study found that individuals who self-reported deficits may not necessarily demonstrate those deficits. This could be due to these individuals developing compensatory mechanisms to overcome associated deficits because of the body’s nature to maintain homeostasis. This translates to these individuals performing at an optimal level compared to healthy individuals.

The results of this study may also indicate limitations in using the Y-Balance Test to identify CAI and associated postural control deficits. These findings suggest that this tool is not sensitive enough to detect associated changes, regardless of the reputation of the Y-Balance Test’s reliability. Limitations were also noted with the Bertec Vision Trainer. The Bertec Vision Trainer is directed at upper extremity movement. The null findings from our research participants suggest that neurocognitive changes are localized to lower extremity functionality, rather than a global CNS change. The Bertec Vision Trainer may be limited to detecting lower extremity functionality.
REFERENCES


Chapter 4: Conclusion

Many speculations have been made regarding CAI, specifically that neurocognitive deficits are present and that proprioception is greatly affected. CAI continues to be a concern for clinicians due to the unknown cause of these deficits. It also remains unknown why some individuals will develop CAI while others will not. Future research should focus on continuing to explore the cause of these prolonged symptoms and resulting deficits. This study suggests that individuals with CAI do not present with functional or neurocognitive deficits when compared to a healthy control group.

This study also suggests that individuals who practice on a regular schedule are highly functioning regardless of self-reported deficits, potentially due to compensatory mechanisms to regain a homeostatic state. Due to the null findings from the present study, this could also suggest that functional tests, such as the Y-Balance Test, are not sensitive enough to detect the presence of CAI. The results from this study could differ from previous literature for several reasons. In previous literature no activity level is noted and also the specifics regarding the implementation of the Y-Balance Test are often absent.

While little is known about the exact cause of these prolonged symptoms, whether it is a neural pathway change or a structural change, CAI should be a concern for all clinicians to keep patients healthy and prevent future injuries. Healthcare providers can use this information to create more efficient rehabilitation plans and lead to a better understanding of CAI.
References


16. Gribble PA, Delahunt E, Bleakley CM, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the


97. Baic LM. The effects of chronic ankle instability and change in visual focus on sensorimotor control in the lower extremity during a drop-landing [dissertation]. Toledo: University of Toledo; 2013.


Appendix A: Specific Aims

Ankle sprains are one of the most common musculoskeletal injuries that occur, not only in athletics but in the general population.\textsuperscript{7,10} When ankle sprains become repetitive and chronic symptoms develop, it can potentially lead to chronic ankle instability (CAI). CAI is defined as having residual symptoms that are directly resulting from a previous injury and symptoms last for at least 1 year.\textsuperscript{10,16} Residual symptoms include, but are not limited to: pain, swelling, and a general feeling of instability.\textsuperscript{16} The individual must also have a history of at least one ankle sprain, experience sensations of the ankle “giving way” at least 2 times during the last 6 months, and have a score greater than 11 on the Identification of Functional Ankle Instability (IdFAI) survey.\textsuperscript{138}

Chronic ankle instability is an umbrella term that encompasses mechanical ankle instability (MAI) and functional ankle instability (FAI). MAI is the true measurement of ligament laxity\textsuperscript{17} while FAI is characterized by subjective symptoms that are reported by the individual that the ankle is repeatedly “giving way”.\textsuperscript{8,14,17} The FAI associated “giving way” or ankle instability is partially due to disruption of the sensory receptors and altered cortical excitability after injury.\textsuperscript{24,97} The damage to the mechanoreceptors, postinjury, reduces the ability to detect joint position at terminal range of motion\textsuperscript{95} and provide afferent feedback for reflexive mechanisms at the level of the spinal cord.\textsuperscript{97} This combined delayed feedback and altered efferent reflex excitability delays reaction time and perturbation responses.\textsuperscript{18,21,28,78,139} These changes may also be feedforward in nature as found by Brown et al.\textsuperscript{140} Individuals with CAI have increased frontal plane displacement when landing specifically due to laxity of the lateral ligaments.\textsuperscript{140}
A relationship between laxity and motor cortex regulation has been established by Needle et al.,\textsuperscript{24} suggesting that cortical regulation changes after initial injury are possible. This altered brain regulation may potentially lead to recurrent joint injuries.\textsuperscript{24} The injury induced sensory-motor neuroplasticity\textsuperscript{24} associated with FAI is disrupted by the dysfunction of the mechanoreceptors, proprioceptors, and joint receptors.\textsuperscript{21} The afferent information received from the somatosensory system is also altered. This depressed ability to control movement via the somatosensory system is displayed during postural control tasks that perturbate visual feedback. Vision is a key component to maintaining postural control\textsuperscript{114} and is a significant source for maintaining dynamic stability, modulation of muscle activity,\textsuperscript{141,142} and provide afferent information.\textsuperscript{97} Postural sway is increased in an eye-closed situation,\textsuperscript{120,121} suggesting that postural control is partially reliant on visual-motor interaction.\textsuperscript{24–27} This change within the central nervous system alters feedback responses and alters movement patterns and muscle activation patterns.\textsuperscript{31} The aforementioned neurophysiologic evidence suggests the central nervous system is fundamentally altered in individuals with CAI, this change in brain function specifically alters visual-motor integration.\textsuperscript{24} The purpose of this study is to determine if visual and neurocognitive changes occur following chronic ankle instability.

**Aim 1: To assess neurocognitive function in individuals with CAI.**

1.1 Participants first completed the Y-Balance Test for a baseline assessment.

Participants then completed a Bertec Vision Trainer (Bertec Inc, Columbus, OH)
protocol that measured for narrow vs. wide reaction time, wide vs. narrow visual processing, and random targets. Scores and time to respond were recorded.
Appendix B: Data Procedure Checklist

1. Written and signed informed consent
2. FAAM-ADL
3. FAAM-S
4. IdFAI
5. Demographic information survey
6. Informed consent – paper copy
7. Y-balance
   1. Barefoot, heel flat
8. Bertec Vision Trainer
   1. Reaction time - narrow visual processing
      1. Pacing self
      2. Auto timing 1
      3. Sensitivity none
      4. Target scale 100%
      5. Static grid size minimum
   2. Reaction time - wide visual processing
      1. Pacing: self
      2. Auto timing: 1
      3. Sensitivity: None
      4. Target scale: 100%
      5. Static grid size: maximum
   3. Visual Memory – narrow visual processing
1. Playback delay: 1.5
2. Pattern difficulty: medium
3. Extended sensitivity zone: none
4. Target scale: 100%
5. Static grid size: minimum

4. Visual Memory – wide visual processing
1. Playback delay: 1.5
2. Pattern difficulty: medium
3. Extended sensitivity zone: none
4. Target scale: 100%
5. Static grid size: maximum

5. Random Target
1. Pacing: Self
2. Target Area: Use full Area
3. Duration: 30
4. Auto Pacing Interval: 3
5. Circle Area: XL
6. In/Out of Circle 80/20
7. Extended Sensitivity Zone: None
8. Target Scale: 100%
9. Static Grid Size: Min
## Identification of Functional Ankle Instability (IdFAI)

<table>
<thead>
<tr>
<th>Identification of Functional Ankle Instability (IdFAI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructions: This form will be used to categorize your ankle stability status. A separate form should be used for the right and left ankles. Please fill out the form completely and if you have any questions, please ask the administrator. Thank you for your participation.</td>
</tr>
<tr>
<td>Please carefully read the following statement: “Giving way” is described as a temporary uncontrollable sensation of instability or rolling over of one’s ankle.</td>
</tr>
<tr>
<td>I am completing this form for my right/left ankle (circle one).</td>
</tr>
<tr>
<td>1.) Approximately how many times have you sprained your ankle?</td>
</tr>
<tr>
<td>2.) When was the last time you sprained your ankle?</td>
</tr>
<tr>
<td>□ Never  □ &gt; 2 years  □ 1-2 years  □ 6-12 months  □ 1-6 months  □ &lt; 1 month</td>
</tr>
<tr>
<td>3.) If you have seen an athletic trainer, physician, or healthcare provider how did he/she categorize your most serious ankle sprain?</td>
</tr>
<tr>
<td>□ Have not seen someone  □ Mild (Grade I)  □ Moderate (Grade II)  □ Severe (Grade III)</td>
</tr>
<tr>
<td>4.) If you have ever used crutches, or other device, due to an ankle sprain how long did you use it?</td>
</tr>
<tr>
<td>□ Never used a device  □ 1-3 days  □ 4-7 days  □ 1-2 weeks  □ 2-3 weeks  □ &gt;3 weeks</td>
</tr>
<tr>
<td>5.) When was the last time you had “giving way” in your ankle?</td>
</tr>
<tr>
<td>□ Never  □ &gt; 2 years  □ 1-2 years  □ 6-12 months  □ 1-6 months  □ &lt; 1 month</td>
</tr>
<tr>
<td>6.) How often does the “giving way” sensation occur in your ankle?</td>
</tr>
<tr>
<td>□ Never  □ Once a year  □ Once a month  □ Once a week  □ Once a day</td>
</tr>
<tr>
<td>7.) Typically when you start to roll over (or ‘twist’) on your ankle can you stop it?</td>
</tr>
<tr>
<td>□ Never rolled over  □ Immediately  □ Sometimes  □ Unable to stop it</td>
</tr>
<tr>
<td>8.) Following a typical incident of your ankle rolling over, how soon does it return to ‘normal’?</td>
</tr>
<tr>
<td>□ Never rolled over  □ Immediately  □ &lt; 1 day  □ 1-2 days  □ &gt; 2 days</td>
</tr>
<tr>
<td>9.) During “Activities of daily life” how often does your ankle feel UNSTABLE?</td>
</tr>
<tr>
<td>□ Never  □ Once a year  □ Once a month  □ Once a week  □ Once a day</td>
</tr>
<tr>
<td>10.) During “Sport/or recreational activities” how often does your ankle feel UNSTABLE?</td>
</tr>
<tr>
<td>□ Never  □ Once a year  □ Once a month  □ Once a week  □ Once a day</td>
</tr>
</tbody>
</table>

Version 1.0
Foot and Ankle Ability Measure – Activities of Daily Living Subscale (FAAM-ADL)

<table>
<thead>
<tr>
<th>Activity</th>
<th>No Difficulty</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Walking on even ground</td>
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<tr>
<td>Walking on even ground without shoes</td>
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<tr>
<td>Walking up hills</td>
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<tr>
<td>Walking down hills</td>
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<tr>
<td>Going up stairs</td>
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<tr>
<td>Going down stairs</td>
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<tr>
<td>Walking on uneven ground</td>
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<tr>
<td>Stepping up and down curbs</td>
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<tr>
<td>Squatting</td>
<td></td>
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<td></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>
Foot and Ankle Ability Measure (FAAM)  
Activities of Daily Living Subscale  
Page 2

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

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty at all</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home responsibilities</td>
<td></td>
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<td></td>
</tr>
<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</td>
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<td></td>
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<tr>
<td>(standing, walking)</td>
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<tr>
<td>Heavy work</td>
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<tr>
<td>(push/pulling, climbing, carrying)</td>
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<tr>
<td>Recreational activities</td>
<td></td>
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</tbody>
</table>

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities.

__ __ __ .0 %

Foot and Ankle Ability Measure – Sports Subscale (FAAM-S)

<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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<tr>
<td>Starting and stopping quickly</td>
<td></td>
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<tr>
<td>Cutting/lateral Movements</td>
<td></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 like</td>
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</tr>
</tbody>
</table>

How would you rate your current level of function during your sports related activities from 0 to 100 with 100 being your level of function prior to your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

__ __ __ . 0%

Overall, how would you rate your current level of function?

- Normal
- Nearly Normal
- Abnormal
- Severely Abnormal

Medical Questionnaire: General

<table>
<thead>
<tr>
<th>HEIGHT</th>
<th>WEIGHT</th>
<th>GENDER</th>
<th>AGE</th>
<th>DATE OF BIRTH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

What is your dominant hand?  
Right □  Left □
Which leg would you use to kick a ball?  
Right □  Left □

Please check below if you have or have had any of the following:
General Medical

- □ Allergies (latex, heat, cold, electricity, medications, etc)
- □ Cancer
- □ Biomedical Devices (implants, pacemaker)
- □ Currently pregnant or nursing
- □ Recent illness (upper respiratory infection, cold, infections)
- □ Diabetes
- □ Asthma
- □ Surgery
- □ Other: _______________________

Please explain any checked items: __________________________________________
________________________________________________________________________

Please provide date of last physical exam: __________________________________

Neurological

- □ Epilepsy/seizures
- □ Anxiety disorders
- □ ADHD
- □ Depression
- □ Diabetic Neuropathy
- □ Concussion OR Traumatic Brain Injury
- □ Cerebral Palsy
- □ Balance Disorder
- □ Vertigo
- □ Parkinson’s Disease
- □ Multiple Sclerosis
- □ Other: _______________________

When was your last concussion: ____________________________________________
________________________________________________________________________

Please explain any checked items: __________________________________________
________________________________________________________________________

Cardiovascular

- □ Stroke
- □ High Blood Pressure
- □ Heart Attack
- □ Shortness of Breath
- □ Sickle Cell Trait
- □ Heart Murmur
- □ Heart Disease (Coronary Heart Disease, Arteriosclerosis)
- □ Thrombosis or Embolism
- □ Marfan’s Syndrome
- □ Cardiac Arrhythmia (Irregular Heart Beat)
- □ Other: _______________________

Subject ID: _____________  IRB# _____________
Movement Analysis Performance Laboratory

Please explain any checked items: __________________________________________

Other
Have you taken any prescription or over the counter medications within the last 24 hours?  
Yes  No

If yes, please list: _______________________________________________________

Have you consumed any of the following stimulants or depressants in the last 12 hours?

☐ Caffeine  ☐ Alcohol
☐ Tobacco  ☐ Other __________________________

If yes, please explain:

_____________________________________________________________________

_____________________________________________________________________

Do you exercise regularly?  
Yes  No

If yes, how often, what type and for how long? __________________________

Are you currently on an athletic team?  
Yes  No

If yes, at what level? _________________________________________________

If yes, for what sport? _______________________________________________

Were you previously on an athletic team (HS, college, recreation)?  
Yes  No

If yes, at what level? _________________________________________________

If yes, for what sport? _______________________________________________
Movement Analysis Performance Laboratory

Orthopedic
Regarding your lower extremity (hips, thighs, knees, shins, ankles, feet) please answer the following questions:

Do you have a history of any broken bones?
*Please explain the extent of the injury including the date and severity:

____________________________________________________________________________
____________________________________________________________________________

Do you have a history of any torn or sprained ligaments? – HOW DID IT HAPPEN?
*Please explain the extent of the injury including the date and severity:

____________________________________________________________________________
Appendix D: Power Analysis

The required number of participants was determined following a power analysis (small effect size (0.25), alpha level (0.05), and power (0.95), two groups, and seven dependent variables), 100 participants (50 in each group) is the minimum number of participants required to be statistical significant.