Ankle Bracing and Fatigue on Time to Boundary Measures with Chronic Ankle Instability

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Abstract

Megan Elizabeth Pomorski: Ankle Bracing and Fatigue on Time to Boundary Measures with Chronic Ankle Instability
(Under the direction of Steven Zinder, PhD, ATC)

Objective: To test the fatigue related effects of ankle bracing on time to boundary measurements between healthy and chronically unstable participants. **Data and setting**: A pre-test post-test experimental design was used to compare the effects of ankle bracing and fatigue on time to boundary measures with chronic ankle instability and control subjects. **Subjects**: 38 physically active subjects; 19 subjects with chronic ankle instability, and 19 subjects to serve as controls. **Measurements**: Time to boundary measurements in the medial/lateral and anterior/posterior direction were evaluated. A three way mixed model analysis of variance was used for statistical analysis. **Results**: A Significant three way interaction was found in the eyes closed condition. Significant two way interactions were found for bracing by group for eyes open, and significant two way interactions were found in the eyes closed condition for bracing by fatigue. Significant main effects were found for bracing and fatigue in both eyes open and eyes closed conditions. **Discussion**: There were no differences between CAI and healthy control participants on TTB measurements. The no braced condition proved to be more stable than the braced condition, as well as post-fatigue proving more stable than pre-fatigue.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Ankle sprains are among the most common injuries in sports (Hootman, Dick et al. 2007). Lateral ankle sprains account for 85% off all ankle injuries (Bot and van Mechelen 1999). As high as 40% of lateral ankle sprains result in chronic ankle instability (Freeman 1965; Freeman, Dean et al. 1965), which is characterized by complaints of frequent and repetitive bouts of ankle giving way during functional activity (Gribble, Hertel et al. 2004). Chronic ankle instability (CAI); a combination of mechanical instability and functional instability (Hubbard, Kramer et al. 2007), can lead to disability and lingering symptoms as well as a decrease in athletic performance (Yeung, Chan et al. 1994). Therefore prevention of the ankle sprain and protection of ankles with CAI is important, especially in the athletic population.

It has been demonstrated that chronic ankle instability is associated with deficits in postural stability (Freeman, Dean et al. 1965; Tropp, Ekstrand et al. 1984; Tropp, Askling et al. 1985; Tropp 1986; Lentell, Katzman et al. 1990; Konradsen and Ravn 1991; Riemann 2002). For example, Tropp et al (Tropp, Ekstrand et al. 1984; Tropp, Askling et al. 1985; Tropp 1986) and Konradsen and Ravn (Konradsen and Ravn 1991) demonstrated a significant deficit in postural control during a single leg stance in patients with chronic ankle instability compared to the control subjects. While a few studies have failed to demonstrate a significant difference in postural stability between stable and unstable participants (Bernier, Perrin et al. 1997; Isakov and Mizrahi 1997; Baier and Hopf 1998), it is generally accepted that chronic ankle instability is associated with deficits in postural stability.

Fatigue is a condition that affects every participant during athletic activity, and has been shown to decrease the body's ability to maintain joint stability. Fatigue results in elevated threshold of the muscle spindle discharge which consequently affects the afferent, integration, and efferent neural signal and ultimately alters the neuromuscular control of the joint (Johnston, Howard et al. 1998; Gribble, Hertel et al. 2004; Shaw, Gribble et al. 2008). The effects of fatigue on postural control have been demonstrated in several studies (Johnston, Howard et al. 1998; Yaggie and McGregor 2002; Gribble, Hertel et al. 2004). Gribble and Hertel et al found that postural stability deficits found in chronic ankle instability patients became magnified after the isokinetic fatigue of the ankle, knee, and hip (Gribble, Hertel et al. 2004). The results of this study suggest that patients with CAI may be particularly more susceptible to ankle injury when they are fatigued.

Traditionally, postural stability has been measured statically using center of pressure (COP), and dynamically using time to stabilization. The COP measurements are traditionally done in a single leg stance, and the variables represent the location and movement of the net ground reaction force vector in response to the counteractive action being taken to maintain equilibrium; measured using forceplate data (Winter 1990). Time to stabilization is the time required to decrease resulting ground reaction forces of a jump landing to within a range of the baseline, or static ground reaction force (Wikstrom, Tillman et al. 2005). Time to stabilization measurements are commonly used in different jump landing tasks that involve both single and double leg stances and are also measured using forceplate data. Both methods of measuring postural control are widely accepted in the literature, however, a more recent measure of postural control known as time-to-boundary has been introduced (Hertel, Olmsted-Kramer et al. 2006).

Time-to-boundary (TTB) is a relatively new method of postural assessment that estimates the amount of time it would take the COP to reach the boundary of the base of support if the COP was to continue on its path at its direct velocity (Hertel and Olmsted-Kramer 2007). Hertel and Olmsted (Hertel and Olmsted-Kramer 2007) conducted a study comparing postural control in participants with chronic ankle instability using TTB and COP measures. The results indicated that all but one of the TTB measurements showed significant impairments in postural control in subjects with CAI, while only one of the measures of COP showed a significant impairment in postural control with CAI participants when compared to controls. This finding indicates that TTB may be more sensitive than COP measurements to the postural stability deficit found in CAI patients (Hertel and Olmsted-Kramer 2007). Since TTB is a relatively new measurement of postural stability, its relationship to the change in postural stability due to muscle fatigue or ankle bracing in individuals with and without CAI has not been investigated.

Ankle braces have been shown to provide support to the ankle, especially during inversion movement (Callaghan 1997). Several studies have demonstrated that ankle braces have a positive effect on increasing ankle stability and function (Gross, Bradshaw et al. 1987; Kimura, Nawoczenski et al. 1987; Tweedy, Carson et al. 1994). Dizon and Reyes conducted a systemic review of the effectiveness of external ankle supports, finding the use of an ankle brace reduced ankle sprains by 69%, with one ankle brace not proven to be significantly superior to another (Dizon and Reyes 2010). Despite evidence that ankle bracing helps reduce the risk of ankle sprains, controversy in the literature still exists (Shaw, Gribble et al.

2008; Gribble, Taylor et al. 2010). Gribble et al investigated the effects of bracing on dynamic stability in the chronic ankle instability population and reported that there was no significant difference in ankle stability measures between the brace condition and the non-braced condition (Gribble, Taylor et al. 2010). These conflicting results may be attributed to the sensitivity of the differing measures of postural stability used in previous studies.

Fatigue of the ankle muscles has been demonstrated to decrease postural stability. Additionally there is evidence to suggest that this fatigue related decline in postural stability may be greater in individuals with chronic ankle instability compared to individuals without instability. While the effects of ankle bracing have been studied, whether the use of ankle braces can negate the change in postural stability occurring with fatigue in individuals with and without chronic ankle instability has not been investigated. Therefore the purpose of this study is to investigate the effects of ankle bracing and fatigue on postural stability in healthy and chronically unstable participants using time-to-boundary measurements.

Independent Variables

- Bracing
    - Bracing
    - No bracing
- Stability
    - CAI
    - Healthy
- Fatigue
    - Pre-fatigue
    - Post- fatigue

Dependent Variables

- Absolute minima time to boundary measurements in the medial and lateral (ML) direction
- Absolute minima time to boundary measurement in the anterior and posterior (AP) direction
- Average mean minima time to boundary measurements in the medial and lateral direction
- Average mean minima time to boundary measurements in the anterior and posterior direction
- Standard deviation mean minima time to boundary measurements in the medial and lateral direction
- Standard deviation mean minima time to boundary measurements in the anterior and posterior direction

Research Questions

- RQ_1: Are there fatigue related differences in TTB between CAI and healthy control individuals across bracing conditions?
- RQ_2: Are there fatigue related differences in TTB between the braced and non-braced conditions across stability conditions?
- RQ_3: Are there differences in TTB between CAI and healthy individuals in the braced and non-braced condition, regardless of fatigue?

Research Hypotheses

- $H_{1,1:}$ TTB values will be greater pre-fatigue compared to post-fatigue in the CAI group.
- $H_{1,2}$: TTB values will be greater pre-fatigue compared to post-fatigue in the control group.
- $H_{2,1}$: TTB values will be greater in the pre-fatigue condition compared to the post-fatigue in the non-braced condition.
- $H_{2,2}$: TTB values will be no different in the pre-fatigue or post-fatigue condition in the braced condition.
- $H_{3,1}$: TTB values will be greater in the braced group as compared to the non-braced group across stability conditions.
- $H_{3,2}$: TTB values will be better in the CAI group as compared to the control group across bracing conditions.
- $H_{3,3}$: TTB values will be greater in the control group compared to the CAI group in the non-braced condition.

- $H_{3,4}$: There will be no difference in TTB values in the control participants compared to the CAI participants in the braced condition.

Operational Definitions

- Time to Boundary: An assessment tool using a forceplate that measures the time it will take the center of pressure to reach the boundary of its base of support, assuming the center of pressure continued to move in that direction at a direct velocity, using a single leg stance with dominate legs for 10 seconds with eyes open and eyes closed (Hertel and Olmsted-Kramer 2007).
- Chronic Ankle Instability: Individuals are considered to have chronic ankle instability if they suffered at least one ankle sprain in the last year, including at least one of the following symptoms; swelling, ecchymosis, or decreased range of motion at time of injury, and suffer frequent and repetitive bouts of the ankle feeling like it is “giving way.” (Gerber, Williams et al. 1998) (Freeman, Dean et al. 1965).
- Isokinetic Everter Fatigue: Fatigue that occurs when a produced torque drops below 50% of his or her maximal torque produced during maximal voluntary isometric contraction for three consecutive repetitions on an Isokinetic Dynamometer.
- Ankle bracing: An ASO® brand ankle brace for external support of the ankle.

Assumptions

- All participants will be honest in his or her level of ankle instability and previous medical and injury history
- The equipment used in the study (Biodex, forceplate) is valid, safe, and accurate in its measures

- All participants will give his or her maximum effort during participation

Delimitations

- Individuals who participate in activity three times per week for at least thirty minutes to capture a relatively homogeneous study sample

Limitations ....

- Isokinetic fatigue may not simulate functional fatigue
- Participants previous experience with Isokinetic machine
- Participants previous experience with ankle braces.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The purpose of this study is to investigate the effects of ankle bracing and fatigue on time to boundary measurements in healthy and chronically unstable participants. Time to boundary is a relatively new measurement tool that has been shown to be more sensitive at detecting postural stability deficits than previously used postural stability measurement tools (Hertel and Olmsted-Kramer 2007). The purpose of this literature review is to discuss the previous research done in the fields of ankle bracing, fatigue, and chronic ankle instability and to discuss the previous research done linking ankle instability to postural stability to justify need to perform this study.

Epidemiology of Ankle Injury ....

Ankle sprains are the most common injury in sports, accounting for approximately 25% of all sports injuries (Miller and Bosco 2001). It has also been shown that injury to the ankle accounts for 25% of all time loss from sport or physical activity (Ashton-Miller, Ottaviani et al. 1996). Incidence rates have been seen as high as 10,000-25,000 ankle sprains occurring per day (Brooks, Potter et al. 1981; McCulloch, Holden et al. 1985; Kannus and Renstrom 1991). Of all first time ankle sprains, 80% result in recurrent instability or incidence of injury, and 59% report considerable disability or lingering symptoms, which lead to an impairment in athletic performance (Yeung, Chan et al. 1994). Yeung et al also found that those participants with unilateral ankle injury were 2.4 times more likely to have the injury on their dominant leg as opposed to the non-dominant leg. The researchers also demonstrated a relationship between the number of recurrent ankle sprains and the severity of the residual symptoms, showing that as ankle sprains increased, so too did the number and severity of residual symptoms, including pain, feeling of instability, crepitis around the ankle joint, and weakness (Yeung, Chan et al. 1994). The most common mechanism of injury for lateral ankle sprains is forced plantarflexion and inversion, causing damage primarily to the anterior talofibular ligament, but also to the calcaneal fibular ligament, and posterior talofibular ligament (Lynch 2002). Sprains of the subtalar joint may also occur with lateral ankle sprains. Although lateral ankle sprains are by far the most common of ankle sprains, accounting for 85% of all ankle sprains, medial ankle sprains can also occur, and are often associated with lateral malleolus fractures and syndesmosis ankle sprains. The most common mechanism of injury for a medial ankle sprain is rolling over on an everted foot, which causes damage to the deltoid ligament (Lynch 2002).

Ankle Anatomy

The ankle joint is a complex, multi joint structure that determines the movement of the foot with respect to the leg. It consists of the talocrural joint, which is the articulation between the mortise consisting of the medial malleolus, distal portion of the tibia, the lateral malleolus, the medial, superior, and lateral surface of the talus; and the talocalcaneal joint, which is the articulation between talus and the calcaneous and is commonly referred to as the subtalar joint. The three ligamentous structures that add stability of to the lateral ankle are 1) the anterior talofibular ligament, which originates on the anterior aspect of the distal fibula and inserts at a 75° angle onto the body of the talus, 2) the calcaneofibular ligament, which originates on the anterior border of the distal fibula and inserts on a small tubercle posterior and superior to the peroneal tubercle on the calcaneous, and 3) the posterior talofibular ligament, which originates on the medial surface of the lateral malleolus and inserts on the posterior talus. Together these ligaments are static stabilizers against ankle inversion mechanisms. The ligament that is most commonly affected during a lateral ankle sprain is the anterior talofibular ligament; however all of the lateral ankle ligaments are affected to some degree (Prentice 2009). Muscles provide a static and dynamic restraint against ankle sprains. The peroneus muscle group, located on the lateral aspect of the lower leg, functions to evert the ankle and counteract inversion movement. Additional muscles involved in ankle eversion include the extensor digitorum longus and peroneus tertius. Muscles that are involved in ankle inversion movement include the flexor hallicus longus, flexor digitorum, tibialis posterior, extensor hallucis longus, and the tibialis anterior (Prentice 2009).

Postural Control

Postural control is a mechanism that keeps the body's center of pressure within the confines of the base of support. The postural control involves interaction of three systems; the somatosensory, the musculoskeletal, and the central nervous system. Components of the somatosensory systems include the vestibular system, vision, proprioceptors, and cutaneous receptors. The vestibular system is located in the inner ear and included the semicircular canals, otholiths, and maculaes. The semicircular canals are sensitive to changes in velocity at frequencies of 0.2 to 10 Hz and have been found to be active at the beginning and end of movement. The otholiths are sensitive to movement frequencies of less than 5 Hz and provide information on linear acceleration, such as gravity. The information from the semicircular canals, otholiths, and the maculaes is then conveyed to the vestibular nuclei of the brainstem (Riemann 2002).

Visual information is received through the retina and processed in two different parts of the brain, depending on the type of visual information delivered. Visual information on object identification is sent to the focal system, and visual information related to movement control is sent to the ambient system of the brain (Trevarthen 1968). The ambient system has been shown to strongly affect both balance and stability. The effects of the visual systems on postural control depend on a number of variables including visual acuity (Paulus, Straube et al. 1984) visual contrast (Leibowitz, Rodemer et al. 1979) object distances, and room illumination.

Proprioceptors are receptors located in muscles, tendons, and joints and relay information about the position of limbs in relation to the position of the body (Jantti, Pyykko et al. 1993). Proprioceptors include muscle spindles, golgi tendon organs, and joint receptors. Exteroceptive receptors are a type of pressoreceptors that are located on the sole of the foot in the cutaneous and subcutaneous tissue. The main types of exteroceptive receptors are Meissner corpuscles and Merkel disks, which are located more superficially, and Ruffini ending and Pacinian corpuscles, which are located deeper into the skin (Jantti, Pyykko et al. 1993).

The central nervous system (CNS) is comprised of the brain and the spinal cord. Central nervous system is where the afferent information from various systems is integrated to send the appropriate efferent motor commands to the muscles. Once the motor commands are sent to the muscles the effectiveness of the body's ability to perform the motor commands depends on physiological and biomechanical factors, including strength, mechanical stability, and available range of motion (Riemann 2002).

Individuals with chronic ankle instability have been shown to have a decrease in detection of plantarflexion (Garn and Newton 1988; Forkin, Koczur et al. 1996) and inversion (Lentell, Katzman et al. 1990) joint position sense. Force sense is an area of ankle instability study that is new to the literature of sensorimotor deficits. Force sense is representative of the ability of an individual to detect and recreate specific force outputs in particular muscle groups. Poor force sense is theorized to be associated with a dysfunction of the muscle spindles and Golgi tendon organs in the musculotendinous units that cross over a joint. A decrease in eversion force sense has been identified in chronically unstable individuals compared to individuals with healthy ankles (Arnold and Docherty 2006). Alpha motoneuron pool excitability has also been shown to be affected with chronic ankle instability. This is associated with athrogenic muscle inhibition which is defined as a continuing reflex reaction of the muscles around a joint after damage has been done to that joint. This athrogenic muscle inhibition is a measure of the alpha motoneuron pool for a specific muscle group and also how much it is activated (Hopkins and Ingersoll 2000). In participants with chronic ankle instability, there is evidence of altered alpha motoneuron pool excitability in the ankle joint as well as proximal joints, indicating spinal level motor control deficits that are associated with chronic ankle instability (Sedory, McVey et al. 2007).

Different measurement tools are used within the literature to measure postural control. One measure of postural control is center of pressure (COP). The COP variables represent the location and movement of the net ground reaction force vector in response to the counteractive action being taken to maintain equilibrium (Winter 1990). Time to stabilization (TTS) is another widely accepted measurement of postural control used commonly in the literature during studies that observe a dynamic task. TTS is defined as the time required to decrease resulting ground reaction forces (GRFs) of a jump landing to within a range of the baseline, or static GRF (Wikstrom, Tillman et al. 2005).

Another measure of postural control that is relatively new and starting to be used in the literature is time to boundary (TTB). Time-to-boundary is a method of postural control that estimates the amount of time it would take the COP to reach the boundary of the base of support if the COP was to continue on its path at its direct velocity. It is calculated by first modeling a rectangle around the foot to separate the anterior/posterior (AP) and medial/lateral (ML) components of the COP. In measuring the COP ML moving in the medial direction, the distance between the COP ML and the medial boarder of the foot would be measured and that difference would be divided by the corresponding velocity of the COP ML. Those measurements would indicate the time it would take the COP ML to reach the medial boarder of the foot if it were to continue to move in that direction. The same principle of measurement is used for both the COP ML moving in the lateral direction, and the COP AP moving in the anterior and posterior directions. TTB and COP are both measurements of postural stability used during a static test (Hertel and Olmsted-Kramer 2007).

Ankle Instability

As stated previously, 80% of the initial ankle injury results in recurrent instability. There are three different categories of ankle instability discussed in the literature; chronic ankle instability (CAI), functional ankle instability (FAI), and mechanical ankle instability (MAI). FAI and MAI have been shown to be the causes of CAI (Freeman, Dean et al. 1965; Tropp, Askling et al. 1985). MAI is attributed to ligamentous laxity, and tested objectively through the use of valid and reliable methods to look at the anatomical abnormalities associated with ankle instability. On the other hand, FAI is tested during functional activities and is measured using variety of postural stability or dynamic stability measures. Hubbard et al found that there were statistically significant findings between three measures of FAI and

MAI. They concluded that there is a relationship between FAI and MAI in terms of laxity, balance, and strength and therefore the two types of instability should be examined together to understand the extent of CAI (Hubbard, Kramer et al. 2007).

Functional ankle instability was first defined by Freeman et al to categorize patients with ongoing complaints of the ankle “giving way” (Freeman 1965; Freeman, Dean et al. 1965). He characterized this instability as joint motion that does not normally go beyond a person’s normal range, but is beyond voluntary control. As demonstrated above in the study by Hubbard et al, deficits in FAI include impaired proprioception, altered neuromuscular control, strength deficits, and decreased postural control (Hubbard, Kramer et al. 2007).

Chronic ankle instability is often used synonymously with functional ankle instability due to the large degree of overlap in terms of impairments between the two. However, as stated previously, CAI takes into account both functional and mechanical aspects of ankle instability to include deficits such as ligamentous laxity, subtalar instability, syndesmosis instability, bony deformity, proprioception deficits, and peroneal muscle weakness (Kaminski and Hartsell 2002). Contrary to Hubbard et al (Hubbard, Kramer et al. 2007) who found a significant correlation between measures of ankle and hip strength and FAI, Kaminski (Kaminski and Hartsell 2002) found that deficits in ankle strength were not highly correlated with CAI. However, Willems et al (Willems, Witvrouw et al. 2002) suggests that a possible cause of CAI is a decrease in proprioception and everter muscle weakness. Despite the exact mechanism or associated factors, ankle instability has a high incidence rate after ankle injury and knowledge on the deficits associated with instability are important in the physically active population. For the current study, participants with CAI will be selected based on the criteria set forth by Hertel and Olmsted, who selected CAI participants based on self reported frequent and repetitive bouts of the ankle giving way during functional activity (Hertel and Olmsted-Kramer 2007).

Chronic ankle instability has been linked to postural control deficits in a number of studies, however the literature on the subject remains inconclusive on the relationship between chronic ankle instability and postural stability and the reliability of the current postural assessment tools available to accurately measure these possible deficits. Riemann (Riemann 2002) conducted a comprehensive literature review to see if a link exists between chronic ankle instability and postural stability. However, there were significant articles relating CAI to postural control deficits. One of the first and most influential researchers to look at ankle injury and postural stability was Freeman et al (Freeman, Dean et al. 1965). His researched examined the mechanical and functional impairments of individuals hospitalized due to an ankle or foot sprain. The researchers concluded that there is a disruption of postural control after ligamentous injury to the foot or ankle that is responsible for the feeling of the ankle "giving way." Through the use of coordination exercises, postural control and the feeling of "giving way" can both be decreased (Freeman, Dean et al. 1965).

The work of Freeman and fellow researchers was ground breaking in the field of chronic ankle instability and postural stability, but his methods and procedures for assessing postural stability were too subjective and future studies employed more objective measures to assess postural stability. Konradsen and Ravn (1991) conducted a study looking at peroneal reaction time and ankle instability, using participants with functional ankle instability and controls with no history of ankle injury. To test peroneal reaction time, a trapdoor system was employed to produce sudden inversion while EMG recorded peroneal activity. Postural sway was assessed using center of pressure measurements taken on the forceplate during a single leg stance with eyes open. Participants with FAI had an increase in postural sway measurements and an increased peroneal reaction time as compared to the control group, supporting the researcher's theory that functional instability is induced by a proprioceptive reflex deficit.(Konradsen and Ravn 1991)

Lentell et al (1990) conducted a study compared isometric and isokinetic muscle strength and postural stability between stable and unstable ankles in individuals with unilateral ankle stability. No significant differences were noted between isometric and isokinetic strength measurements but a significant difference was noted between stable and unstable limbs in the postural assessment (Lentell, Katzman et al. 1990).

Hertel and Olmsted (2007) evaluated the postural control in participants with chronic ankle instability comparing time-to-boundary measures and COP measures. Postural stability for both TTB and COP was performed on the forceplate for three ten second trials of eyes open single leg quiet stance on their dominant (or injured) and non-dominant (or uninjured) limb. The COP measures were mean COP velocity, standard deviation of COP, range of COP, and percent of available range utilized. The TTB measures were absolute minimum TTB, mean of the minimum TTB samples, and standard deviation of the minimum TTB samples. All samples were measured in both the anteroposterior and mediolateral direction. The results showed that all but one of the TTB measurements showed significant impairments in postural control in subjects with CAI and only one of the measures of COP showed a significant impairment in postural control with CAI participants as compared to controls. These results show that TTB was able to detect deficits in postural control that COP measures were unable to detect (Hertel and Olmsted-Kramer 2007).

Although an abundance of research shows a decrease in different postural stability measures and ankle instability, there are some studies that did not find any difference in postural stability measures between stables and unstable participant. Baier and Hopf (1998) showed that there was no significant difference in postural control in a non braced condition between a control group and FAI group (Baier and Hopf 1998). Similarly, Isakov and Mizrahi (1997) failed to find a significant difference in postural stability measures between participants with a history of recurrent ankle sprains as compared to the control group using single leg stances measures (Isakov and Mizrahi 1997). Lastly, Beriner et al (1997) compared health subjects with functionally unstable subjects on measures of strength and postural control to see if a difference existed and found no differences in single leg postural sway measures or everter strength between an FAI and control group. (Bernier, Perrin et al. 1997). These research studies show that a discrepancy exists as to the disruption of postural control in individuals with CAI.

Ankle Bracing

Ankle bracing is an external device used to stabilize the ligaments and joints of the ankle during physical activity (Callaghan 1997). It can also be used in the acute stages of injury to control swelling and restrict range of motion (Callaghan 1997). The most common motions that are being addressed with ankle bracing are inversion and eversion of the ankle (Bot and van Mechelen 1999); which is the most common mechanisms of ankle injury. The function of the brace is to give the ankle more stability as the joint moves through range of motion without limiting the normal joint mechanics (Bot and van Mechelen 1999). Ankle taping is also used to stabilize the ankle and restrict inversion and eversion motions (Callaghan 1997).

The advantages to the ankle brace, as compared to the traditional method of taping is that the brace can be applied without the assistance of experienced personnel. The brace is easy to apply and remove, reusable, washable, and re-adjustable (Callaghan 1997). Several studies have evaluated the effectiveness of ankle braces in limiting inversion range of motion in healthy uninjured subjects. Tweedy et al (1994) investigated the effectiveness of the Nessa and Leuko ankle braces in preventing inversion before and after exercise in healthy Australian rules football players. Results showed that both braces significantly restricted ankle inversion immediately after the brace was applied, 20 minutes after exercise, and also 40 minutes after exercise; proving clinical significance in the use of ankle braces in the prevention of inversion ankle sprains (Tweedy, Carson et al. 1994). Similar studies that advocate the use of ankle braces for ankle injury prevention include Anderson et al, who investigated the effectiveness of a nonrigid subtalar stabilizer ankle brace and demonstrated that the ankle brace significantly reduced the maximum calcaneal inversion angle, lengthened the inversion time, and decreased peak calcaneal inversion velocity (Anderson, Sanderson et al. 1995). Kimura et al (Kimura, Nawoczenski et al. 1987) showed that the AirStirrup significantly decreased the amount of inversion at the ankle as compared to a no brace condition during a controlled inversion platform drop to 35° inversion. Gross (1987) compared the effectiveness of taping and a semirigid orthosis support before and after exercise. Passive inversion and eversion were measured on the Cybex IP prior to tape or brace, after application of tape or brace, and after a brief period of specified exercise. The results showed that post application ankle motion was significantly less for both taping and bracing than pre application, however, inversion motion of post exercises was significantly greater in the taping condition as compared to the bracing condition; which significantly restricted ankle inversion movement both post application and post exercise (Gross, Bradshaw et al. 1987). Greene and Hillman (1990) similarly looked at the effect of taping and a semirigid orthosis in providing inversion and eversion restriction before, during, and after a three hour volleyball practice as well as the effects of the tape and brace on vertical jump. Results showed a significant decrease in inversion and eversion restrictions after 20 minutes into exercise. The semi-rigid orthosis showed no mechanical restrictions to inversion and eversion motion, except when comparisons of pre exercise and post exercise were made in which a decrease in eversion range of motion was noted. No deficits were noted in vertical jump scores with either condition (Greene and Hillman 1990). Dizon and Reyes (2010) performed a systematic review of the effectiveness of external ankle supports in the prevention of inversion ankle sprains among elite and recreational athletes. The main significant finding among the studies was the reduction of ankle sprain by 69% with the use of ankle brace; with one ankle brace not proven to be significantly superior to another and a reduction of ankle sprains by 71% with the use of ankle tape was seen among a sample of previously injured participants for each group (Dizon and Reyes 2010). These studies show the effectiveness of ankle orthosis devices in restricting ankle motion, and possibly aiding to a decrease in ankle sprains.

Although no studies have been done to investigate the long term effects of ankle bracing or ankle tape use, there is little evidence to support that long term use would result in any negative effects to the surrounding tissues of the ankle or joints within the kinetic chain (Callaghan 1997). Additionally, there is little research to prove any adverse effects in athletic performance after long term use of ankle supports; especially in the areas of sprinting and agility testing (Callaghan 1997).

There is a controversy in the literature regarding the effectiveness of ankle braces in providing static and dynamic support to the ankle. Although some of the research supports the notion that the ankle brace does in fact provide external stability to the ankle, there are studies that have shown no difference between a bracing condition and a non-bracing condition. Additionally, very few articles have looked at the effects of CAI and ankle bracing on postural stability. Studies have been conducted comparing the effects of bracing on postural stability measures. Shaw et al (2008) looked at the effects of ankle bracing and fatigue on time to stabilization measurements in collegiate volleyball players. The purpose of the study was to compare the effectiveness of the 2 types of ankle braces in providing dynamic stability under a fatigued and non fatigued condition. The resulted showed that under no fatigue condition, neither ankle braces improved dynamic stability compared to the control condition. However, under a fatigued condition, wearing the Swede-O Universal lace up brace resulted in improved TTS scores; whereas the Active Ankle brace showed no improvements on TTS post fatigue (Shaw, Gribble et al. 2008).

In the absence of fatigue, Gribble et al (2010) also looked at the effects of bracing on dynamic stability in the CAI population. Subjects with CAI completed two testing sessions of a jump landing task, one in lace up brace condition and one without a brace. The study demonstrated that there was no significant difference between the brace condition and the non-braced condition in TTS scores. The researches comment that a limitation of the study may be the fact that TTS is not a sensitive enough measurement tool for looking at the effects of bracing on postural stability (Gribble, Taylor et al. 2010). Additional research needs to be completed on the effects of CAI and bracing to advocate the use of external supports for preventing recurrent injury in individuals with CAI.

Fatigue

Muscular fatigue has been defined in the literature as the decrease in maximal force-generating capability during exercise. Fatigue is common in almost all athletic activity due to the repetitive contractions of the different muscles in the body. There are two types of fatigue; peripheral fatigue, and central fatigue. Peripheral fatigue is caused by metabolic inhibition of the contractile process and also by excitation-contraction coupling failure (Cady, Jones et al. 1989; Miller, Green et al. 1990; Baker, Kostov et al. 1993). On the other hand, central fatigue is caused by a progressive failure of voluntary neural drive (Vollestad 1997). Decline in motivation from prolonged activity is considered one of the aspects of the central fatigue (Hollge, Kunkel et al. 1997). Fatigue increases the threshold of muscle spindle discharge which consequently disrupts the feedback and alters joint awareness (Gribble, Hertel et al. 2004), and thus ultimately influences postural stability.

In a research setting, fatigue is induced by either an isokinetic exercise protocol or a functional exercise protocol. In isokinetic exercise protocol, fatigue is induced by a specialized machine that allows variable resistance to a movement that is set at a specified, constant speed. Isokinetic fatigue protocols are usually done in an open kinetic chain fashion and involve isolated joint motions and muscle groups. In functional exercise protocol, fatigue is induced during different functional or sport specific activities that involve movements at multiple joints in multiple planes.

A study by Wikstrom et al (2004) compared an effect of isokinetic ankle fatigue protocol and a functional fatigue protocol on dynamic stability following a jump landing task. Isokinetic fatigue was induced using the KinCom isokinetic dynamometer. Participants were first tested with three maximal contractions for plantarflexion and dorsiflexion. Fatigue was induced using continuous concentric contractions of the plantarflexors and dorsiflexors at velocities of 30°/s and 120°/s. The researchers determined fatigue as the point at which the plantarflexion and dorsiflexion torques decreased below 50% of their maximum concentric values for three consecutive repetitions, as was the protocol used in multiple other research studies (Voight, Hardin et al. 1996; Carpenter, Blasier et al. 1998; Yaggie and McGregor 2002). The functional fatigue protocol consisted of the Southeast Missouri Agility Drill; which consists of a series of athletic tasks including forward sprints, diagonal back pedaling, side shuffling, side-to-side bounds minitramp jumps, co-contraction arc, and two-legged hop sequence. Fatigue was determined as the point at which the time to complete the course was increased by 50% of the baseline (Shills JJ 2003). The results showed that isokinetic and functional fatiguing protocols resulted in similar decline in dynamic stability (Wikstrom, Powers et al. 2004).

There have been multiple studies done in the area of the effects of fatigue on postural stability. Yaggie and McGregor (2002) investigated the effects of ankle fatigue on the maintenance of balance and postural limits in individuals without previous history of ankle injury. The results were most significant immediately post fatigue and gradually returned to baseline as the time post fatigue increased (Yaggie and McGregor 2002). Similarly, Salavati et al (2007) investigated changes in postural stability with fatigue of the lower extremity frontal and sagittal plane movers using an isokinetic fatigue protocol. The results of the study show that localized muscle fatigue of the lower extremities decreases postural stability in both the frontal and sagittal planes (Salavati, Moghadam et al. 2007).

Gribble and Hertel (2004) completed a study looking at the effect of muscle fatigue at multiple lower extremity joints on postural control using healthy subjects with no previous history of lower extremity or neurologic deficit. The results demonstrated that postural control in the medial/lateral direction is affected more significantly by fatigue of the hip and the knee musculature than the ankle musculature, while the postural control in the anterior/posterior direction is similarly affected by the fatigue of the ankle, knee, and hip musculature. (Gribble, Hertel et al. 2004). Johnston et al (1998) found similar results to previously stated studies when they looked at the effects of lower extremity muscle fatigue on motor control performance. (Johnston, Howard et al. 1998). Harkins et al (2005) conducted a study looking at the effects of two ankle fatiguing models on the duration of postural stability dysfunction. The two fatiguing models used in this study were 30% and 50% isokinetic fatigue. The 30% fatigue protocol is equal to a 70% decrease in strength and the 50% fatigue protocol is equal to a 50% decrease in strength. The researchers concluded that the 30% isokinetic fatigue protocol would be best suited for research purposes because it results in a great fatigue effect, but it relatively short lived (Harkins, Mattacola et al. 2005).

The purpose of this study is to examine the fatigue related effects of ankle bracing on time-to-boundary measurements in healthy and chronically unstable participants. The research presented in this literature review shows that gaps are evident in the areas of time to boundary research and the effects of bracing and on postural stability. The research also shows that fatigue is a prevalent independent variable for testing postural stability due to the overwhelming evidence of its negative effects on postural stability. Therefore, information gained from looking at the effects of bracing and fatigue on time to boundary with hopefully validate the research that time to boundary is a more sensitive research tool by means of postural stability measurement, and ankle bracing has a positive effect at counteracting instability and fatigue during stability tasks.

CHAPTER III

METHODOLOGY

Subjects

Nineteen subjects with a history of chronic ankle instability ((mean ± SD, age = 20.4 ± 1.9 yrs, height = 170.2 ± 7.0 cm, mass = 74.7 ± 13.6 kg) and nineteen subjects with no history of chronic ankle instability ((mean ± SD, age = 20.8 ± 2.0 yrs, height = 169.5 ± 6.4 cm, mass = 75.6 ± 15.9 kg) were recruited for this study. Healthy subjects were recruited if they were within four and a half kilograms and five centimeters of a CAI subject. All subjects ranged in age from eighteen to twenty-five. All subjects were physically active as defined as participating in any variety of physical activity for thirty minutes, at least three times per week. Subjects were included in the healthy group if they had no previous history of an ankle or lower extremity injury in the past year and no history of a concussion or vestibular condition in the past six months. Subjects were included in the chronic ankle instability group if they had suffered at least one ankle sprain in the past year that resulted in at least one of the following symptoms; swelling, ecchymosis, and decreased range of motion (Hertel and Olmsted-Kramer 2007), and multiple recurrences of minor ankle sprains in the past year. Subjects were also included in the chronic ankle instability group if they reported a feeling of instability or "giving way" in their ankle after an ankle sprain. Exclusion criteria for subjects with CAI included not participating in rehabilitation for an ankle injury in the past six months, and not presenting with acute signs of an ankle sprain at time of testing.

Instrumentation

Raw data used to calculate time-to-boundary measurements was collected with a forceplate (Bertec Corporation, Columbus, OH) integrated with the Motion Monitor software system (Innovative Sports Training, Chicago, IL, USA). A grid was placed over the forceplate to ensure exact placement of the foot during each trial (Figure 1). Marks on the subjects' foot that bisected the foot into anteroposterior (AP) and mediolateral (ML) midlines were aligned on the grid so that the foot was centered on the forceplate prior to each trial.

Isokinetic ankle everter fatigue was performed using the Biodex Isokinetic Dynamometer (Biodex Medical Systems, Shirly, NY). An ASO® ankle brace (Medical Specialties Inc, Charlotte, NC) was used for braced condition.

Procedures

The study employed a pre-test post-test design evaluating the effect of time to boundary measurements on fatigue (pre and post) and bracing (brace and no brace) on individuals with and without chronic ankle instability. All testing took place in the Sports Medicine Research Laboratory (FH029). Subjects reported for testing on two separate occasions, at least one week apart from each other, with each session lasting approximately one hour. Testing was performed under the bracing condition during one of the sessions, and the no bracing condition for the other session. The order of conditions was counter-balanced. Subjects were instructed not to engage in any physical activity for one hour prior to scheduled testing time.

Prior to participation, subjects read and signed a University Institutional Review Board approved informed consent form. Following consent, subjects were screened for inclusion and exclusion criteria for each group. If the subject met the inclusion/exclusion criteria, anthropometric measurements of height (centimeters) and body mass (kilograms), and demographic information (age and sex) were collected. The testing limb for the participants in the chronic ankle instability group was the limb that is self identified as chronically unstable. The testing limb of the control participants was matched to the subjects with CAI for limb dominance. Dominant limb was defined as the leg that subjects would choose to kick a ball for maximum distance. Control subjects were matched for height, weight, and gender based on the CAI participants.

Once testing preparations were complete, subjects were pre-tested in time-to-boundary measurements. For time-to-boundary measurement, it is critical that the subject's foot is positioned on the exact center of the forceplate for each testing trial. Therefore prior to beginning the measurement, subject's test foot was marked using a custom made wood platform. The custom made platform consisted of a flat wood panel with a perpendicular L shaped raised edges (Figure 2). A sheet of paper was placed along the edges. The subjects placed the test foot on the paper by aligning the heel and the medial or lateral edge of the foot against the edges (medial edge for the right foot and lateral edge for the left foot) (Figure 3). Once the foot was placed on the paper, the widest and longest part of the foot were marked, and the subject's foot was removed from the platform. A rectangular model of the foot was constructed on the paper by drawing two lines with a T-square that are perpendicular to the edges of the paper and intersecting the marks drawn on the paper. The length and the width of the rectangle was measured to define the boundary of the foot, and to draw lines that bisect the rectangle in AP and ML directions (Figure 4). The subject placed his or her foot back on the sheet of paper and the investigator made four small tick marks at the edges of the foot that correspond with the lines drawn on the paper. These tick marks were lined up with the grid marks on the forceplate to ensure exact foot placement on the forceplate for the repeated single leg stance trials.

Subjects were tested for six trials of ten second single leg stance holds. Three trials were performed with the eyes open, and three trials were performed with the eyes closed. Vision was counterbalanced among subjects. Subjects performed single leg stance with hands on iliac crests and non-testing foot elevated off the floor and positioned to personal comfort. Subjects were instructed to look straight ahead during the trials. Subjects were allowed one practice trial of the single leg stance before pre-testing began. If a subject was unable to complete a trial, the trial was discarded and repeated after a thirty second rest period (Hertel and Olmsted-Kramer 2007). An incomplete trial was defined as any trial in which the subject touches the non-testing foot outside the boundaries of the forceplate before the trial is complete. The subject was allowed to touchdown on the forceplate during testing, and the number of touchdowns was recorded.

After completing the pre-test, subjects completed an isokinetic fatigue protocol of the ankle everters using the Biodex Isokinetic Dynamometer. The machine was set up per manufacturer's recommendations for ankle inversion and eversion. The subjects were seated in the chair with two straps crossed over his or her chest, and another strap across the distal thigh of the limb that was tested. The knee of the limb tested was flexed to 30-45° using the limb support pad and t-bar and the foot was placed on the footplate of the ankle attachment configured for inversion/eversion movement. The axis of the dynamometer was aligned to the subject's ankle joint, and two straps were used to secure the subject's foot onto the footplate (Figure 6).

Once the subject was in the proper position, they completed three, five second maximum voluntary isometric contractions (MVIC) of the ankle everters. After MVIC measurements are collected, subjects will have a one minute rest period before beginning the fatigue protocol. The everter fatigue protocol began with a familiarization to the movement by performing three repetitions of sub-maximal ankle eversion movements at 60°/s. Once the subject was familiarized to the movement, subjects began the isokinetic fatigue protocol, consisting of repetitive maximal ankle eversion at 60°/s until the subject's peak torque output decreased below fifty percent of the average MVIC for three consecutive trials (Yaggie and McGregor 2002). Continuous encouragement from the researcher was given to the subject throughout the isokinetic fatigue protocol to promote maximal effort. Once subjects completed the fatigue protocol, they immediately completed a post-test of time-to-boundary using the same protocol that was employed during the pre-test. Less than one minute was allowed between isokinetic fatigue and post-test time-to-boundary. Once post-testing was completed, subjects immediately repeated the MVIC test for ankle eversion to ensure fatigue was maintained throughout the post-testing.

When the testing was performed for the no brace condition, subjects completed these tasks (time-to-boundary measurement and fatigue protocol) on a bare foot. When the testing was performed for the bracing condition, subjects completed these tasks while wearing the ASO® ankle brace. The subjects were fitted to the brace by the fitting recommendations supplied by the company by themselves, while the investigator oversees the application to make sure it is correct. The subject was instructed to readjust the brace as necessary to maintain proper tightness; and the number of adjustments was recorded.

Data Reduction

Tri-axial forces (Fx, Fy, Fz) and moments (Mx, My, Mz) from the forceplate were recorded at a sampling frequency of 50 Hz. A time series of 500 center of pressure (COP) data points was calculated and then filtered with a fourth order zero lag, low pass filter with a cutoff frequency of 5 Hz for each trial within the Motion Monitor software (Innovative Sports Training, Chicago, IL, USA).

To calculate time-to-boundary, distance between the COP in the ML direction and the medial and lateral boarder of the rectangular model of the foot was calculated. If the COP was moving medially, then the distance between the COP ML and the medial border of the rectangular model of the foot was calculated. The distance was then divided by the velocity of the COP ML in the medial direction at the corresponding time point. The calculated values represent the time it would take the COP ML to reach the medial border of the rectangle if it were to continue to move in that direction with no acceleration or deceleration (time-to-boundary). Similarly, if the COP is moving laterally, then the distance between the COP ML and the lateral border of the rectangular model of the foot was calculated. The distance was then divided by the velocity of the COP ML in the lateral direction at the corresponding time points. The absolute minima, mean of the minima, and standard deviation of the minima of the time-to-boundary during each trial will be calculated for eyes open and eyes closed.

Three-trial means of time-to-boundary measurements were calculated for each vision condition (eyes open vs. eyes closed), for each bracing condition (braced vs. non-braced) and for each fatigue status (pre-fatigue vs. post-fatigue). Dependent variables were calculated using a custom-written MatLab software program (The MathWorks Inc, Natick, MA).

Statistical Analysis

Two 3-way mixed model analysis of variance (ANOVA) with group (chronic ankle instability vs. control) as the between subjects factor and bracing condition (braced vs. non-braced) and fatigue (pre and post) as the within subjects variable were used to assess the difference in time-to-boundary in the ML and AP direction for both eyes open and eyes closed. A Tukey post hoc test was used when significant interaction effects were present. All statistical analysis was run using Statistical Package for Social Science (SPSS) 18 (SPSS Inc, Chicago IL). The level of significance was set at an alpha level of 0.05

CHAPTER IV

RESULTS

Under the eyes open condition, there were no significant three way interactions between bracing, fatigue, and group, for any of the dependent variables. There were significant bracing by group interactions for the absolute TTBML minima ($F_{2,36}$= 5.85, P= 0.021), and absolute TTBAP minima ($F_{2,36}$= 6.55, P= 0.015). However, post hoc testing revealed no significant pair-wise differences in absolute TTBML minima (Tukey HSD= 0.074sec) (95% CI of control braced condition: LB: 0.019, UB: 0.157) (95% CI of CAI braced condition: LB: 0.084, UB: 0.221); or absolute TTBAP minima (Tukey HSD= 0.201) (95% CI of CAI braced condition: LB: 1.020, UB: 1.328) (95% CI of control non-braced condition: LB: 1.053, UB: 1.397). There were no significant bracing by group interactions for mean of the TTBML minima ($F_{2,36}$= 0.04, P= 0.847), mean of the TTBAP minima ($F_{2,36}$= 0.13, P= 0.721), standard deviation of the TTBML minima ($F_{2,36}$= 0.81, P= 0.374) and standard deviation of the TTBAP minima ($F_{2,36}$= 2.64, P= 0.113). There were no significant bracing by fatigue interactions for absolute TTBML minima ($F_{2,36}$= 0.34, P= 0.562), absolute TTBAP minima ($F_{2,36}$= 0.85, P= 0.363), mean of the TTBML minima ($F_{2,36}$= 0.01, P= 0.908), mean of the TTBAP minima ($F_{2,36}$= 2.681, P= 0.110), standard deviation of the TTBML minima ($F_{2,36}$= 1.87, P= 0.180) and standard deviation of the TTBAP minima ($F_{2,36}$= 3.01, P= 0.091).

There were no significant fatigue by group interactions for absolute TTBML minima ($F_{2,36}$= 3.64, *P*= 0.064), absolute TTBAP minima ($F_{2,36}$= 0.01, *P*= 0.930), mean of the TTBML minima ($F_{2,36}$< 0.001, *P*= 0.978), mean of the TTBAP minima ($F_{2,36}$= 0.07, *P*= 0.789), standard deviation of the TTBML minima ($F_{2,36}$= 2.40, *P*= 0.130), and standard deviation of the TTBAP minima ($F_{2,36}$= 3.01, *P*= 0.091).

There were significant bracing main effects for absolute TTBAP minima (F_{36}= 6.34, *P*= 0.016) (Figure 6), and mean of TTBAP minima (F_{36}=4.706, *P*= 0.037) (Figure 7), with the non-braced condition having significantly higher TTB measures than the braced group (Table 1). No bracing main effects were found for absolute TTBML minima (F_{36}= 0.14, *P*= 0.709), mean of the TTBML minima (F_{36}= 0.05, *P*= 0.826), standard deviation of the TTBML minima (F_{36}= 3.16, *P*= 0.084), or standard deviation of the TTBAP minima (F_{36}= 4.04, *P*= 0.052).

Significant fatigue main effects were found for the mean of TTBML minima (F_{36}=15.67, *P*< 0.001) (Figure 8), and standard deviation of TTBML minima (F_{36}= 17.97, *P*< 0.001) (Figure 9), with the post-fatigue condition having significantly higher TTB measures than the pre-fatigue condition (Table 1). No significant fatigue main effects were found for absolute TTBML minima (F_{36}< 0.001, *P*= 0.991), absolute TTBAP minima (F_{36}= 0.16, *P*= 0.696), mean of the TTBAP minima (F_{36}=0.215, *P*= 0.645), or standard deviation of the TTBAP minima (F_{36}= 0.75, *P*= 0.393).

There were no significant group main effects for absolute TTBML minima (F_{36}= 0.56, *P*= 0.459), absolute TTBAP minima (F_{36}= 0.11, *P*= 0.748), mean of the TTBML minima (F_{36}= 1.36, *P*= 0.251), mean of the TTBAP minima (F_{36}= 0.18, *P*= 0.672), standard deviation of TTBML minima (F_{36}= 0.35, P= 0.556), or standard deviation of the TTBAP minima (F_{36}= 0.02, P= 0.895).

Under the eyes closed condition, there was a significant bracing by fatigue by group interaction for standard deviation of TTBAP minima ($F_{3,36}$= 4.68, P= 0.037). However post hoc testing revealed no significant pair-wise differences in standard deviation of TTBAP (Tukey HSD= 0.216) (95% CI of control braced pre-fatigue condition: LB: 0.939, UB: 1.202) (95% CI of CAI braced pre-fatigue condition: LB: 1.145, UB: 1.409). No significant bracing by fatigue by group interaction was found for absolute TTBML minima ($F_{3,36}$= 0.11, P= 0.742), absolute TTBAP minima ($F_{3,36}$= 0.28, P= 0.602), mean of the TTBML minima ($F_{3,36}$= 0.53, P= 0.470), mean of the TTBAP minima ($F_{3,36}$= 1.75, P= 0.194) and standard deviation of the TTBML minima ($F_{3,36}$= 0.06, P= 0.816).

There were no significant bracing by group interactions for absolute TTBML minima ($F_{2,36}$= 0.002, P= 0.967), absolute TTBAP minima ($F_{2,36}$= 0.94, P= 0.340), mean of the TTBML minima ($F_{2,36}$= 0.37, P= 0.544), mean of the TTBAP minima ($F_{2,36}$= 1.73, P= 0.196), standard deviation of the TTBML minima ($F_{2,36}$= 0.37, P= 0.549), and standard deviation of the TTBAP minima ($F_{2,36}$= 2.40, P= 0.130).

There were no significant fatigue by group interactions for absolute TTBML minima ($F_{2,36}$= 0.37, P= 0.547), absolute TTBAP minima ($F_{2,36}$< 0.001, P= 0.993), mean of the TTBML minima ($F_{2,36}$= 0.19, P= 0.665), mean of the TTBAP minima ($F_{2,36}$= 0.90, P= 0.348), standard deviation of the TTBML minima ($F_{2,36}$= 0.24, P= 0.626), and standard deviation of the TTBAP minima ($F_{2,36}$= 0.51, P= 0.480).

A significant bracing by fatigue interaction was found for the mean of TTBML minima ($F_{2,36}$= 5.76, P= 0.022). The post hoc analysis pair wise comparison revealed that the mean of the TTBML minima was significantly higher for the post-fatigue non-braced condition compared to the pre-fatigue non-braced condition (Tukey HSD= 0.122). No significant difference was found between the post-fatigue braced condition or the pre-fatigue braced condition with any other condition . No significant bracing by fatigue interactions were found for absolute TTBML minima ($F_{2,36}$= 1.45, *P*= 0.236), absolute TTBAP minima ($F_{2,36}$= 1.16, *P*= 0.289), mean of the TTBAP minima ($F_{2,36}$= 0.05, *P*= 0.817), standard deviation of the TTBML minima ($F_{2,36}$= 4.00, *P*= 0.053), and standard deviation of the TTBAP minima ($F_{2,36}$= 0.24, *P*= 0.625).

There were significant bracing main effects for absolute TTBML minima (F_{36}= 5.84, *P*= 0.021) (Figure 10), absolute TTBAP minima (F_{36}= 4.24, *P*= 0.047) (Figure 11), mean of TTBAP minima (F_{36}= 5.59, *P*= 0.024) (Figure 12), and standard deviation of TTBML minima (F_{36}= 7.37, *P*= 0.011) (Figure 13). The absolute TTBAP minima, mean of the TTBAP minima, and standard deviation of TTBML minima were higher under the non-braced condition compared to the braced condition (Table 1), while the standard deviation of the TTBML minima was higher under the braced condition compared to the non-braced condition (Table 1). There were no significant bracing main effects for mean of the TTBML minima (F_{36}= 0.85, *P*=0.362), and standard deviation of the TTBAP minima (F_{36}= 2.75, *P*= 0.106).

There was a significant fatigue main effect for the mean of TTBML minima (F_{36}= 9.98, *P*= 0.003) (Figure 14), with the post fatigue condition having significantly higher TTB measures than the pre-fatigue condition (Table 1). No significant fatigue main effects were found for absolute TTBML minima (F_{36}= 0.85, *P*= 0.363), absolute TTBAP minima (F_{36}= 0.04, *P*= 0.845), mean of the TTBAP minima (F_{36}= 0.08, *P*= 0.782), standard deviation of the

TTBML minima (F_{36}= 2.54, P= 0.119), and standard deviation of the TTBAP minima (F_{36}= 0.18, P= 0.675).

There were no significant group main effects for absolute TTBML minima (F_{36}= 1.94, P= 0.172), absolute TTBAP minima (F_{36}= 1.28, P= 0.266), mean of the TTBML minima (F_{36}= 2.04, P= 0.162), mean of the TTBAP minima (F_{36}= 0.63, P= 0.433), standard deviation of the TTBML minima (F_{36}= 1.18, P= 0.285), or standard deviation of the TTBAP minima (F_{36}= 0.20, P= 0.658).

CHAPTER V

DISCUSSION

The purpose of this study was to investigate the effect of ankle bracing and fatigue on postural stability between healthy and chronically unstable participants using time-to-boundary (TTB) measurements. Our results indicate that there were no differences in TTB measures between individuals with CAI and healthy controls, and the non-braced condition had significantly better TTB measures than the braced condition.

When analyzing the TTB measures, the absolute, mean, and standard deviation of the TTB minima are reported. The absolute value of TTB minima and mean of the TTB minima are indicative of the time the individual has to make postural corrections. Therefore, the higher absolute mean TTB is considered to indicate better balance. The standard deviation of the TTB minima scores represents a greater number of solutions available to maintain balance, and thus higher standard deviations of the TTB minima represent a less constrained sensorimotor system and more options available to help maintain balance (Matthew C. Hoch 2011). A more constrained system is bad because it does not allow for as many solutions to maintain balance, and therefore can make an individual more likely to get injured.

This is the first study to investigate the effects of ankle bracing on TTB measures. We hypothesized that bracing would result in improved balance performance indicated by higher TTB measures in both individuals with and without chronic ankle instability, because the brace would provide medial and lateral support to the ankle. However, our results failed to demonstrate this hypothesis. Instead, we demonstrated that bracing resulted in poorer postural stability. We also found that the standard deviation of the TTBML minima in the eyes closed condition was much higher in the non-braced condition as compared to the braced condition. This may indicate that bracing resulted in greater constraint in the sensorimotor system, and thus limited the number of solutions the individual can use to maintain balance. While our findings did not support our hypothesis, this finding is in agreement with the findings from the study by Hadadi et al (Mohammad Hadadi 2011) that demonstrated an increase in postural sway measures, indicative of poorer balance performance with the use of a semi-rigid orthosis in healthy participants. Bennell and Goldie (Bennell and Goldie 1994) also found that the implementation of tape or a brace resulted in a significant increase in postural sway and made individuals touchdown more often as compared to the use of an elastic bandage. It was suggested in the research that the increase in postural instability may be due to the increase in mechanical restriction caused by the external ankle support, which alters the proprioceptive feedback (Bennell and Goldie 1994). This is an interesting assumption of decreased proprioception considering that an external support should in theory increase proprioception. Wearing an external support will increase the cutaneous input as the afferent response enters the brain, which in turn affects the efferent response at the ankle (Feuerbach et al 1994). It is unclear at this time what causes this decrease in proprioception with the addition of an external ankle support, therefore further research in this area is necessary. Based on these findings, it may be recommended that an individual have time to become accustomed to an external ankle support before participating fully in an athletic activity due to the risk of increased instability and risk of injury. None of the study participants had prior experience with using external ankle supports, and thus were unaccustomed to balancing while wearing a brace. The study's findings may have been different if the participants were regular users of ankle braces, however this study only looked at the acute effects of ankle bracing. Further investigation is needed understand the effects of bracing in regular ankle brace users.

We hypothesized that participants with CAI would have greater deficits in postural stability indicated by higher TTB measures across fatigue. However, we did not find any significant differences in balance performance between participants with CAI and healthy participants before or after the fatigue. This is contrary to previous studies that demonstrated that individuals with CAI have a significantly decreased capability to balance as compared to healthy controls, indicated by lower TTB measures and increased postural sway (McKeon and Hertel 2008) (Hertel and Olmsted-Kramer 2007) (Mohammad Hadadi 2011). Similar to our study, Bernier et al (Baier and Hopf 1998) found no difference between participants with functional ankle instability and healthy controls on measures of postural sway. A possible explanation for the lack of significant difference may be variation in the definition of functional ankle instability or CAI used in the study. For this study, we defined CAI as having one ankle sprain in the last year that resulted in one of the following symptoms; swelling, ecchymosis, or loss of motion at the time of injury, as well as a feeling of "giving way" during functional activities. Hertel and Olmsted-Kramer defined CAI participants as having one substantial ankle sprain in their lifetime that required medical attention, and recurrent incidences of the ankle giving way during functional activities in the past three months (Hertel and Olmsted-Kramer 2007). Wikstrom et al defined their CAI participants has having a history of one severe ankle sprain that involved immobilization or non-weight bearing for three days, followed by a recurrent sprain at least six months prior to the study, and at least one episode of the ankle giving way in the last year (Wikstrom 2010). We were the only study to use these inclusion criteria and the only TTB study that did not find any differences between CAI and healthy controls. We chose to use TTB because it has been shown to be a more sensitive balance assessment than previous measures; however we did not get the results that previous studies managed to produce. Perhaps CAI criteria in the present study was not specific enough to show differences between those with and without instability and a more rigid inclusion criteria should be considered for further research. It is also possible that participants' were not truthful in their injury history or that the severity of their self reported CAI was not significant enough to be included in the study. These variables could contribute to the lack of significant difference between groups.

Although we hypothesized that individuals with CAI would have increased postural sway compared to CAI individuals across fatigue conditions and between groups, we hypothesized that in the braced condition, CAI individuals would have the same postural sway as healthy individuals due to the support of the brace. However, we failed to prove this hypothesis correct. In the eyes open condition, we did find significant differences between CAI and controls between the braced and non-braced conditions, however the significance was so slight that it may not be clinically relevant, again showing that ankle braces may not provide the amount of stability intended on first time users.

We hypothesized that fatigue would result in worse TTB measures, and thus decreased postural stability in both CAI and healthy controls across bracing conditions. We thought that the ML measures would be more affected due to the fatigue, because it is more of a natural reaction to attempt to regain balance on the medial or lateral aspects of one's foot. However, we did not find differences between the ML and AP measures pre and post fatigue. No other TTB study has looked at the effects of fatigue on TTB measures. For this study, an isokinetic fatigue protocol of the ankle everters was chosen to target the fibularis muscles, which are the dynamic stabilizers responsible for preventing inversion ankle sprains. We chose the isokinetic fatigue protocol for time considerations, because this protocol would be quicker to complete than a functional protocol; and also because we had actual quantitative values to verify that an individuals' specific muscle group was fatigued as opposed to an overall fatigue limiting the results of functional fatigue. We measured everter MVIC's before fatigue and after the last balance exercise. To ensure that an individual was fatigued, we placed a line across the computer screen indicating the peak torque they needed to fall below to be considered fatigued, based on their previous MVIC. All participants met the study's definition of fatigue, of falling below 50% of peak torque for three continuous repetitions before completing the post fatigue TTB. Although comparison of the ankle eversion strength during an MVIC before fatigue and after completion of the data collection demonstrated no significant difference pre vs. post-fatigue, indicating that the fatigue protocol was not successful at producing lasting fatigue during the post testing. A variable that could have added to the lack of lasting fatigue were the touchdown mistrials during post testing. A mistrial was defined as the opposite foot making contact with the forceplace during the trail. Every time a touchdown occurred, that trial needed to be discarded and repeated. The number of touchdowns post fatigue was significantly higher than pre-fatigue. Therefore, the overall time that an individual had to recover from the fatigue was greater due to the number of mistrials. Based on this analysis, it is unclear whether fatigue was truly achieved through the fatigue protocol, or how long during the post testing the fatigue lasted, which threatens the internal validity of the study findings, related to the effects of fatigue. In pilot test analysis, we looked at the detriment of fatigue over time and found that fatigue effects lasted as long as one minute after the protocol. The pre and post balance testing each consisted of six trials of ten second trials, which took a little over one minute to complete. While the bracing condition was counterbalanced, there was no way to counterbalance the fatigue condition to wash out a learning effect on balance performance. Unfortunately it appears that a large learning effect took place in this study for the balance protocol that was not affected by fatigue. In further research, it may be considered to reduce the total number of trials of the balance protocol by only using the eyes closed condition for testing to help minimize the learning effect and employ a fatigue protocol that fatigues an individual to 70 percent of their MVIC as opposed to 50 percent as was used in this study. The addition of a practice day or more practice trials to help eliminate the learning effect might also prove effective.

Although not one of the original research questions in the study, we found that all of the eyes open conditions would yield better balance when compared to the eyes closed conditions. These findings have also been found in previous TTB research where eyes open and eyes closed trials were examined in various populations (McKeon, Booi et al. 2010) (McKeon and Hertel 2008). In a study that examined the effects of four week balance training on postural stability, McKeon et al (McKeon, Ingersoll et al. 2008) found no significant differences in any of the TTB variables in the eyes open condition, but was able to find significant differences in the eyes closed condition. This shows that the eyes closed condition of TTB is more sensitive in detecting differences in postural stability and subsequent studies should consider only using testing with eyes closed to help minimize a learning effect of the balance protocol.

This study was not without its limitations. We were limited by the fatigue protocol chosen for this study. In looking at previous research of fatigue protocols, we decided that a protocol that isolated the everter muscles would give us the best results when looking at ankle instability. However, looking at the results, our fatigue protocol did not create lasting fatigue throughout the entire test. In future research, this same protocol could be used again to gain specific muscle fatigue, however the parameters should be different so that the individual gains a more lasting fatigue. It may also be more appropriate to use a functional or isokinetic fatigue protocol that targets all the muscle groups of the lower leg. We were also limited by participants' previous exposure to the equipment in this study. Most participants had no previous experience using a Biodex isokinetic machine. Because of this, their overall fatigue values may be lower than their actual maximum values that could contribute to the insignificance of the fatigue protocol. Additionally, participants may also not have been previously exposed to wearing ankle braces prior to this study. With no previous experience, participants may have been uncomfortable attempting to maintain balance while having a device that restricts movement. In future research, giving participants more of a familiarization period with both the isokinetic machine and the ankle brace may have yielded different results.

Future research on this subject area should continue to look into the effects of bracing on TTB, without the variable of fatigue. As evident by the confidence intervals reported, increasing the power of this study by increasing the sample size or effect size could yield more significant results. Special attention should be paid toward the effect of the ankle brace on constant velocity on postural sway. In the TTB calculation, the distance between the COP and the border of the foot is divided by the corresponding velocity, assuming that velocity stays constant. The mechanical restriction of the ankle brace is made to prevent motion, and therefore it may be contraindicated to use an external ankle brace with TTB measurements and should be studied further. Additional research should also look into alternative methods of fatigue related to TTB. Consider looking at isokinetic fatigue protocols that encompass all the muscles of the lower extremity, combined with a shorter balance protocol to ensure lasting fatigue and decrease a learning effect. TTB has been shown to be a more sensitive measurement of postural control than traditional COP measures, and therefore should be used to look at different training methods to help improve balance. Previous research was done looking at plantar hypoesthesia (McKeon and Hertel 2007) and TTB, but further research could be done looking at the effects of foot intrinsic rehab on TTB measures.

In conclusion, this study demonstrated no differences in postural stability between individuals with CAI and healthy controls. The effect of fatigue on postural stability is inconclusive based on this study, due to the observed significant learning effect. The study also demonstrated that the use of an external ankle support in individuals (with or without CAI) who normally do not wear one may be detrimental to postural stability. This is not to say that the use of ankle braces should be discontinued for means of injury prevention or additional support, yet we suggest that adequate accommodation time may need to be given to an individual to become comfortable with the ankle brace during functional activities before wearing the brace during full athletic activity

FIGURES

Figure 1. Tape grid placed over the forceplate to ensure exact foot placement for each trial

Figure 2: Flat wood panel with perpendicular L shaped raised edges to measure the foot

Figure 3: Foot placement in platform for proper measurement

Figure 4: Foot measurement made into a rectangle by measuring the greatest length and width of the foot

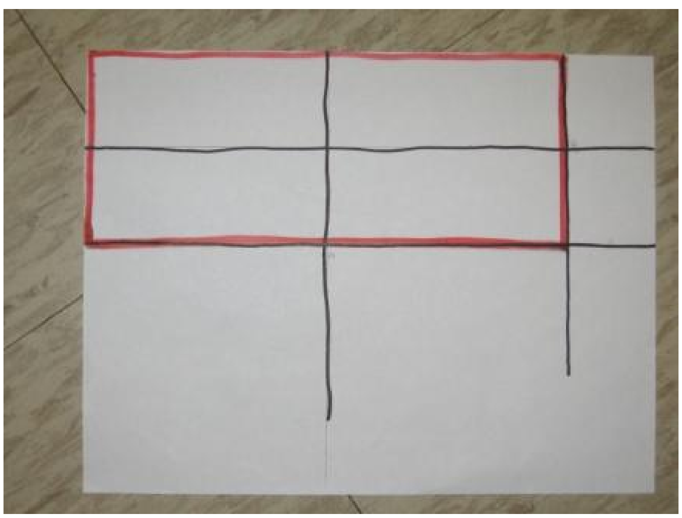


Figure 5: Proper set-up for ankle everter isokinetic fatigue

Figure 6: Means and standard deviation error bars of the bracing main effect of the absolute TTBAP minima for the eyes open condition

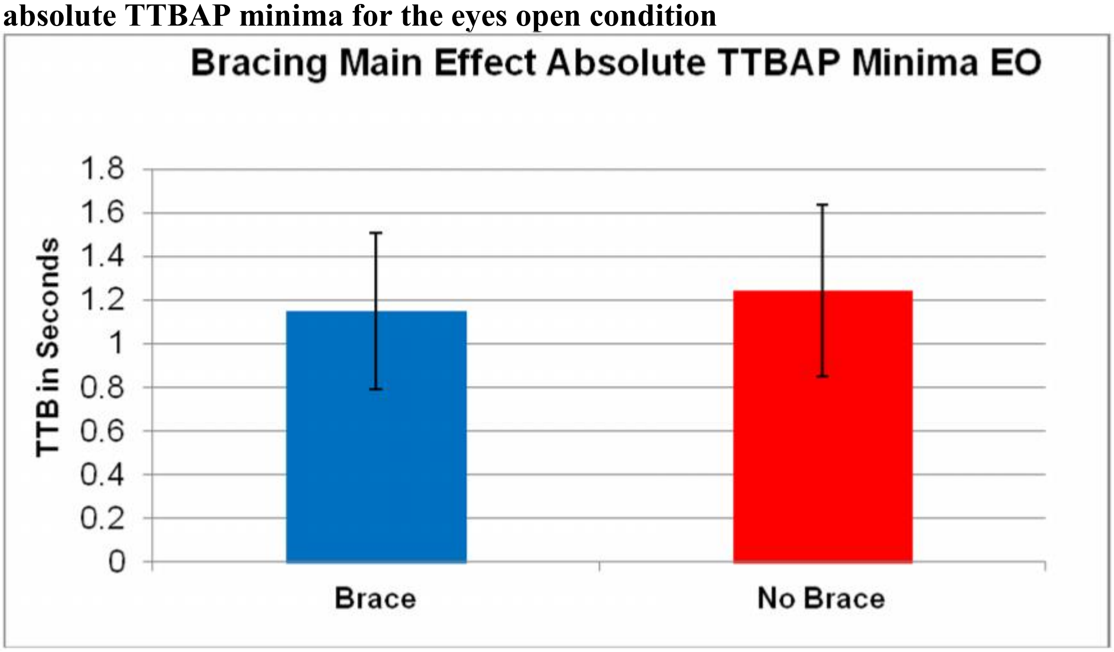


Figure 7: Means and standard deviation error bars for the bracing main effect of the mean of TTBAP minima for the eyes open condition

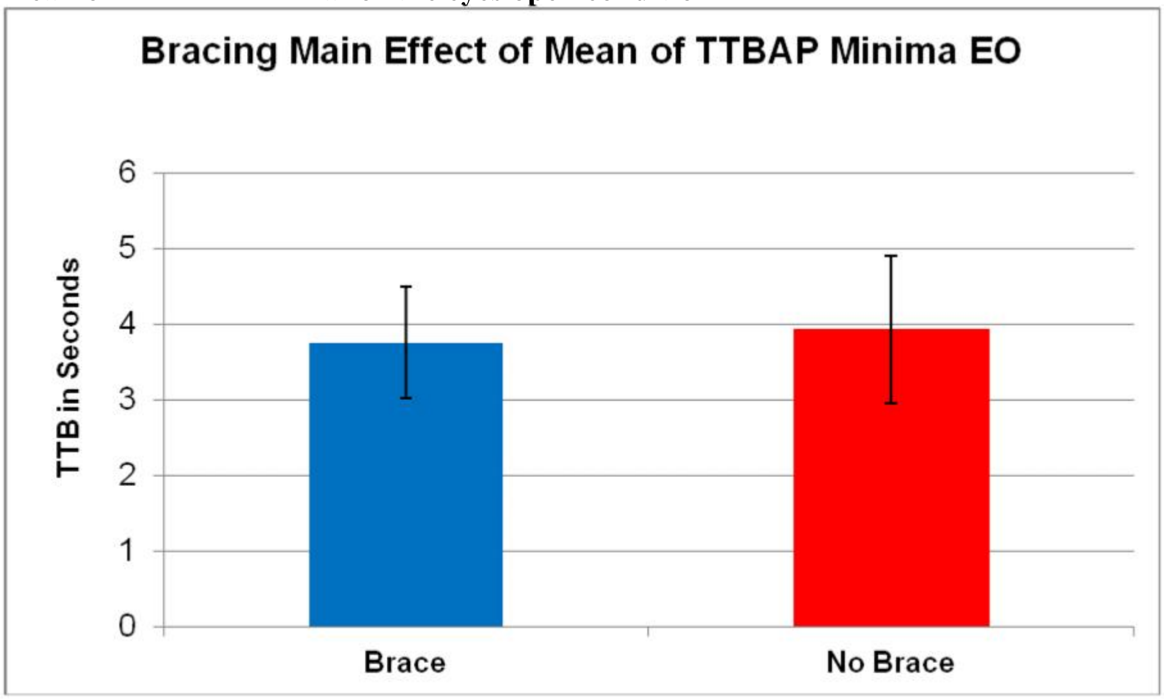


Figure 8: Means and standard deviation error bars for the fatigue main effect for the mean of the TTBAP minima for the eyes open condition

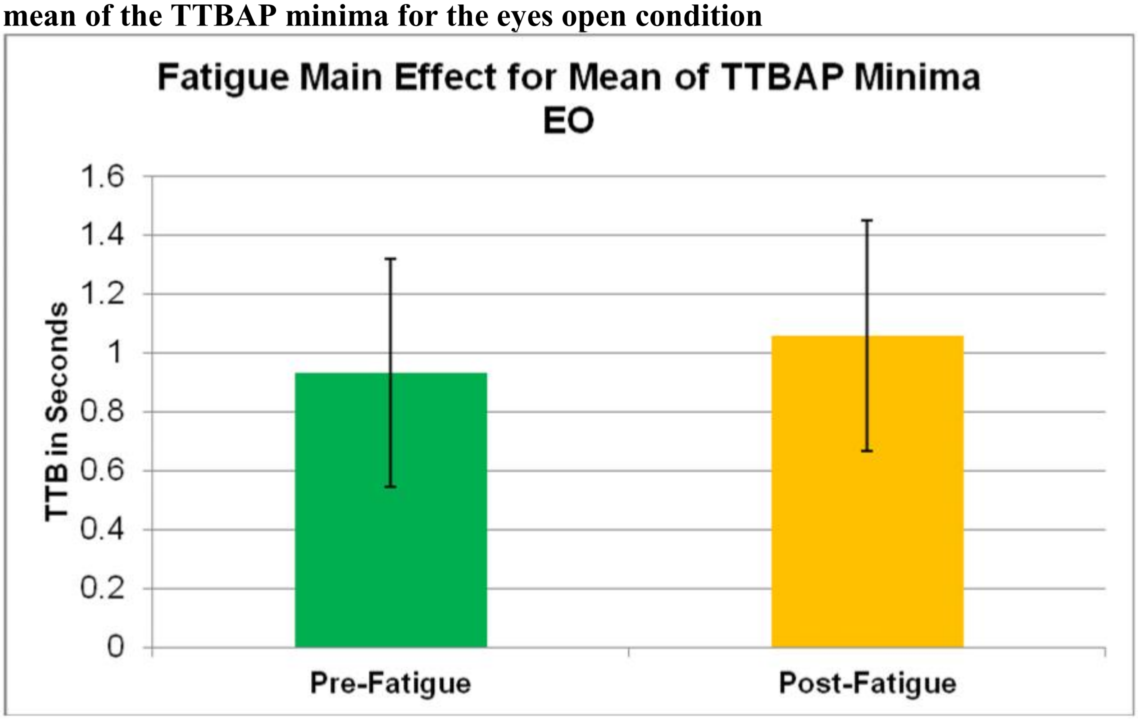


Figure 9: Means and standard deviation error bars for the fatigue main effect of the standard deviation of the TTBML minima in the eyes open condition

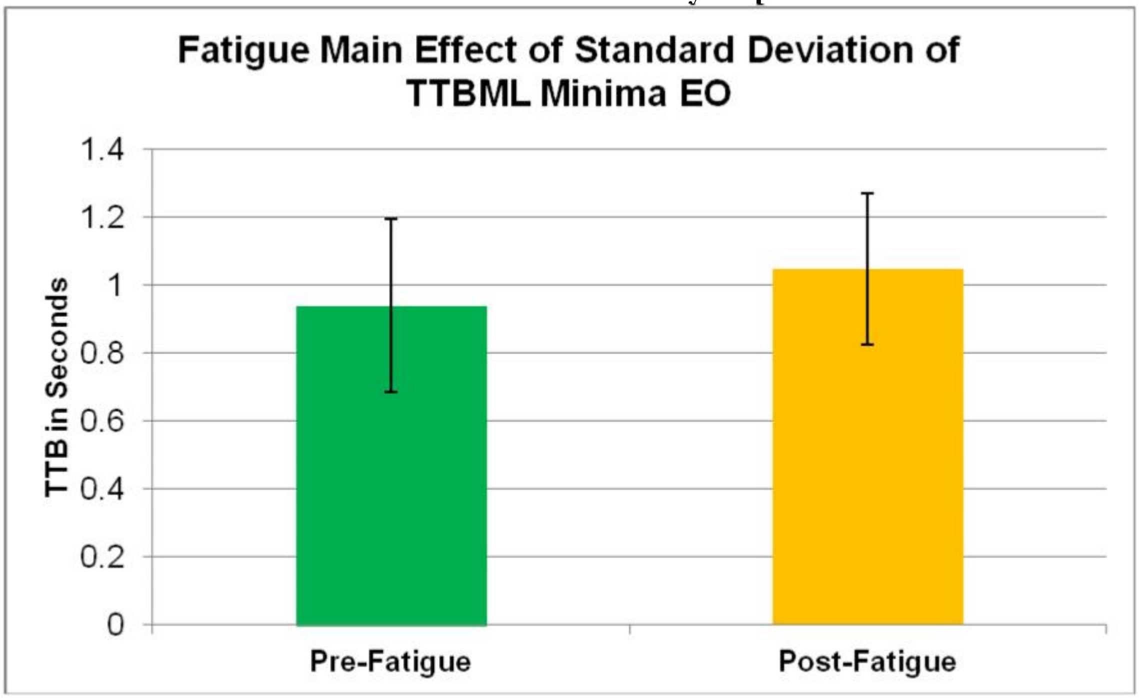


Figure 10: Means and standard deviation error bars for the bracing main effect of the absolute TTBML minima for the eyes closed condition

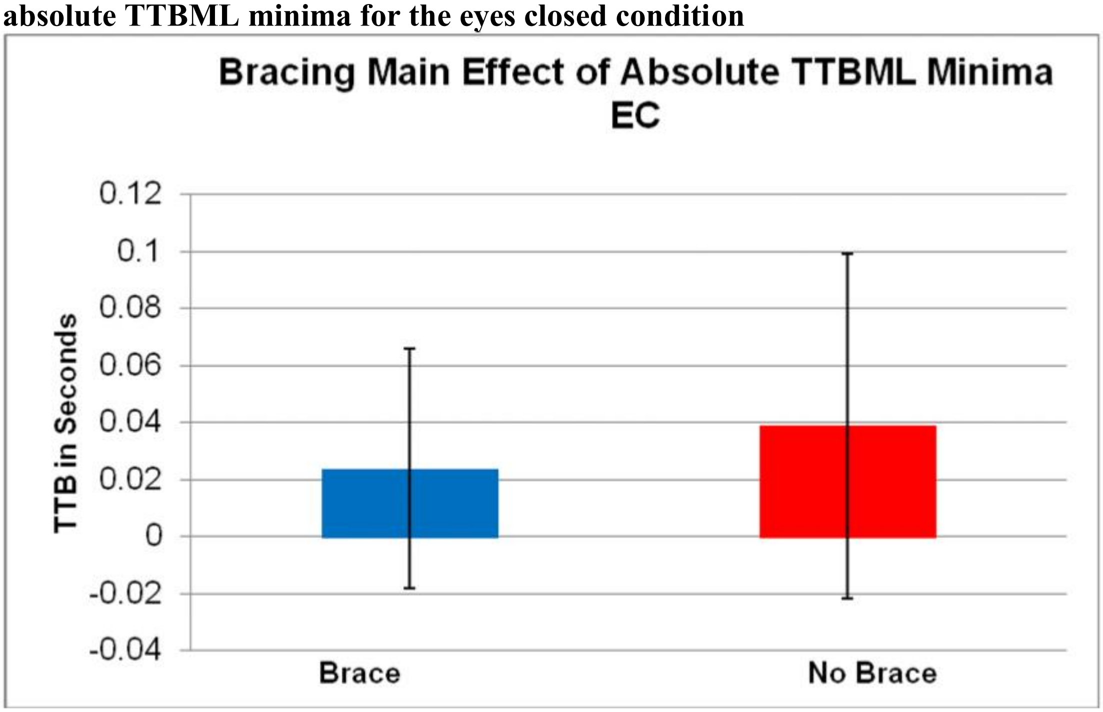


Figure 11:Means and standard deviation error bars for the bracing main effect for absolute TTBAP minima in the eyes closed condition

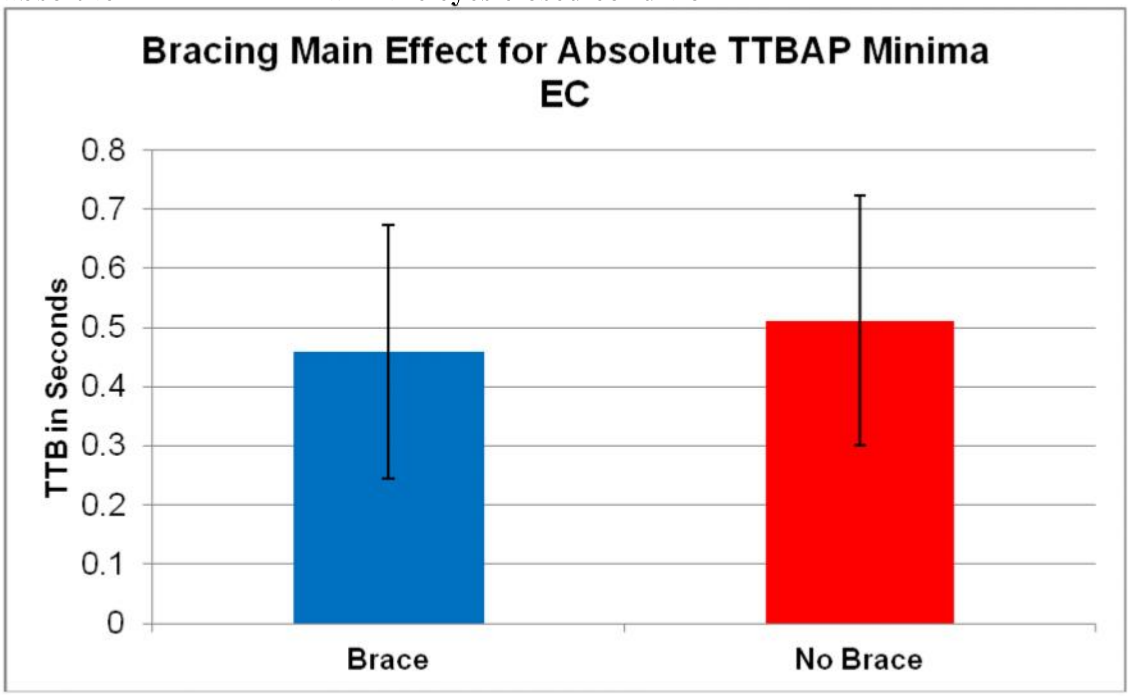


Figure 12: Mean and standard deviation error bars for the bracing main effect for the mean of TTBAP minima in the eyes closed condition

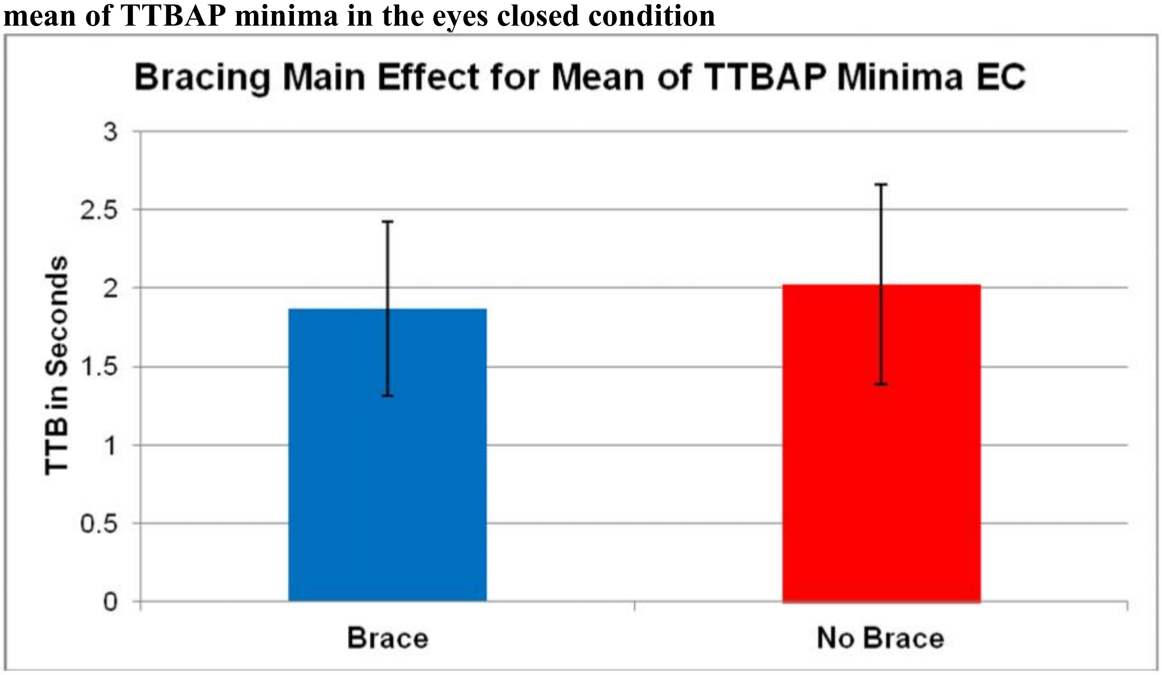


Figure 13: Mean s and standard deviation error bars for the bracing main effect of the standard deviation of TTBML minima in the eyes closed condition

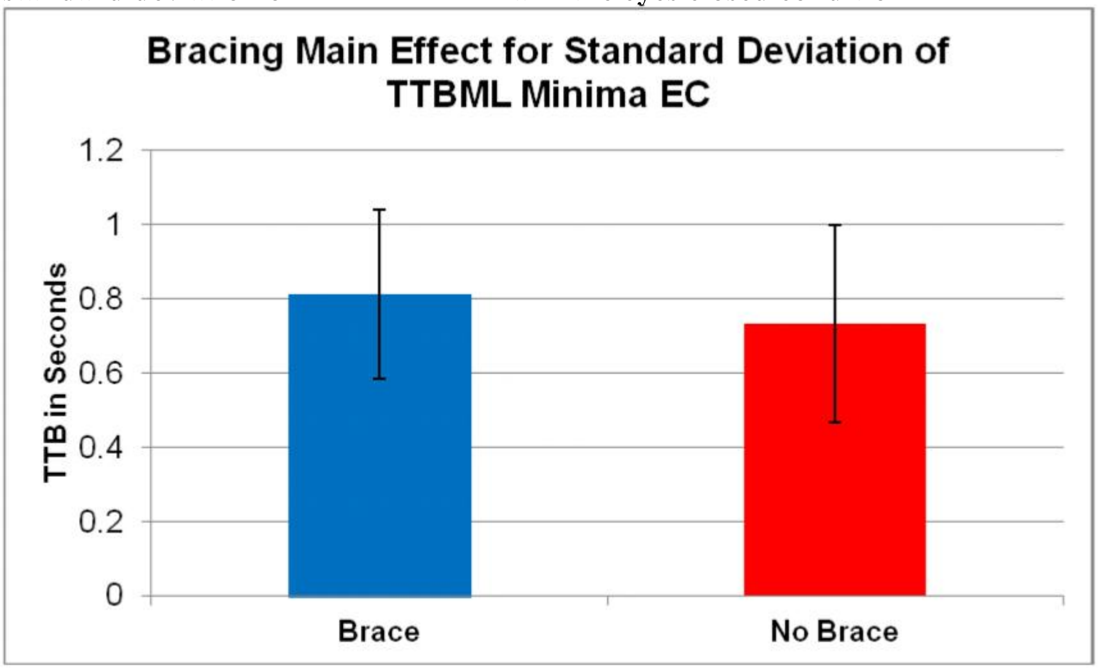
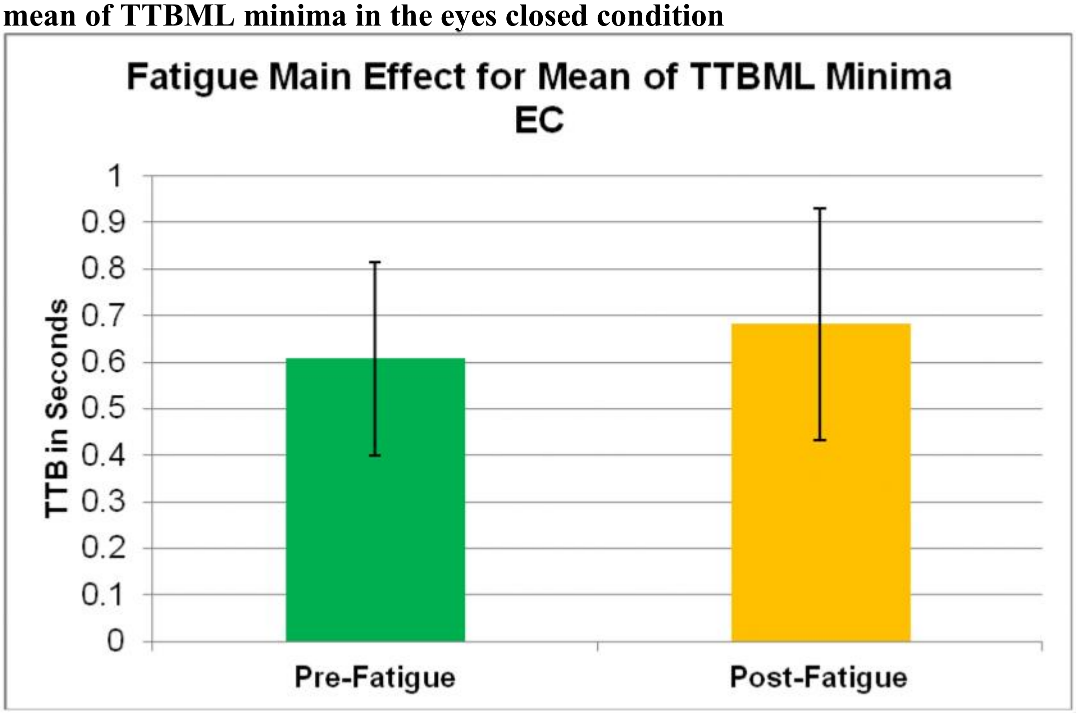


Figure 14: Means and standard deviation error bars for the fatigue main effect of the mean of TTBML minima in the eyes closed condition



Appendix A:Screening and Demographics Form

Do you participate in physical activity at least 3 times a week for a minimum of 30 minutes per session?	Yes / No
Do you have a history of a concussion or vestibular condition that has affected your balance?	Yes / No
Have you suffered an ankle sprain in the last year that resulted in a feeling of the ankle giving way?	Yes / No
Have you participated in any ankle rehabilitation in the past six months?	Yes / No

Subject number: _________________

Age: _________________

Sex: □ Male □ Female

Height: _________________

Weight: _________________

Unstable ankle: □ Right □ Left

Appendix B: Touchdown Form

Subject Number ______ Date ____________ Testing Condition ____________________

Testing limb ___________ Test/Control

Pre-Fatigue

Trial Number	Vision	Touchdowns
1		
2		
3		
4		
5		
6		

Post-Fatigue

Trial Number	Vision	Touchdowns
1		
2		
3		
4		
5		
6		

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