COMPARISON OF BAREFOOT AND SHOD REHABILITATION EXERCISES FOR INCREASING BALANCE AND INTRINSIC FOOT STRENGTH FOR CHRONIC ANKLE INSTABILITY

A thesis submitted to the Kent State University College of Education, Health, and Human Services in partial fulfillment of the requirements for the degree of Masters of Exercise Physiology

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Although most ankle sprains are resolved with conservative treatment, persistent symptoms might remain and a number of them may develop into Chronic Ankle Instability (CAI). The purpose of this study was to observe whether barefoot training exercises would increase balance and intrinsic foot strength in chronic ankle instability as opposed to shod rehabilitation or no rehabilitation. 20 volunteers (height = 173.85 ± 10.75, weight = 80.16 ± 23.17, age = 21.05 ± 2.39) were recruited and placed into 3 separate rehabilitation protocols. A 3-week rehab protocol focusing on balance training and intrinsic foot muscle strength was performed and measurements were taken for the Athletic Single Leg Test, modified Clinical Test of Sensory Interaction & Balance, Functional Ability and Ankle Measure (FAAM), and Intrinsic Foot Muscle Test (IFMT). Change scores for FAAM were significant between participants who were shod during rehabilitation and control \( (p = 0.032) \) and for barefoot rehabilitation and control \( (p = 0.001) \). SLO (Single Leg Overall Stability) was significant between barefoot and control \( (p = 0.02) \) and trending toward significance for shoes and control \( (p = 0.051) \). No difference was seen between barefoot and shod conditions during rehabilitation. Balance training and intrinsic foot muscle strengthening significantly improved self-reported functional and static postural control for CAI and was not dependent on footwear.
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CHAPTER 1
INTRODUCTION

A multitude of injuries involving the ankle occur each year that can be attributed to an active lifestyle. These injuries can impact not only on the individuals’ overall wellbeing, but also place a significant burden on national medical costs. Worldwide, the cost of sports injuries has been estimated at $1 billion annually (Murphy, Connolly, & Beynnon, 2003). Additionally, there is an estimated 3–5 million injuries that occur annually among competitive and recreational athletes in the United States alone (Hootman, Dick, & Agel, 2007; Kerrigan et al., 2009; Kraus & Conroy, 1984). Specifically, it is estimated that in the United States nearly 23,000 ankles are sprained daily and 85% of those sprains affect the lateral ligaments (Garrick, 1977; Kannus & Renstrom, 1991). In a recent review of literature related to sports-ankle injuries, Fong, Hong, Chan, Yung, and Chan (2007) identified the ankle as being the second most commonly injured body site in 24 of 74 (34%) sports, with lateral ankle sprains being the most common. The most recent data provided by the National Collegiate Athletic Association (NCAA) injury surveillance system for 2006–2007 concurred indicating that the most common injury sites were the ankle, knee, and lower leg (Hootman et al., 2007). This condition is not always limited to adults. A recent study among high school athletes in 2005 reflected that 52.8% of reported injuries were lower extremity related injuries (Fernandez, Yard, & Comstock, 2008).

After initial injury, the rate of reoccurrence may be as high as 80% among active individuals (Fernandez et al., 2008). The longstanding residual symptoms of an ankle
sprain affect over 70% of those who suffer an ankle sprain (Anandacoomarasamy & Barnsley, 2005; Braun, 1999; Gerber, Williams, Scoville, Arciero, & Taylor, 1998). In a recent study by Hertel (2002), it was suggested that although most lateral ankle sprains are resolved with conservative treatment, persistent symptoms might remain and a number of them may develop into Chronic Ankle Instability (CAI). CAI is a broad term used to describe the presence of mechanical and functional (perceived) instability following an ankle sprain (Delahunt et al., 2010; Hiller, Kilbreath, & Refshauge, 2011). The symptoms of CAI are reported to persist in up to 25% of people at 3 years after the initial sprain (van Rijn et al., 2008).

A proposed mechanism by which individuals sustain ankle injuries may be that the feet of normally shod individuals become rigid and are unable to yield to normal loading forces potentially decreasing balance and strength of the intrinsic muscles of the foot (Nigg, 2009). It is understood that atrophy of the foot intrinsic musculature may occur in a shod environment, which has been suggested to be a factor in foot, ankle, and other lower extremity injuries (Nigg, 2009). Specifically, intrinsic foot muscles, including the flexor digitorum brevis and interosseous muscles, lumbricals, and abductor hallucis contribute to arch support during gait (Mann & Inman, 1964). Recent EMG studies show that the abductor hallucis contracts to support the medial longitudinal arch and controls pronation during static stance (Headlee, Leonard, Hart, Ingersoll, & Hertel, 2008). Interestingly, navicular drop will increase when the abductor hallucis is fatigued, thus leading to decreased arch support in the foot, leaving the ankle prone to injury (Headlee et al., 2008). It has been suggested that strengthening and thus improving the
endurance of these intrinsic foot muscles in individuals may reduce over pronation of the foot, thus promoting proper biomechanics, increasing balance, and reducing the subsequent pathologies such as CAI. Therefore new methods of prevention and rehabilitation of lateral ankle injuries are needed to reduce medical costs, prevalence and reoccurrence of lateral ankle injuries. New methods can also advance the rehabilitation knowledge of chronic ankle instability injuries in an active population to help increase patient outcomes.

Coaches and health professionals have used barefoot training for many years yielding anecdotal support that barefoot training improves the strength of the overall muscular system and trains all intrinsic foot muscles, together with the large muscles like the biceps femoris and gastrocnemius, and small muscles like the soleus and peroneus longus (Robbins & Hanna, 1987). Barefoot running has been given additional attention recently and has become a new phenomenon within endurance related sports to facilitate a reduction in running associated injuries. The goal of barefoot training has been to decrease prevalence of ankle and foot injuries, while in turn increasing balance and strength for functional activity.

Training of the musculature upon injury to the ankle may become increasingly difficult if left untreated and allowed to persist and evolve into CAI. For this reason proper training of intrinsic muscles of the foot aims to correct dysfunctions, such as decreased stability of the ankle and foot as well as increase balance and decrease lateral ankle injury prevalence. Active rehabilitation as a result has become the norm for the treatment of lateral ankle injuries, specifically CAI, involved with many sports related
activities. In addition, rehabilitation protocols are ever adapting to facilitate the greatest gains possible for a patient or athlete. Therefore, barefoot training exercises in relation to a modification to increase intrinsic foot muscle strength and balance along with decrease CAI symptoms and enhance CAI rehabilitation has been given little to no attention in the research to highlight potential beneficial gains in comparison to shod rehabilitation for CAI. It has been suggested that a well-balanced development of all muscles crossing a joint is essential for performance and therefore injury prevention (Robbins & Hanna, 1987). It is deemed noteworthy then to determine the relationship of barefoot training exercises and CAI in rehabilitation. If performed correctly barefoot training may contribute to increasing intrinsic foot muscle strength, balance and furthering the knowledge for rehabilitation of chronic ankle instability.

**Statement of Problem**

A main focus of barefoot training research has been centered on the preventive measures of chronic ankle instability. However, little research has been done to outline the specific guidelines for the rehabilitation of individuals that currently live with CAI. Therefore, a need for increasing patient gains in balance and intrinsic foot strength, while decreasing rehabilitation time in a medical setting for CAI, is warranted. Increasing barefoot activity has been shown to produce favorable outcomes to individuals in the prevention of lower extremity related injuries (Robbins & Hanna, 1987). Thus, barefoot training as a modification in the protocols of foot and ankle rehabilitative exercises should be addressed due to lack of research outlining potential gains from a rehabilitative standpoint for chronic ankle instability.
**Purpose Statement**

The purpose of this study was to determine whether barefoot training exercises in a rehabilitative program would increase balance and intrinsic foot strength in individuals with chronic ankle instability better than shod rehabilitation exercise or no rehabilitation.

**Research Questions**

1. Does barefoot rehabilitation generate greater increases in balance and intrinsic foot muscle strength better than shod rehabilitation or no rehabilitation?
2. Do barefoot rehabilitation exercises increase the intrinsic strength of the foot for chronic ankle instability as measured subjectively by the Intrinsic Foot Muscle Test (IFMT)?
3. Does barefoot rehabilitation enhance balance as measured by the Biodex Balance System SD™ in chronic ankle injuries?
4. Does barefoot rehabilitation produce a greater increase in self-reported function scores assessed by the Foot and Ankle Ability Measure (FAAM) more than shod or no rehabilitation?

**Research Hypothesis**

Individuals with chronic ankle injuries undergoing the barefoot training rehabilitation program will experience a greater increase in balance and intrinsic foot muscle strength as well as an increase in their self-reported function score than those who have undergone an ankle rehabilitation program with shoes or no rehabilitation at all.
Operational Definitions

Chronic Ankle Instability: Characterized by residual lateral instability leading to repetitive ankle sprains and is a result of perceived ankle instability, mechanical ankle instability or a combination of the two (Hiller et al., 2011).

Neuromuscular Control: The unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining and restoring joint stability (Riemann & Lephant, 2002).

Postural Control: The ability to detect motion in the foot and to respond by making postural adjustments (Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002).

Proprioception: specialized variation of the sensory modality within the body and encompasses the sensations of joint movement (kinesthesia) and joint position (joint reposition sense; Lee & Lin, 2008).

Shod: Used to define a person or group of persons that would be wearing a shoe of a specific kind.

Assumptions

For the purpose of this study, the following assumptions were made:

1. All subjects will report honestly that they are free from any previous health conditions and surgeries that may compromise results, consisting of, but not limited to, head trauma, balance disorders, total joint replacements of the ankle, recent fractures of the bony structures of the lower extremity within the last 6 months, sensation dysfunctions, and heart conditions.
2. All subjects will only participate in exercise they are accustomed to outside the study and will not exceed the time and intensity at which they usually participate.

3. All measurement tools will be calibrated to the optimal standards to insure accurate data collection.

**Delimitations**

All individuals unable to perform single and double leg and single leg standing balance exercises, due to head trauma or balance disorders, were deemed unable to participate in this study due to their inability to properly complete balance intended rehabilitation exercises. Any subjects who have had corrective orthopedic surgery on the foot or ankle were excluded from the study due to the corrective nature of the study.

**Significance of Study**

Ankle injuries are a very prevalent condition that can impact an individual’s ability to engage in physical activity and in activities of daily living. If left untreated and allowed to persist as a common injury for an individual, the chances of chronic ankle instability is likely to form yielding further complications. Chronic ankle injuries can have many different causes, and therefore, many different alternatives exist for its treatment, yet few significant findings have been produced outlining the relevance of barefoot training exercises for balance and intrinsic foot muscle strengthening in the rehabilitation setting. It is hypothesized that barefoot training will increase an individual’s balance and intrinsic strength of their foot, more so than shod or no
rehabilitation, which will aid the active population in returning faster to their healthy active lifestyle as well as any activities of daily living.
CHAPTER II

REVIEW OF RELATED LITERATURE

The cause of lateral ankle injuries in the average individual can be attributed to trauma or muscular imbalances. Left untreated lateral ankle injuries may persist and develop into a condition known as Chronic Ankle Instability (CAI), leaving individuals prone to future injuries. There is strong evidence that inadequate rehabilitation places an individual at increased risk of suffering an injury to the ankle, knee, and all other injuries as a group (Murphy et al., 2003).

In relation, footwear has been developed over the years for prevention of foot and ankle injuries, but since it maintains foot movement within boundaries, it inadvertently decreases muscular recruitment leading to potential injuries (Hart & Smith, 2008). Thus, barefoot activity has spiked interest recently for decreasing injury and has been shown to have positive results in relation to prevention of foot and ankle injuries (Robbins & Hanna, 1987). Barefoot running specifically has been gaining a dedicated following within the running sports community as a new technique for prevention and strengthening modification in runners (Jenkins & Cauthon, 2011).

Identifying modifiable risk factors that are common to the majority CAI related injuries result in noticeable reductions in injury rates and possibly reductions in related medical costs over time (Hootman et al., 2007). Intrinsic foot muscle activity makes a significant contribution for maintaining a stable base of support during dynamic activity, which may aid in injury reduction (Rothermel, Hale, Hertel, & Denegar, 2004). As a result, barefoot activity, due to its simplicity, needs to be considered for possible
rehabilitation modifications to help patients achieve greater and faster gains in balance and intrinsic foot muscle strength throughout the rehabilitation process for CAIs. This study examines which of the two interventions, barefoot or shod balance exercises, along with intrinsic foot muscle exercises is best for the treatment of chronic ankle instability as it relates to balance and intrinsic foot muscle strength in a rehabilitation setting for active individuals.

**Chronic Ankle Instability**

**Definitions**

After an acute ankle sprain, problems such as residual pain, swelling, weakness, ankle instability, and recurrent ankle sprains are commonly observed (Anandacoomarasamy & Barnsley, 2005). In the case of repeated occurrence of ankle injuries in which an individual exhibits residual symptoms such as repetitive lateral ankle instability, the patient is said to be suffering chronic ankle instability (CAI; C. F. Lin, Chen, & Lin 2011). Medically, CAI is described as altered mechanical joint stability due to repeated trauma of ankle integrity with resultant perceived and observed deficits in neuromuscular control (Beynnon, Murphy, & Alosa, 2002; Hiller et al., 2011). A recent model by Hiller et al. characterized CAI by residual lateral instability leading to repetitive ankle sprains and is a result of perceived ankle instability, mechanical ankle instability, or a combination of the two. Perceived instability (PI) of the ankle joint refers to a situation whereby a subject reports experiencing frequent episodes of ankle joint “giving way” and feelings of ankle joint instability (Hiller et al., 2011). Mechanical instability (MI) of the
ankle joint is characterized by excessive inversion laxity of the rear foot or excessive anterior laxity of the talocrural joint (Delahunt et al., 2010).

**Prevalence**

Ankle sprains are the most common injury in physically active people and account for approximately 23% and 15% of all injuries in high school and collegiate athletics, respectively (Hootman et al., 2007; Nelson, Collins, Yard, Fields, & Comstock, 2007). This places the risk and rate of injury in intercollegiate athletics at about 1 injury every 2 games and 1 injury every 5 practices (Hootman et al., 2007). In terms of total burden in the athletic population lower extremity injuries account for about half of all injuries in athletes as a whole (Hootman et al., 2007). Further evidence indicates two-thirds of all ankle injuries are left untreated by health care professionals, suggesting that the true incidence of ankle injuries may be greater than initial estimate (Waterman, Owens, Davey, Zacchilli, & Belmont, 2010). This being said, about 40% of the patients who have a lateral ankle sprain develop some sort of symptom related to CAI (Braun, 1999; Konradsen, 2002). Research has shown that around 74% of patients with residual symptoms such as general ankle instability, giving way, or recurrent ankle sprains may develop CAI (Anandacoomarasamy & Barnsley, 2005).

**Possible Etiology**

The cause of ankle injuries varies depending on certain extrinsic and intrinsic factors. Many of the extrinsic risk factors that can result in the ankle injury would include level of competition, skill or competition level, shoe type, use of tape or bracing, and playing surface (Taimela, Kujala, & Osterman, 1990). Intrinsic risk factors include
age, sex, previous injury and inadequate rehabilitation, aerobic fitness, body size, limb dominance, flexibility, limb girth, postural stability, anatomical alignment, and foot morphology (Taimela et al., 1990). Altered muscle activation is thought to be an important factor that might contribute to re-injury after a lateral ankle sprain, thus leading to CAI (Hertel, 2002). Deficits in postural control and strength are involved after an ankle injury, as well as structural laxity of the joint (Hertel, 2002; Tropp & Odenrick, 1988). In addition, a recent study by Nigg (2009) found that imbalances of musculature, impact forces, and biomechanical deficits have all been shown to affect lower extremity injury rates, thus relating to the overall prevalence of CAI injuries. Recently, aspects of both perceived and mechanical ankle instability have been demonstrated to be significantly different in those with CAI compared with matched healthy ankles (Hiller et al., 2011; Hubbard, Kramer, Denegar, & Hertel, 2007).

**Recurrence**

The rate of recurrent ankle injuries might be as high as 28.3% and might be due to factors related to CAI (Swenson, Yard, Fields, & Comstock, 2009). This recurrence of injury is a main focus that many clinicians aim to address in regards to ankle rehabilitation. Strong evidence suggests that previous injuries in conjunction with inadequate rehabilitation are some risk factors for re-injury of the same type and location anatomically (Murphy et al., 2003). Patients with muscular imbalances tend to display a higher recurrence of injury in an athletic setting (Murphy et al., 2003). Prevention and rehabilitation efforts may be more effective in terms of both numbers affected and costs if
focused on modifications to correspond toward a larger number of general ankle injuries (Hootman et al., 2007).

**Current Guidelines for Treatment of Chronic Ankle Injuries**

The current clinical guidelines for the management of CAIs vary, but recent studies have shown that after an ankle sprain, there is evidence for the use of functional support and nonsteroidal anti-inflammatory drugs (NSAIDs; C. W. C. Lin, Hiller, & de Bie, 2010). There is weak evidence suggesting that the use of manual therapy may lead to positive short-term effects (C. W. C. Lin et al., 2010). Electro-physical agents do not appear to enhance outcomes and are not recommended (C. W. C. Lin et al., 2010). Lastly, it has been shown that exercise may reduce the occurrence of recurrent ankle sprains and may be effective in managing CAI (C. W. C. Lin et al., 2010). A recent trend in CAI rehabilitation is to move toward a more functional based approach, including more emphasis on functional movement than quiet standing and more closed than open kinetic-chain positioning (Webster & Gribble, 2010).

**Rehabilitation**

According to Hentges and Lee (2011), appropriate and aggressive rehabilitation should be attempted in all cases of chronic ankle and subtalar instability before electing surgical reconstruction. Early functional treatment in comparison to anatomic reconstruction produced the fastest recovery of ankle mobility and thus the earliest return to activity without affecting mechanical stability (Kerkhoffs et al., 2012). Health care providers and rehabilitation specialists tend to treat CAI as a global/central and not just a local/peripheral injury, which may decrease benefits of rehabilitative exercise for CAI.
In a current study by Urguden et al. (2011), investigating patients after ankle sprains, especially in patients with chronic instability, found that strengthening of the muscles around the ankle with well-planned proprioceptive exercises helped the patients return to normal living and sports activities. In conjunction they also found that proprioceptive exercises might help to prevent unnecessary surgery, especially in cases with functional instability within individuals (Urguden et al., 2011). Functional rehabilitation has shown improvements in measures of dynamic postural control and self-reported outcomes, which may help reduce the actual recurrence of injury (Webster & Gribble, 2010).

**Balance and Proprioception**

Damage to the proprioception system is thought to be a major cause of functional instability after ankle injuries (Lee & Lin, 2008). Specifically, it is believed that ankle proprioception is critical to the balance of the human body during functional activities such as standing, walking, and running (Leanderson, Eriksson, Nilsson, & Wykman, 1996; Robbins & Waked, 1998). Maintaining postural balance involves complex coordination and integration of multiple sensory, motor, and biomechanical components (Irrgang, Whitney, & Cox, 1994). It has been demonstrated that subjects with functional ankle instability show impaired postural stability, decreased proprioception, and altered peripheral control of the ankle muscle function when compared with non-impaired subjects (Hertel, 2002; Mckeon et al., 2008).

In addition, the nervous system employs the ankle strategy in response to small losses of balance and to adjust balance in quiet standing (Woollacott & Shumway-Cook,
The ankle strategy is also called ankle sway and uses the length of the foot as a lever to correct for minor losses of balance (Woollacott & Shumway-Cook, 2001). It is suspected that this strategy has the potential to become decreased with repeated lateral ankle injuries resulting from an individual's CAI, thus hindering overall balance (Hertel, 2002; Mckeon et al., 2008).

The generic term “neuromuscular training” is used to describe a combination of functionally based exercises, including postural stability, proprioceptive, and strength training, as part of a rehabilitation regimen (C. W. C. Lin, Delahunt, & King, 2012). The ability to detect motion in the foot and to respond by making postural adjustments is widely considered crucial in the prevention of ankle injury (Willems et al., 2002). In a review of literature by Holmes and Delahunt (2009), balance-training protocols were found to help patients improve postural control in subjects with CAI, but that a specific protocol had not yet been determined as a standardized plan.

Still there is only limited evidence regarding the efficacy of balance training rehabilitation for chronic ankle instability. Furthermore, there is controversy as to the length of the training program required for adaptations to occur (Riemann, Tray, & Lephart, 2003). In one study performed by C. W. C. Lin et al. (2010), there appears that a 4-to-6 week program performed 3 to 5 times a week can improve dynamic measures of postural control. A later study shows that small, short-term treatments benefit individuals supervised through neuromuscular training conducted over 20 to 30 minutes a few times a week for 4 weeks (C. W. C. Lin et al., 2012). Therefore a need is presented to determine a standardized, time specific, proprioceptive protocol for CAI.
**Strengthening**

During injury to the ankle, an individual usually presents with loss of functional movement and thus atrophy of the surrounding musculature. An imbalance in this muscular co-contraction as a result of strength deficits may have the ankle joint susceptible to injury due to less efficient dissipation of ground reaction forces (Kaminski & Hartsell, 2002). Strength training has typically been a major element in rehabilitation programs following ankle sprains and is most often initiated once pain-free range of motion is regained (Caulfield, 2000). The ankle joint musculature plays an integral role in dynamic stabilization of the ankle joint, which is achieved by co-contraction of musculature surrounding the joint (Kaminski & Hartsell, 2002). Therefore, strengthening techniques of the foot and ankle musculature should concentrate on intrinsic and extrinsic muscles (Kaminski & Hartsell, 2002). Increasing the surrounding musculature strength of the foot and ankle both extrinsic and intrinsic aims to generate faster healing times and a quicker return to normal function. The intrinsic foot muscles in particular contribute to the support of the medial longitudinal arch, and reduce foot pronation during static stance (Soysa, Hiller, Refshauge, & Burns, 2012). In addition, intrinsic muscles of the foot make a significant contribution for maintaining a stable base of support during dynamic activity (Rothermel et al., 2004). Plantar intrinsic foot muscles are thought to work in conjunction with the plantar aponeurosis, plantar ligaments, and extrinsic foot muscles to control the stresses on the foot during gait (Soysa et al., 2012). Extrinsic muscles, in particular ankle evertors, with strength deficits, do not appear to contribute to the development of CAI, so the use of evertor strengthening protocols in clinical practice
requires careful consideration (Holmes & Delahunt, 2009). Strengthening protocols addressing invertor muscle deficits may be more efficacious as subjects with CAI exhibit invertor strength deficits (Holmes & Delahunt, 2009).

**Barefoot Training**

Currently numerous advantages and benefits stem from the use of barefoot activity, some of which include gait alterations, reduced impact forces, decreased oxygen consumption, reduced running related injuries, increases in strength, increased in proprioception, and decreases in foot deformities (Jenkins & Cauthon, 2011). Much of this research remains inconsistent, and anecdotal statements of the research are the only available measurements to date (Jenkins & Cauthon, 2011).

**Gait Alterations**

Gait plays a substantial role in determining function of the lower extremities, and therefore abnormal alterations may lead to injury. That being the case, several investigators have found consistent changes when the runner is barefoot, including decreased stride length; increased stride rate; decreased range of motion at the ankle, knee, and hip; and a more plantar flexed ankle at contact (Jenkins & Cauthon, 2011). Another observation in barefoot runners was a higher electromyographic activity (EMG) in pre-activation of plantarflexor muscles (Jenkins & Cauthon, 2011; Divert, Mornieux, Baur, & Mayer, 2005).

**Decreased Oxygen Consumption**

It has been suggested that the use of shoes increases the oxygen consumption of the runners and thus increases energy expenditure (Jenkins & Cauthon, 2011). There is
an estimated 4.3% higher oxygen consumption on average in those wearing shoes 700 g
versus those in barefoot conditions (Flaherty, 1994; Jenkins & Cauthon, 2011). In
addition Webb, Saris, Schoffelen, Van Ingen Schenau, and Ten Hoor (1988) noted that
further inefficiency in the use of energy while shod may happen when the actual
repetitive deformation of the shoe occurs requiring additional energy for striding that
could be saved in the barefoot state. Therefore, with a reduction in energy within the
body a greater role can be put toward prevention of injuries or increases in the healing
process of CAI related injuries.

**Impact Forces**

Impact forces in the lower extremity during activity have been identified as a
main contributing factor for injuries to the lower extremity, more importantly directly
affecting the foot and ankle (Hart & Smith, 2008). The foot does not need any external
cushioning to deal with the impact of running. Robbins and Hanna (1987) found that
through training, improved sensory feedback resulted in gait alterations that allowed for
foot strike to be at the metatarsal heads instead of the heel. In addition, there is
adaptation of the intrinsic musculature with resulting increased strength and, therefore,
the medial longitudinal arch is higher and better able to deform with impact and provide
improved shock attenuation (Nigg, 2009). Barefoot runners also have increased
variations in the lower-extremity joints, which relates to the ability of their
mechanoreceptors to adjust the joint pattern and reduce repetitive impact forces and,
therefore, reduce injuries (Jenkins & Cauthon, 2011). Shakoor and Block (2006) found
that walking barefoot resulted in decreased peak joint loads at the hips and knees.
Alternatively, shod runners are less likely to institute necessary shock-reducing behaviors, due to the cushioning of the shoes, and would therefore be more susceptible to injury (Jenkins & Cauthon, 2011; Robbins & Hanna, 1987).

**Increased Proprioception**

A variety of investigators claim that improved proprioceptive ability directly leads to a reduction in foot positions errors, thus, fewer lower extremity injuries. Robbins and Hanna (1987) discovered that there was a loss of proprioception with aging, but also those that wear shoes. It is believed that there is barrier between the plantar mechanoreceptors and any supporting surfaces, which would thus inhibit foot position awareness, decreasing proprioception (Jenkins & Cauthon, 2011; Robbins & Hanna, 1987). Weakness in the plantar intrinsic foot muscles has previously been implicated as a contributing factor to balance impairment (Menz, Morris, & Lord, 2005; Mickle, Munro, Lord, Menz, & Steele, 2009). Plantar intrinsic foot muscle activation is strongly correlated with mediolateral postural sway in single leg stance, with increasing activity observed during sway to the medial border of the foot (Kelly, Kuitenen, Racinais, & Cresswell, 2012). Therefore, as foot posture and function are known to impact on single leg balance activation of the plantar intrinsic, foot muscles may be utilized to help stabilize the foot, thereby improving balance (Menz et al., 2005; Tsai, Yu, Mercer, & Gross, 2006). In conjunction by removing the shoes from the activity, the individuals are able to recruit a greater density of sensory and mechanoreceptors, which thus leads to stimulating greater proprioceptive responses (Robbins & Hanna, 1987).
Increased Strength of the Musculature

Physical stressors can be positive stimuli for strengthening unless they exceed tolerance boundaries, in which case they turn into negative stressors that cause fatigue and possible injury (Hart & Smith, 2008). It has been suggested that rigid shoes prevent motion and development of the intrinsic musculature (Jenkins & Cauthon, 2011). Another study suggested that during human evolution, toe flexor force and function are gradually diminishing and therefore plantar intrinsic muscles are becoming largely redundant in the foot (Rolian, Lieberman, Hamill, Scott, & Werbel, 2009). Barefoot runners on the other hand develop, through training, increased muscular strength adaptations of the intrinsic musculature (Jenkins & Cauthon, 2011). Likewise, there is also an increase in intrinsic muscle size and strength with the use of minimalist shoe, which mimics barefoot movement (Jenkins & Cauthon, 2011). Therefore, it may be warranted to incorporate intrinsic foot musculature exercises into rehabilitation exercise for the ankle and foot.

Decreased Risk of Foot Deformities

Optimum foot development can only occur in barefoot conditions (Jenkins & Cauthon, 2011; Wolf et al., 2008). It has been shown that competitive footwear tends to lead to deformity of the foot along with stiffness (Jenkins & Cauthon, 2011; Rao & Joseph, 1992). The wearing of shoes constrains the natural motions of the foot, especially regarding forefoot to rearfoot motion (Jenkins & Cauthon, 2011). There is also evidence that barefoot training allows a better arch development than those that wear shoes due to the strengthening of the intrinsic foot muscles (Jenkins & Cauthon, 2011;
Rao & Joseph, 1992). In addition, the discontinuance of barefoot training has been shown to lead to the loss of arch flattening that had been achieved through barefoot programs (Hart & Smith, 2008).

**Reduction in Running-Related Injuries**

No evidence currently exists that demonstrates a reduced prevalence of running injuries in barefoot runners; however, studies exist that demonstrate reduced injury factors in a laboratory setting (Jenkins & Cauthon, 2011). Ankle injuries can be caused by impaired proprioception that results in the inadequate use of anticipatory muscular movements under dynamic conditions (Robbins & Hanna, 1987). Thus, foot position corrections, improved intrinsic musculature, increased proprioception ability, all found within a barefoot training program aim to correct injuries of the lower extremity (Hart & Smith, 2008).

**Current Disadvantages to Barefoot Training**

Even though there are many benefits to introducing a barefoot training protocol into a patient’s daily routine, there is still a need to understand current disadvantages to help deter from potential adverse effects. Some of the few considerations that a clinician should be aware of include possible injury from surface debris and general hazards, availability of adequate training surfaces, exposure to microorganism/infectious agents, any additional sensation problems, and possible increased shock transmission to back muscles (Hart & Smith, 2008). It is important to note however that by introducing minimalist shoes, that mimic barefoot activity, you may avoid certain issues that arise with barefoot training.
**Implementation of Barefoot Training**

No studies currently exist that demonstrate the safest or most efficacious method for instituting a barefoot training program (Hart & Smith, 2008). Therefore, implementing a barefoot training regimen should begin with a minimal amount of activity and should progress gradually (Hart & Smith, 2008). The current guidelines that exist suggest that people should slowly reduce the level of external support (shoes and orthotics) to allow time for strength and tolerance to improve as they participate in barefoot activities (Jenkins & Cauthon, 2011). Weakened structures may need considerable time to adjust to the new stimuli, and gradually progress over a period of several weeks or months is recommended (Jenkins & Cauthon, 2011). Additionally, the total daily participation should be broken into short sessions that can progressively combine into longer sessions (Jenkins & Cauthon, 2011). Also the type of surface on which the barefoot training takes place should depend on the individual’s needs (Jenkins & Cauthon, 2011). This is because barefoot activity conditions the skin on the sole of the foot by causing it to thicken and become tougher (Hart & Smith, 2008). The thickening of the skin allows for determination of running surface to help avoid terrain hazards. However, the overall implementation of a barefoot training program needs to consider the safety of the individual and the goals that the clinician wishes to accomplish.

**Tools of Measurement for Chronic Ankle Instability**

**Foot and Ankle Ability Measure**

The “Foot and Ankle Ability Measure” (FAAM) is one of the most appropriate evaluation instruments available to quantify functional disabilities in active individuals
with CAI (Carcia, Martin, & Drouin, 2008). The FAAM questionnaire is used by
subjects for self-reported assessment of pain and disability associated with CAI (Carcia et
al., 2008). The FAAM comprises the separately scored 21-item ADL and 8-item sports
subscales (Martin, Irrgang, Burdett, Conti, & Van Swearingen, 2007). Each item is
scored on a 5-point Likert scale anchored by 4 (no difficulty at all) and 0 (unable to do).
Item score totals, which range from 0 to 84 for the ADL subscale and from 0 to 32 for the
sports subscale, are transformed to percentage scores (Martin et al., 2007). The lower the
percentage scores the higher degree of ankle instability is perceived to be by an
individual. A higher score represents a higher level of function for each subscale (Carcia
et al., 2008). The FAAM has evidence of content validity; construct validity, reliability,
and responsiveness in athletes with a broad range of musculoskeletal disorders of the leg,
ankle, and foot (Martin, Irrgang, Burdett, Conti, & Van Swearingen, 2005). Its main
advantage over other available evaluation instruments is that the FAAM has a sports
subscale in addition to activities of daily living (ADL) subscale (Carcia et al., 2008).
This sports subscale has been proven particularly useful when addressing the limitations
of collegiate athletes with CAI (Carcia et al., 2008). In the same study conducted by
Carcia et al. (2008) athletes with CAI scored lower on ADL and sports subscales
compared with healthy athletes.

**Biodex Balance System SD™**

Many systems are used to assess balance and postural control. The Biodex
Balance System SD™ is one of the most frequently force plate systems used by clinicians.
It uses a circular platform that is free to move about the anterior-posterior (AP) and
medial-lateral (ML) axes simultaneously. In addition to moving about these axes, it is possible to vary the stability of the platform by varying the resistance force applied to the platform (Arnold & Schmitz, 1998). Springs apply this force to the underside of the platform and can be adjusted to preset resistances established by the manufacturer. Rather than measuring the deviation of the center of pressure (COP) during static conditions, this device measures the degree of tilt about each axis during dynamic conditions (Arnold & Schmitz, 1998). From the degrees of tilt about the AP and ML axes the Biodex Balance System SD™ calculates the medial-lateral stability index, the anterior-posterior stability index, and the overall stability index (Arnold & Schmitz, 1998). Thus, the Biodex Balance System SD™ appears to provide more specific information on ankle joint movements (Arnold & Schmitz, 1998).

**Intrinsic Foot Muscle Test**

Measuring intrinsic muscle strength of the foot poses many different challenges. Diverse methods are available for measuring intrinsic muscle properties both directly and indirectly, but there is lack of agreement regarding the most appropriate measure of strength (Soysa et al., 2012). The indirect methods include Magnetic resonance imaging (MRI); computerized tomography (CT); ultrasonography; electromyography (EMG) and muscle biopsy (Soysa et al., 2012). Indirect methods are generally used to estimate muscle structure, activity (EMG), and histochemical properties (Soysa et al., 2012). Indirect methods can discriminate between intrinsic and extrinsic muscles, but are unable to directly determine force or strength (Soysa et al., 2012). Most studies have focused on toe flexor strength as a surrogate measure of intrinsic muscle strength (Soysa et al., 2012).
Toe flexor strength is a combination of intrinsic and extrinsic muscle activity; therefore all ‘direct’ methods are actually measuring intrinsic and extrinsic toe muscle strength (Soysa et al., 2012). A variety of methods have been described that purport to measure toe flexor force: toe hand-held dynamometry; paper grip test; plantar pressure, and the Intrinsic Foot Muscle Test (Soysa et al., 2012). Handheld dynamometry is a promising method of measuring intrinsic muscle strength, but it is unclear which intrinsic muscles are active during the test or how much force is attributed to extrinsic muscles (Soysa et al., 2012). The Intrinsic Foot Muscle Test also shows promise, but has not been studied enough extensively to warrant reliability or validity contributions (Soysa et al., 2012). Therefore, more studies are required using these two methods to establish guidelines for measuring intrinsic foot muscle strength.

**Conclusion**

Barefoot training advocates numerous benefits, including stronger muscles of the foot, improved sensory feedback and proprioception, reduced injuries of the lower extremity, decreased impact during gait, and prevention of injuries (Hart & Smith, 2008). Due to high prevalence rates of ankle injuries, and an increase in the ability to identify and diagnose CAI, there is a call for modifications of exercises in prevention and rehabilitation techniques of the CAI. Current guidelines address many key issues associated with lower extremity injuries, but still adaptations are needed to facilitate better and faster gains with patients with CAI specifically. Thus, the benefits of barefoot training found in runners should correlate over well into a higher quality standard within a chronic lateral ankle rehabilitation setting.
CHAPTER III

METHODOLOGY

Subject Population

Twenty active male and female participants, ages 18–40 years old, presenting with CAI from Kent State University and the surrounding area were recruited for this study. A Certified Athletic Trainer (ATC) assessed all participants with CAI and randomly assigned them to a group. Participants were randomly divided into one of three distinct groups: a barefoot rehabilitation group, a shod rehabilitation group, and a control group that performed no rehabilitation exercises.

All subjects needed to be participating in an active lifestyle, which was considered exercising 3 times a week for at least 30 minutes, and remained involved in daily or weekly routines that involved recreational or interscholastic athletics and/or fitness exercises within the last three months. Subjects were said to have CAI if they had self-reported at least 2 lateral ankle sprains within the last 5 years, episodes of “giving way,” residual symptoms (i.e., pain, weakness, swelling, or instability) during functional activities, that the condition limited the ability to participate in sports activities, and that they would participate in treatment for their conditions (Freeman, Dean, & Hanham, 1965; Hale & Hertel, 2005; Refshauge, Kilbreath, & Raymond., 2000).

Subjects were excluded if they have had corrective surgery to the ankle or foot, or suffered from visual, vestibular, or balance disorders. Subjects also were excluded from the study if they reported an ankle injury within the last 3 months, history of a lower extremity fracture on the same side as the affected ankle, concussion within the last 6
months, or current participation in a rehabilitation program for the affected ankle (Carcia et al., 2008).

All subjects were assigned a number that was used to identify the subject on all documents throughout the research study. They were informed of the purpose of this study and any potential risks associated with the procedures. The subjects, both men and women, were required to be of at least 18 years of age. All participants were placed in their designated rehabilitation task for a period of three times a week for three weeks. This study has undergone a review and was approved by the Kent State University Institutional Review Board. Each subject signed an informed consent and participation was voluntary.

**Instruments/Apparatus**

The original “Foot and Ankle Ability Measure” (FAAM) questionnaire was used by subjects for self-reported assessment of pain and disability associated with CAI (Carcia et al., 2008). Subjects with percentage score totals of 88% and below for the ADL subscale and 76% and below for sports subscale were considered to have CAI. The FAAM has evidence of content validity; construct validity, reliability, and responsiveness in athletes with a broad range of musculoskeletal disorders of the leg, ankle, and foot (Martin et al., 2005).

Epic 600 MX Treadmill™ was used in the warm-up of the subject before they began their rehabilitation program. The Epic 600 MX Treadmill was set at a desirable walking speed for 5 minutes to allow for the foot and ankle musculature to warm-up.
The warm-up was performed to allow proper blood flow to exist within the intrinsic musculature during rehabilitation.

Intrinsic Foot Muscle Test (IFMT) was used for the subjective assessment of the strength of the internal musculature of the foot. Observations were made on the unsteadiness of the subject’s navicular height and the over activity of extrinsic musculature (Jam, 2006). The subject was then classified under three distinct groups of satisfactory, fair, or poor (Jam, 2006).

Biodex Balance System SD™ examines neuromuscular control by quantifying the ability of the individual to maintain dynamic postural stability on either static or unstable surfaces. The subject performed a modified Clinical Test of Sensory Interaction & Balance (mCTSIB), and an Athletic Single Leg Stance Test protocol (Cohen, Blatchly, & Gombash, 1993). The mCTSIB & Athletic Single Leg Stance was used to measure the Sway Index and the Stability Index of the subject.

**Procedure**

Upon consent to be in the study, subjects filled out a screening questionnaire consisting of 15 questions related to frequency and severity of previous ankle sprains. If subjects met at least 3 of the inclusion criteria and none of the exclusion criteria for the study, they were randomly divided into a barefoot rehabilitation group, a shod rehabilitation group, or control group. All FAAM score, balance, and intrinsic strength were measured using a FAAM questionnaire, a Biodex Balance System SD™, and the Intrinsic Foot Muscle Test (IFMT), respectively, before they began any rehabilitation.
The original FAAM questionnaire was filled out before and after the study. It was used as both a factor in the inclusion criteria and as a pre- and post-measurement. The FAAM comprises the separately scored 21-item ADL and 8-item sports subscales (Martin et al., 2007). Each item was scored on a 5-point Likert scale anchored by 4 (no difficulty at all) and 0 (unable to do). Item score totals, which ranged from 0 to 84 for the ADL subscale and from 0 to 32 for the sports subscale, were transformed to percentage scores (Martin et al., 2007). A higher score represented a higher level of function for each subscale (Carcia et al., 2008). Subjects with percentage score totals of 88% and below for the ADL subscale and 76% and below for sports subscale were considered to have CAI. The FAAM has evidence of content validity, construct validity, reliability, and responsiveness for athletes with a broad range of musculoskeletal disorders of the leg, ankle, and foot (Martin et al., 2005).

The Biodex Balance System SD™ was set up for measuring degrees of movement and variation in the foot and ankle during balanced activities to determine the extent of the subject’s balance and neuromuscular control. The subject performed a modified Clinical Test of Sensory Interaction & Balance (mCTSIB), and an Athletic Single Leg Stance Test (Cohen et al., 1993). The mCTSIB was used to assess balance under a double leg stance using an eyes open and eyes closed conditions on firm and foam surfaces. The mCTSIB takes into account the vestibular and visual input during a balance activity. The Athletic Single Leg Stance Test was used to assess balance for the affected ankle during a single leg stance under dynamic conditions.
The subjects completed the mCTSIB protocol which consisted of 4 conditions: eyes open on a firm surface, eyes closed on a firm surface, eyes open on a dynamic surface, eyes closed on a dynamic surface. Each condition was done standing on the balance plate of the Biodex Balance System SD™ for 30 seconds, with a 10 second relaxation period in between each condition (Cohen et al., 1993). The mCTSIB was used to measure the Sway Index and the Stability Index of the subject. The Stability Index is the average position from the center of gravity the subject’s balance is. The Stability Index does not indicate how much the subject swayed or moved during stance; only their position. The Sway Index is a standard deviation of the Stability Index. The higher the sway index score the more unsteady the subject was during the test. The Sway Index is an objective quantification for completing the mCTSIB in 30 seconds intervals without falling, or assigning a value of 1(minimal sway) to 4(a fall) to characterize the sway (Cohen et al., 1993).

The subject also then performed an Athletic Single Leg Stance Test for 30 seconds for three trials, on their affected ankle, on the balance plate of the Biodex Balance System SD™ with 10 seconds of rest in between sets. The platform was set to a standard movement variation of level 4 and subjects were required to keep their hands on their hips throughout the trials. Subject’s overall stability index was assessed as well as his or her anterior-posterior movement stability index and medial-lateral movement stability index.

Subjects then underwent an Intrinsic Foot Muscle Test that consisted of the subject completing an isometric medial arch contraction involving the intrinsic foot
musculature to examine the navicular height and extrinsic muscle activity of the foot (Jam, 2006). This was accomplished by instructing the patient, with his or her foot on the floor, to extend the toes off the floor, which raised the medial longitudinal arch (Jam, 2006). He or she was then told to gently bring the toes back down to the ground while maintaining the arch height (Jam, 2006). The focus of the subjects was to be on flexing the metatarsophalangeal joints without moving the toes (Jam, 2006). This is referred to as squeezing the forefoot or “Foot Doming,” most commonly seen in Pilates (Jam, 2006).

The Intrinsic Foot Muscle Test itself involves four steps. Firstly, subtalar neutral was found by rolling the foot through pronation and supination until both heads of the talus could be palpated. Subjects then stood in a double limb stance facing a wall with feet shoulder width apart; the subjects and ATC then again found subtalar neutral (Sauer, Beazell, & Hertel, 2011). The participants were allowed to put their fingertips on the wall for balance support. The subject then stood on one leg for 30 seconds while contracting the foot core (doming of the foot) maintaining subtalar neutral and the medial longitudinal arch height (Sauer et al., 2011).

Observations were made on the unsteadiness of the subject’s navicular height and the over activity of extrinsic musculature (Jam, 2006). The subjects were then classified under three distinct groups of satisfactory, fair, or poor (see Figure 1). Satisfactory was classified if neutral navicular height was maintained without over activity of extrinsic foot muscles (Jam, 2006; Sauer et al., 2011). Fair was classified as unsteadiness of the navicular heights and over activity of the extrinsic foot muscles are inconsistently observed (Jam, 2006; Sauer et al., 2011). And poor was classified as unable to maintain
neutral navicular height, and over-activity of the extrinsic foot muscles was frequently observed (Jam, 2006). Each test was again repeated following the 3-week period of the subject’s rehabilitation protocols.

Participants who were assigned to both of the rehabilitation groups were given 30 minutes of rehabilitation exercises per session. The shod group performed their balance exercises with the use of shoes while the barefoot group was done without the use of stabilizing braces or shoes. For the first 5 minutes, they performed a warm-up on the Epic 600 MX Treadmill set at a desirable steady walking speed. The exercise programs followed a series of six exercises, of which three were closed kinetic chain dynamic single leg balance exercises and three were intrinsic strengthening exercises of the dorsal and plantar aspects of the foot an ankle (see Table 1).

The next 20 minutes, following warm up, focused on strengthening, coordination, and stabilizing exercises for the foot and ankle as well as exercises for plantar and dorsal intrinsic foot musculature. The subjects performed short foot exercises for three sets of 25 repetitions maximum. Short foot exercises involved doming of the foot contraction,
Table 1

Rehabilitative Exercises and Function

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Leg Balance</td>
<td>Proprioception</td>
</tr>
<tr>
<td>Trampoline Single Leg Standing</td>
<td>Proprioception</td>
</tr>
<tr>
<td>Balance Board Single Leg Standing</td>
<td>Proprioception</td>
</tr>
<tr>
<td>Short Foot Exercise</td>
<td>Plantar Intrinsic Foot Strengthening</td>
</tr>
<tr>
<td>Towel Toe Crutches</td>
<td>Plantar Intrinsic Foot Strengthening</td>
</tr>
<tr>
<td>Toe Raises</td>
<td>Dorsal Intrinsic Foot Strengthening</td>
</tr>
</tbody>
</table>

similar to that found in the IFMT, which involved utilizing the plantar intrinsic foot muscles to contract the medial longitudinal arch. They then performed towel toe crutches for three sets of 10 towels, with 10 repetitions per towel, to focus on plantar intrinsic foot muscles. Next they performed toe extension raises with their ankle in subtalar neutral for three sets of 10 repetitions to focus on the dorsal intrinsic foot muscles. Balance exercises involved single leg standing exercises and were done at a rate of three sets for 30 seconds with a 10-second rest in between reps. Subjects began balance exercises with single leg standing on a firm surface, followed by a trampoline single leg standing, and then ended with balance board single leg standing.

All exercises were completed in the same order for each session to avoid conflict with exercise progression and ordering. Subjects were observed and guided closely by the ATC responsible for treatment. Increases in weight, resistance, or angle variability
for balance were added if subjects started to experience no difficulty and were pain free throughout the exercise. All exercises were monitored using a modified progress note to keep track of the subject’s difficulty and resistance of exercises from each session. Rehabilitation took place in the Kent State University Athletic Training Competency & Research Lab under the supervision of an ATC. Subjects were encouraged to stretch on their own, but to exclude or limit the amount of strengthening done on the lower extremity. Heat and ice modalities were allowed, as part of the standard of care, but electrical stimulation, ultrasound, and massage were not allowed during the treatment period.

The control group only had pre- and post-measurements and did not perform rehabilitation. Subjects within the barefoot group performed exercises without the aid of shoes or stabilizing braces. Participants in the shod group performed their exercises wearing the subject’s preferred athletic footwear. Any exercises using only bare feet were done on a carpeted surface to avoid differences in surface environment among subjects. The subjects in the rehabilitation groups started with low-impact, low resistance exercises and gradually progress based on their improvements. Participants were encouraged to maintain stretching of the foot and ankle, but not repeat strengthening exercises at their homes. All exercises and measurements were administered by the same ATC involved with the study limiting any variability that might have existed. The group then participated in their designed rehabilitation plan for a period of three times a week for three weeks. After the study, at three weeks post measurements were taken for balance, FAAM scores, and intrinsic foot strength again using the FAAM questionnaire,
a Biodex Balance System SD™, and a Intrinsic Foot Muscle Test respectively and compared to pre-study results. All subjects were encouraged to continue with their daily routines of physical activity, but to not exceed duration or intensity to which they were normally accustomed. If subjects did wish to continue with exercise outside of the study, their activity, intensity, and duration were logged using a standardized time/intensity/activity sheet to monitor subjects. Subjects were asked not to visit a chiropractor, physical therapist, or other health care provider, involving issues with their CAI outside required visits, as this could compromise the results of the study. If subjects did wish to go see a health care provider for their CAI they were encouraged to do so, but were removed from the study.

**Design and Analysis**

The research design composed of a pre-test, post-test randomized true experimental design. This experiment involved the separation of subjects into three distinct groups and randomization into different treatment or control groups. The first group underwent barefoot rehabilitation protocol for balance and intrinsic foot strength; the second group received shod rehabilitation for balance and intrinsic foot strength and the last group served as a control group. Between and within subjects values for intrinsic musculature strength of the foot, balance, and FAAM scores measured via the Intrinsic Foot Muscle Test, Biodex Balance System SD™, and FAAM questionnaire served as variables for this study.

A three by two multivariate-ANOVA was used to measure the differences of change scores between groups for balance and FAAM scores. In addition, a Wilcoxon
Signed Ranks analysis was used to analyze subjective intrinsic foot muscle strength data for the Intrinsic Foot Muscle Test pre to post. Outcome measures included a subjective observational evaluation of the intrinsic foot muscles using three conditions of satisfactory, fair, or poor. Outcomes also included measurements of balance via the Biodex Balance System SD™ for the mCTSIB which quantified balance as a Stability index and Sway index for closed eyed firm surface, open eyed firm surface, closed eyed foam surface, and open eyed foam surface. In addition there were objectively quantified data for the Athletic Single Leg Stance test for the overall stability index, anterior-posterior index, and medial-lateral index. Lastly, FAAM questionnaire percentages for both the ADL subscale and sports subscale were taken pre and post and analyzed. Between subjects variables were compared from shod rehabilitation to barefoot rehabilitation, shod rehabilitation to control group, and barefoot rehabilitation to control group. Within subjects were compared pre and post with respect to time within the shod rehabilitation, barefoot rehabilitation, and control groups. All data analyses were done by the Statistical Package for the Social Sciences ([SPSS] SPSS Inc, Chicago, IL; Version 21, 2011).
CHAPTER IV

RESULTS

A sample size of 20 participants, both males \((n = 9)\) and females \((n = 11)\), was recruited for this study and divided randomly into three groups of shod \((n = 6)\), barefoot \((n = 7)\), and control \((n = 7)\); see Table 2.

Table 2

Demographic Means and Standard Deviations Among Groups

<table>
<thead>
<tr>
<th></th>
<th>Shoes ((n = 6))</th>
<th>Barefoot ((n = 7))</th>
<th>Control ((n = 7))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Height</td>
<td>174.81</td>
<td>10.80</td>
<td>171.62</td>
</tr>
<tr>
<td>Weight</td>
<td>86.94</td>
<td>20.85</td>
<td>78.66</td>
</tr>
<tr>
<td>Age</td>
<td>21.17</td>
<td>3.97</td>
<td>20.86</td>
</tr>
</tbody>
</table>

Overall change scores were calculated for Foot and Ankle Ability Measure (FAAM), Foot and Ankle Ability Measure Sports (FAAMS), Single Leg Overall Stability Index (SLO), Single Leg Anterior Posterior Stability (SLAP), Single Leg Medial Lateral Stability (SLML), modified Clinical Test of Sensory Interaction & Balance (mCTSIB), Open Eyed Firm Surface (OF), Closed Eyed Firm Surface (CF), Open Eyed Foam Surface (OFO), and Closed Eyed Foam Surface (CFO) and compared between and within subjects (see Table 3). No significant difference existed between shod and barefoot rehabilitation protocols (see Table 3). Also no significant differences in change scores
Table 3

Change Score Means and Standard Deviations Among Groups

<table>
<thead>
<tr>
<th></th>
<th>Shoes</th>
<th>Barefoot</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Δ FAAM</td>
<td>8.50</td>
<td>8.67</td>
<td>14.57</td>
</tr>
<tr>
<td>Δ FAAMS</td>
<td>15.00</td>
<td>16.89</td>
<td>18.00</td>
</tr>
<tr>
<td>Δ SLO</td>
<td>0.92</td>
<td>0.62</td>
<td>1.07</td>
</tr>
<tr>
<td>Δ SLAP</td>
<td>0.83</td>
<td>0.70</td>
<td>0.92</td>
</tr>
<tr>
<td>Δ SLML</td>
<td>0.26</td>
<td>0.19</td>
<td>0.44</td>
</tr>
<tr>
<td>Δ mCTSIB OF</td>
<td>0.17</td>
<td>0.20</td>
<td>0.05</td>
</tr>
<tr>
<td>Δ mCTSIB CF</td>
<td>0.09</td>
<td>0.34</td>
<td>-0.07</td>
</tr>
<tr>
<td>Δ mCTSIB OFO</td>
<td>0.19</td>
<td>0.20</td>
<td>-0.05</td>
</tr>
<tr>
<td>Δ mCTSIB CFO</td>
<td>0.41</td>
<td>1.14</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Note. *= p ≤ 0.05; FAAM (Functional Ankle and Ability Measure), FAAMS (Functional Ankle and Ability Measure Sports Scale), SLO (Single Leg Overall Stability), SLAP (Single Leg Anterior-Posterior Stability), SLML (Single Leg Medial-Lateral Stability) mCTSIB (modified Clinical Test of Sensory Interaction & Balance), OF (Open Eyed-Firm Surface), CF (Closed Eyed-Firm Surface), OFO (Open Eyed-Foam Surface), CFO (Closed Eyed Foam Surface)

were present between Δ FAAMS, Δ SLAP, and Δ SLML (see Table 3). Lastly, no significant differences were found among change scores using the Δ mCTSIB OF, Δ mCTSIB CF, Δ mCTSIB OFO, and Δ mCTSIB CFO (Closed Eyed Foam Surface; see Table 3).

Overall change scores were compared between groups and significant interactions were found for the Δ FAAM scores (p = 0.004) and Δ SLO (p = 0.044). A post-hoc
analysis was run for FAAM and found that significant interactions existed between participants who were shod during rehabilitation and those in the control group (shod=8.50 ± 8.66, control=−1.29 ± 4.57, \( p = 0.032 \); see Figure 2). This shows that a significant increase existed between FAAM score for the shod group over the control group. The barefoot rehabilitation group (barefoot=14.57 ± 8.79, control=−1.29 ± 4.57, \( p = 0.001 \); see Figure 2) also showed a significant increase when compared to control group. Therefore, a significant increase was also present for FAAM scores for barefoot rehabilitation group over the control group that received no rehabilitation.

![FAAM Change Score Comparison Between Groups](image)

*Figure 2. FAAM change score comparison between groups.*

Significant increase in the FAAM (Function Ankle Ability Measure) Shod vs. Control (shod=8.50 ± 8.66, control=−1.29 ± 4.57, \( p = 0.032 \)) and Barefoot vs. Control (barefoot=14.57 ± 8.79, control=−1.29 ± 4.57, \( p = 0.001 \)).
A post-hoc analysis was run for \( \Delta \text{SLO} \) and found significance between the barefoot rehabilitation group and control groups (barefoot=1.07 ± 0.85, control=0.00 ± 0.84, \( p = 0.02 \); see Figure 3). A significant difference was present for balance between the barefoot rehabilitation protocols and the control group.

**Figure 3.** SLO change scores comparison between groups.
Significant increase in SLO (Single Leg Overall Stability) Change Scores for Barefoot vs. Control (barefoot=1.07 ± 0.85, control=0.00 ± 0.84, \( p = 0.02 \)) and a trend toward significance for Shod vs. Control (shod=0.92 ±0.62, control=0.00 ± 0.84, \( p = 0.051 \)).

No significant difference was found between shoes and barefoot rehabilitation protocols (see Table 3). A trend toward significance was found between shoes and control (shod=0.92 ±0.62, control=0.00 ± 0.84, \( p = 0.051 \)) rehab protocols, however significance is still not to be considered (see Figure 3).
A comparison of the IFMT was made between pre and post protocols and found significant differences between shoes rehabilitation (mean pre=0.17± 0.41, mean post= 1.07 ± 0.41, z score = -2.12, \( p = 0.034 \)) and for barefoot rehabilitation (mean pre=0.29± 0.49, mean post= 1.14 ± 0.38, z score = -2.45, \( p = 0.014 \)). (See Table 4.) This shows that participants that completed a barefoot and shoes rehabilitation protocol showed subjective improvements in intrinsic foot muscle strength. No significant difference was found for the control group for the IFMT (mean pre=0.43± 0.54, mean post= 0.43 ± 0.54, z score = 0, \( p=1 \)).

Table 4

**IFMT Means and Standard Deviations Among Groups**

<table>
<thead>
<tr>
<th></th>
<th>Shoes</th>
<th>Barefoot</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>IFMT Pre</td>
<td>0.17</td>
<td>0.41</td>
<td>0.29</td>
</tr>
<tr>
<td>IFMT Post</td>
<td>1.07</td>
<td>0.41</td>
<td>1.14</td>
</tr>
<tr>
<td>Z Score</td>
<td>-2.12</td>
<td></td>
<td>-2.45</td>
</tr>
<tr>
<td>p Value</td>
<td>0.034*</td>
<td></td>
<td>0.014*</td>
</tr>
</tbody>
</table>

*Note. Wilcoxon Signed Ranks Comparison of Intrinsic Foot Muscle Test (IFMT) (mean pre=0.17± 0.41, mean post= 1.07 ± 0.41, z score = -2.12, \( p = 0.034 \)) (mean pre=0.29± 0.49, mean post= 1.14 ± 0.38, z score = -2.45, \( p = 0.014 \)) (mean pre=0.43± 0.54, mean post= 0.43 ± 0.54, z score = 0, \( p=1 \)). \* = \( p \leq 0.05 \).
CHAPTER V
DISCUSSION

A 3-week rehabilitation protocol focusing on balance and intrinsic foot muscle strength significantly improved self-reported function and single leg static balance as measured by the Biodex Balance System™ regardless of whether the subjects were shod during rehabilitation or did rehabilitation barefoot. Performing no rehabilitation did not improve these two measures. These measures were chosen to provide patient-oriented evidence and clinical evidence, respectively, for the effectiveness of balance training in conjunction with intrinsic foot muscle strengthening for CAI.

The change scores for the shod group and barefoot group over the control group on the FAAM were found to be significant. The control group did not have a significant change in functional status after 3 weeks, which indicates that the balance training in conjunction with intrinsic foot muscle strengthening was effective in restoring self-reported function. However, barefoot rehabilitation was not found to be more effective then rehabilitation with shoes in terms of self-reported function. Our findings thus suggest that after undergoing only a 3-week rehabilitation protocol focusing on balance and intrinsic foot muscle strength regardless of foot wear in individuals with CAI may result in improvements in self-reported measures. McKeon et al. (2008) reported similar improvements on the Foot and Ankle Disability Index (FADI) when comparing two groups with CAI who underwent a longer 4-week balance training protocol. They found that individuals who underwent 4 weeks of balance training had improvements in self-reported function than those who did not. In addition, Rozzi, Lephart, Sterner, and
Kuligowski (1999) reported similar improvements on the Ankle Joint Functional Assessment Tool when comparing a group with CAI to a group of healthy controls who underwent balance training. They found that individuals who underwent 4 weeks of training on the Biodex Stability System™ had improvements in self-reported function, regardless of group membership. Therefore, our study found that a shorter 3-week rehabilitation protocol focusing on balance and intrinsic foot muscle strength will find improvements in self-reported function, regardless of the footwear, sooner than a protocol focusing on balance alone for CAI.

There were also significant improvements in the IFMT for barefoot and shod rehabilitation protocols pre and post rehab, but not to the control group. These changes reflect a significant improvement in intrinsic foot muscle strength subjectively. This may be related to an increase in co-muscular contraction and joint position sense within the plantar and dorsal foot aspects of the foot as a result of intrinsic foot muscle strengthening (Jenkins & Cauthon, 2011). These increases in co-muscular contractions and joint position sense produce increases in the ability to make better adjustments to balance via postural control and neuromuscular control distally to the ankle. Research by Menz et al. (2005) suggested that foot posture and function have an impact on single leg balance activation and that the plantar intrinsic foot muscles may be utilized to help stabilize the foot. This is similar to our findings that show significant increases in intrinsic foot muscle strength correlated to increases in postural control with a shorter rehabilitation protocol. The intrinsic foot muscles are dynamically and directly related to the support of the longitudinal, transverse, and metatarsal arches (Headlee et al., 2008).
They also provide a stable platform for extrinsic foot muscle function by assisting in synergistic activation to global extrinsic foot muscle actions (Headlee et al., 2008). Deficits in the intrinsic foot muscles may reduce the phasic support for the foot and ankle and recruitment of tonic muscles that typically function as global movers, such as the tibialis posterior, flexor digitorium longus, flexor hallucis longus, may be called upon as stabilizers (Headlee et al., 2008). This reduction in support of the foot arches and intrinsic foot muscle activation may correlate over to the deficits in balance that are seen within CAI. Therefore, intrinsic foot muscle strength needs to be continually considered as a factor when approaching rehabilitation for the CAI population due to its simplicity and overall inherent benefits stemming from increases in strength.

Measures of static postural control, specifically SLO, also significantly improved in the barefoot rehabilitation group compared to the control group. It was hypothesized that barefoot rehabilitative measures when compared to shod rehabilitation and control would improve balance. Significant changes in balance for barefoot rehabilitative measures over shod rehabilitation protocols were not observed. There was however a strong trend toward significance found for shod rehabilitation versus control group for balance. This indicates that doing balance training for intrinsic foot strength improves postural control regardless of the footwear that is worn by the individual for CAI. This is different than what has been suggested by other similar research looking at barefoot running. A study by Menz et al. (2005) showed that weakness of plantar intrinsic foot muscles because of the constraints of shoes contributed to balance impairments in subjects. Other research has also shown that plantar intrinsic foot muscle activation is
strongly correlated with mediolateral postural sway in single leg stance, with increasing activity observed during sway to the medial border of the foot (Kelly et al., 2012). That was not observed in this research. Therefore, it may be that intrinsic foot muscle strength alone does not provide enough correlation for proprioceptive feedback in regards to postural control in a CAI population to show significant improvements. It is also a possibility that a longer duration protocol is needed to establish significant changes for intrinsic foot muscle activity alone. The suggestion of our research is then that intrinsic foot strength in conjunction with balance training protocols produces the quickest gains in balance in CAI and is not dependent on footwear present during rehabilitation.

An explanation for this phenomenon has previously been suggested from various other research studies (Davids, Glazier, Araujo, & Bartlett, 2003; McKeon et al., 2008; van Emmerik & van Wegen, 2002). From the balance systems perspective, the sensorimotor system has multiple degrees of freedom that afford a variety of strategies, such as the ankle strategy and hip strategy, to be generated to maintain postural control (van Emmerik & van Wegen, 2002). The constraints that act to limit these degrees of freedom include the complexity of the task, the changes in the environment, and the health of the individuals (Davids et al., 2003). These constraints interact to shape these postural control strategies, more specifically the ankle strategy, to maintain a single leg upright stance (Silsupadol, Siu, Shumway-Cook, & Woollacott, 2006). However, CAI may place greater constraints on the sensorimotor system, via decreased kinesthesia, joint position sense and structural laxity, and may reduce the amount of degrees of freedom and, consequently, the amount of strategies available to maintain postural control.
(McKeon et al., 2008). By progressively manipulating the rehabilitation on individuals with CAI, balance training in conjunction with intrinsic foot muscle strengthening aided the sensorimotor system in freeing up degrees of freedom that were not available to these individuals previously due to the constraints of CAI. After rehabilitation, individuals experienced a significant improvement in the SLO stability index measures as compared to the control group, indicating that the sensorimotor system may not have been constrained to the same magnitude after focusing on balance and intrinsic foot muscle strength. McKeon et al. (2008) hypothesized similar suggestions for their reported findings showing that self-reported function and static postural control as measured by time-to-boundary (TTB), and Star Excursion Balance Test (SEBT) reach distance in the posterior medial (PM) and the posterior lateral (PL) directions, all significantly improved. Therefore, some variation of rehabilitation that involves balance training and intrinsic foot muscle strengthening appears to provide benefit to a CAI population for self-reported function and balance regardless of the footwear that is worn.

**Implications**

A limitation of this study is the lack of activity monitoring of the individuals outside the study. To help regulate this, all participants were informed to log any bouts of exercise training outside the study to decrease any confounding variables that may alter the results. Balance tests were done barefoot and differences might not have been seen across individuals due to the varying degrees of severity of CAI that was present between subjects. It is also important to note that although changes in these measures seem to follow improvements in self-reported function, it has yet to be determined
whether these sensorimotor changes reduce the risk of re-injury in this population. Lastly, because rehabilitation exercises were not compared between intrinsic foot muscle strength and balance training, it is difficult to determine where the improvements persisted predominately from increases in postural control or from greater intrinsic foot muscle strength.

**Recommendations**

This study looked at a shortened 3-week protocol with only 9 overall rehabilitation sessions. Although significant changes occurred, it may be noteworthy to look at longer duration rehabilitation for training balance and intrinsic foot muscle within a CAI population to see if duration has an effect on CAI rehabilitation. In addition, because of the subjective nature of the IFMT, it is recommended that future research look at more objective quantified measurements for intrinsic foot muscle, specifically the hand-held dynamometer for intrinsic foot strength as it relates to CAI. Further investigations examining the effects of balance training in combination with other interventions that address local deficits associated with CAI are continually warranted. Addressing both global sensorimotor function and local arthrokinematic impairments may also elicit a greater response in these measures (McKeon et al., 2008). Lastly, dynamic balance tests, such as the Star Excursion Balance Test (SEBT) or the Y-Test, should be looked at to determine if increases exist with intrinsic foot muscle strength dynamically for CAI. The effect of balance training with intrinsic foot muscle strength as a preventive treatment to reduce the recurrence of ankle sprains needs to be systematically investigated in this population to establish rehabilitation parameters.
Conclusion

The 3-week progressive rehabilitation protocol that emphasized balance training and intrinsic foot muscle strength significantly improved self-reported functional status measured by the FAAM questionnaire, and static postural control as assessed by the Biodex Balance System™ in measures of the SLO stability index. By purposefully manipulating task and environmental constraints in those with CAI, it is believed that progressive balance training with specific emphasis on intrinsic foot muscle strengthening significantly enhanced the ability of the sensorimotor system to overcome the sensorimotor constraints related to CAI.
REFERENCES
REFERENCES


