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Mechanical ankle instability: relationship with active joint position sense

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RELATIONSHIP WITH ACTIVE JOINT POSITION SENSE

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MASTER'S THESIS

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Abstract

Current research defines chronic ankle instability (CAI) as the combination of mechanical ankle instability (MAI) and functional ankle instability (FAI). Previous research has found individuals with CAI and FAI to have deficits in proprioception, more specifically joint position sense (JPS). The purpose of this study was to examine the relationship between MAI and active JPS. Twelve participants (5 male, 7 female) were selected for this study based upon their subjective ankle instability as assessed by a score on the Cumberland Ankle Instability Tool (CAIT) and objective ankle instability as assessed by measurements taken using a portable ankle arthrometer. Eligible participant's absolute error in JPS was assessed as a non-weight bearing, active-to-active joint replication, and measured with a Biodex System 3 dynamometer. The absolute error of each joint angle replication was averaged after a reliability analysis. Statistical analysis had planned on using a 2x2 and a 2x3 factorial ANOVA. The research question could not be assessed in the frontal and the sagittal plane. The pilot study showed that there was a population of individuals with unilateral MAI exclusive of functional ankle instability (FAI).

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Chapter 1

Introduction

One third of all participants in physical activity will experience a sports-related injury (Conn, Annest, & Gilchrist, 2003; Mitchell, Finch, & Boufous, 2010; Schneider, Seither, Tonges, & Schmitt, 2006). The lower extremity is the most commonly injured extremity with an ankle injury being the most common type of injury sustained overall (Agel, Evans, Dick, Putukian, & Marshall, 2007; Conn et al.). The complex anatomy of the ankle lends itself to injury. The lateral malleous protrudes more distally than the medial malleous guiding the foot into an inverted position. This position of inversion and plantar flexion is the most common mechanism for an ankle sprain (Konradsen, 2002; Wright, Neptune, van den Bogert, & Nigg, 2000).

Most individuals suffering an acute ankle injury will either self-treat or receive no treatment at all, and adequate healing often does not occur (Hertel, 2002; Mitchell et al., 2010). Hubbard & Cordova, (2009) and Hubbard & Hicks-Little, (2008) indicated that it takes at least eight weeks after an acute ankle sprain before there is a significant decrease in mechanical 'laxity' regardless of the rehabilitative efforts (Hubbard & Cordova, 2009; Hubbard & Hicks-Little, 2008). Laxity is the stretching of connective tissue beyond its physiological limits (Liu, Siegler, & Techner, 2001). If an individual returns to activity without enough time for adequate healing to occur, then they become subject to long term complications (Freeman, 1965; Hertel; Holder-Powell & Rutherford, 2000; Kynsburg, Halasi, Tállay, & Berkes, 2006).

One of the complications that may occur is long-term instability within the ankle joint (Freeman, 1965). After an initial ankle sprain, 60% of individuals will experience repetitive sprains (Freeman). The phenomena of a sudden tendency for an individual to frequently sprain an ankle is termed ankle instability (Brown, Ross, Mynark, & Guskiewicz, 2004; Freeman; Hale & Hertel, 2005; Hiller, Refshauge, Bundy, Herbert, & Kilbreath, 2006). An individual is classified as having chronic ankle instability (CAI) if he or she has experienced frequent ankle sprains, if there is a sensation of 'giving way' with functional activity, and if there is a presence of pain and weakness within the ankle joint (Brown, Padua, Marshall, & Guskiewicz, 2008; Hertel, 2002; Hubbard, Kramer, Denegar, & Hertel, 2007; Monaghan, Delahunt, & Caulfield, 2006; Sefton et al., 2009). Chronic ankle instability is composed of a functional and a mechanical aspect (Brown et al., 2008; Brown Padua, Marshall, & Guskiewicz, 2009; Hubbard et al.). The functional aspect, or functional ankle instability (FAI), is described as frequent sprains and 'giving way' with physical activity without the presence of a mechanical 'laxity' within the ankle joint (Lee & Lin, 2008; Yokoyama, Matsusaka, Gamada, Ozaki, & Shindo, 2008). The mechanical aspect, or mechanical ankle instability (MAI), is physiological looseness within the ankle joint (Brown et al., 2008; Brown et al., 2009).

A mechanical ‘laxity’ in the ankle places an individual at higher risk for injury (Decoster, Bernier, Lindsay, & Vailas, 1999). Laxity within the foot changes how pressure is absorbed within the foot, and it is suggested that this changes the mechanical advantage of the peroneus longus causing less eversion (Barber Foss, Ford, Myer, & Hewett, 2009; Leduoux & Hillstrom, 2002). Brown et al. 2008 examined the mechanics of individuals with MAI compared to those with FAI and those without any instability. During gait, step-down, and drop jump, individuals with MAI exhibited less motion in the sagittal plane and an increased motion in the frontal plane in comparison to those with

FAI and no instability (Brown et al.). The findings in the 2008 study prompted the same authors to do a follow-up study examining the mechanics of those with MAI, FAI, and no instability during a more complex jump-stop maneuver. The results of the 2009 study further supported their initial findings: individuals with MAI exhibited less motion in the sagittal plane and more motion in the frontal plane than those with FAI or no instability (Brown et al., 2009). These findings support what Hubbard, Kaminski, Vander Giend, & Kovaleski stated in 2004, that it is important to distinguish a mechanical instability with frequent ankle sprains in order to understand the underlying cause of the CAI. Further, these findings suggest that MAI and FAI should be distinguished, separate experimental groups in all future studies about CAI.

Despite the support to understand mechanical instability in those with CAI, there is limited research that separates out and examines the mechanical aspect of ankle instability (Brown et al., 2008; Brown et al., 2009; Hubbard et al., 2004). There is potential in research related to proprioception to exclusively investigate mechanical instability. Loss of proprioception has been linked to individuals with CAI and FAI (Forkin, Koczur, Battle, & Newton, 1996; Konradsen & Magnusson, 2000; Liu, Jeng, & Lee, 2005). However, there is a gap within the literature about the effects of MAI on proprioception.

Proprioception is a sensory system that regulates muscle action and contributes to overall joint stability (Refshauge, 2003). After an initial injury there is damage to the surrounding ligaments. Freeman, Dean, & Hanham (1965), hypothesized that this ligamentous injury also damages the surrounding joint mechanoreceptors leading to overall joint deaffernation. Joint afferents are important contributors to overall proprioceptive awareness, and Freeman et al.'s hypothesis of the cause of proprioceptive deficits after an initial injury is commonly accepted in current literature. Recent researchers have used joint position sense (JPS) as a way to assess overall proprioception (Liu et al., 2005; Payne, Berg, & Latin, 1997; Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002). Joint position sense is an individual's awareness of a particular joint in relation to the surroundings without the assistance of sight. For example, it is how an individual would know if his/her foot was in a dorsiflexed or plantar flexed position without looking. Deficits in proprioception can be evaluated through deficits in JPS (Ghani Zadeh Hesar, Calders, Thijus, Roosen, & Witvrouw, 2008; Liu et al.; Payne et al.).

Compromised JPS is an important contributor to injury occurrence (Payne et al., 1997; Willems, Witvrouw, Delbaere, Philippaerts, De Bourdeaudhuij, & De Clercq, 2005). Payne et al., followed multiple sports teams for a nine week season. At the beginning of the season, each athlete's JPS was evaluated, and the authors kept track of the frequency of ankle injury throughout the season. The results showed that there was a higher ankle injury rate in individuals with an increase in JPS error. Payne et al., concluded that deficits in JPS could be a predictor of ankle sprains before they occur. When evaluating JPS in individuals with CAI and FAI, several authors found an increase in JPS error in those with CAI and FAI compared to those without any instability (Konradsen & Magnusson, 2000; Liu et al., 2005; Willems et al., 2002; Yokoyama et al., 2008). Despite the support of an increase in JPS error in those with CAI and FAI, no one has evaluated MAI with respect to JPS.

Current literature defines CAI as a combination between FAI and MAI. Functional ankle instability is generally accepted to be the occurrence of frequent sprains and sensations of giving way with activity. Mechanical ankle instability is known as the physiological looseness within the ankle joint. Current literature links both CAI and FAI to deficits in JPS, and yet no authors have evaluated the JPS of those with MAI. Therefore, the purpose of this study was to examine the relationship between MAI and active JPS.

Operational Definitions

Joint position sense (JPS).

Measured as the absolute error in active joint position sense.

Absolute error.

The absolute difference between a known joint angle, and an individual's perception of that joint angle, measured in degrees.

Chronic ankle instability (CAI).

The combination between functional and mechanical ankle instabilities.

Functional ankle instability (FAI).

The occurrence of repetitive ankle sprains without the presence of a mechanical instability indicated by a score of 27 or lower on the Cumberland Ankle Instability Tool (CAIT) questionnaire (Hiller et al., 2006).

Mechanical ankle instability (MAI).

Current literature defines MAI as: "physiologic laxity at the ankle joint following severe or repeated lateral ankle sprains" (Brown et al., 2009). For the purpose of this study, we defined MAI as the presence of a physiological laxity (at least 1 mm anterior/posterior displacement, or 1^{o} inversion/eversion rotation) within the ankle joint without the presence of a functional instability (as indicated by a score of 28 or higher on the CAIT).

Hypothesis

It was hypothesized that individuals with mechanical ankle instability would have a significant increased error in active JPS than individuals with stable ankles in both the sagittal plane and frontal plane.

Assumptions, Delimitations, and Limitations

It was assumed that individuals were truthful on the subjective questionnaires and health history. If the participant was not truthful when filling out the health questionnaire, they may have had exclusion criteria and yet still been included in the present study. If participants were not truthful completing the CAIT (Hiller et. al, 2006), they may have been included or excluded in the present study under false assumptions. It was also assumed that the participants were motivated to engage in the present study. If the participant was not motivated, then he/she may not have given full effort when trying to actively replicate JPS, causing an increase in JPS error due to the lack of motivation, not the presence of MAI. It was assumed that individuals did not consume alcohol, or another controlled substance before JPS testing. These substances impair balance and inhibit motor control, since balance and motor control are import contributing factors to proprioception and proprioception can be evaluated through JPS, there is a chance that an outside substance could affect an individual's JPS.

The sample was delimited to individuals with unilateral MAI, not FAI or CAI. This study assessed only MAI due to the lack of distinction within the existing literature related to ankle instability. This study was further delimited to individuals between the ages of 18 and 39 years. This age group was chosen because JPS decreases with an increase in age, and after the age of 39 years, individuals have greater error in active JPS (Deshpande, Connelly, Culham, & Costigan, 2003; Kaplan, Nixon, Reitz, Rindfleish, & Tucker, 1985).

The limitations of this study were based upon the delimitations. Since this study only evaluated individuals with MAI, the results of this study cannot be applied to individuals with CAI or FAI. Because this study evaluated individuals between the ages of 18 and 39 years, the results of this study cannot be applied to anyone with MAI outside of this age group. Some authors believe that there are two parts to proprioception, kinesthesia and JPS (Deshpnade et al., 2003). Since this study only measured JPS, the results of this study cannot be applied to overall proprioception. Furthermore, there are two types of JPS, active and passive. Since JPS was evaluated with an active replication, the results of this study may only be applied when addressing active JPS.

Significance

If the data supports the hypothesis, then there are practical implications for the general population who already self-treat or receive no treatment at all after an injury. The work of Lee and Lin (2008), showed that a 12 week treatment on a BAPS board increases JPS. If individuals with MAI have an increased error in JPS then there is more evidence that a proper intervention (rehabilitation) would be necessary after an injury before returning to activity.

This study also has implications for an athletic population already receiving proper treatment. If the data supports the hypothesis, then this study would provide a greater knowledge base for health care professionals when making decisions about taping and bracing after an initial injury. Spanos, Brunswic, and Billis (2007), measured the effects of prophylactic taping on JPS after an initial injury. These authors found that there was an improved JPS with the application of prophylactic taping. If the data supports the hypothesis, it would also add to the knowledgebase for health care professionals when making decisions for injury prevention. If individuals with MAI have error in JPS, then a healthcare provider may decide to place someone with MAI on a preventative exercise program or apply taping or bracing before an ankle injury occurs.

Some authors already support the need to distinguish individuals with MAI separately from FAI. If there is a greater deficit in JPS compared to healthy controls, then there is further implication that MAI should be classified separately from FAI (Brown et al., 2008; Brown et al., 2009; Hubbard et al., 2004). This would suggest that MAI should be a separate experimental group from FAI or CAI on all ankle instability studies. Also, if the hypothesis of this study is supported by the data then there may be a need to distinguish MAI as a separate experimental group during future studies on JPS. If individuals with MAI have increased error in JPS, then they may also have a deficit in other aspects of proprioception. Further studies should then be performed to determine the role of proprioception in individuals with MAI.

Chapter 2

The purpose of the current study was to examine the relationship between mechanical ankle instability (MAI) and active joint position sense (JPS). Chapter two will review the current literature in the following areas: injury, ankle instability, and neurological proprioception.

Injury

Participation in physical activity and exercise can lead to injury (Conn et al., 2003; Mitchell et al., 2010; Schneider et al., 2006). One third of participants will experience a sports-related injury resulting in 7 million sports-related injuries per year (Conn et al.; Mitchell et al.). Sports-related injuries can affect other aspects of life, for example, at least 25% of injuries require time off from school or work (Conn et al.; Schneider et al.).

After an injury, most people either self-treat or receive no formal treatment for their injuries (Mitchell et al., 2010). If an injury is not treated correctly, it can lead to problems later in life (Holder-Powell & Rutherford, 2000; Hubbard, Hicks-Little, & Cordova, 2009). Holder-Powell & Rutherford found that if an injury is not properly rehabilitated then balance remains impaired and will not return to the same stabilization as the uninjured limb. An untreated injury can also lead to problems such as osteoarthritis: individuals with ankle osteoarthritis have difficulties later in life with greater stiffness, less strength, and subjectively less function than healthy individuals (Hubbard et al.). Performance after an injury is also affected, and individuals subjectively perceive their performance as inadequate as long as 13 years after an injury (Munk, Holm-Christensen, & Lind, 1995). The lower extremity is the most commonly injured, with the lower leg and ankle being the most commonly injured body part (Conn et al., 2010).

Ankle injury.

Of all reported injuries, the most common type of injury is a sprain/strain (Conn et al., 2010; Schneider et al., 2006). The ankle is a complex joint whose anatomical characteristics lend itself to injury. The lateral malleolus protrudes more distally than the medial malleolus, making the loose packed position of inversion and plantar-flexion a common mechanism for an ankle sprain (Wright et al., 2000). The ankle complex is composed of two joints: the talocrural joint and the subtalar joint. The talocrural joint--comprised of the boney structures of the talus, tibia, and fibula--is responsible for the movement of dorsiflexion and plantarflexion. The subtalar joint--comprised of the boney structures of the talus and calcaneus--is responsible for the movement of inversion and eversion, and combines with the talocrural joint and midtarsal joints to perform pronation and supination.

The lateral ankle sprain is the most common ankle injury (Agel et al., 2007). After the initial sprain, most individuals will experience repetitive acute ankle sprains (Freeman, 1965). These repetitive acute injuries can lead to chronic injuries such as ankle osteoarthritis, osteochondritis dissecans, or chronic ankle instability (Freeman; Hubbard et al., 2009).

Ankle Instability

After an initial ankle sprain, the ankle is unstable due to acute tissue damage (Hertel, 2002). Current research has been devoted to the healing process in the ankle (Hubbard & Cordova, 2009; Hubbard & Hicks-Little, 2008). Hubbard & Hicks-Little found it takes at least 6 weeks before a ligament can heal. With a natural recovery, there is still a significant increase in mechanical ‘laxity’ at least 8 weeks after the initial ankle sprain (Hubbard & Cordova; Hubbard & Hicks-Little). Severe acute laxity after an ankle sprain is treated by immobilization of the ankle through the use of crutches, a walking boot or cast and, in severe cases, surgery (Freeman, 1965; Freeman et al., 1965; Munk et al., 1995). Many people self-treat after the initial injury and underestimate the amount of time required for proper healing to occur (Hertel; Mitchell et al., 2010). If the ankle is not treated with proper rehabilitation or an individual returns to activity too soon after the acute injury, then that individual is at risk for long-term ankle instability (Freeman, 1965; Hertel; Kynsburg et al., 2006).

Ankle instability generally includes 3 indicators: frequent ankle sprains, sensations of ‘giving way’, and pain or weakness in the joint (Brown et al., 2004; Freeman, 1965; Hale & Hertel, 2005; Hiller et al., 2006). The use of specific terms to identify the types of ankle instability within the literature, however, lacks consistency. Some authors refer to ankle instability as chronic functional ankle instability (Kynsburg et al., 2006; Yokoyama et al., 2008). Other authors do not define a type of instability and only refer to the condition as a recurrent ankle sprain (de Jong et al., 2005). Some authors will use one type of ankle instability in the title of the research article, only to use a different term to describe ankle instability within the text (Hiller et al., 2006; Willems et al., 2005; Yokoyama et al.). For the purpose of this literature review, our focus will remain on those terms most widely used: chronic ankle instability (CAI), functional ankle instability (FAI), and mechanical ankle instability (MAI).

Chronic ankle instability (CAI).

CAI is described within the literature as recurrent sprains and a subjective sensation of 'giving way' after the initial injury (Monaghan et al., 2006; McKeon et al., 2009; Sefton et al., 2009). CAI is frequently described as a combination of functional instability and mechanical instability (Brown et al., 2008; Hubbard et al., 2007; Hertel, 2002; Monaghan et al.; Sefton et al.). Functional instability is the subjective sensation of 'giving way' with physical activity (Lee & Lin, 2008; Yokoyama et al., 2008). Mechanical instability is described as a physiological "looseness" within the joint (Brown et al., 2008; Brown et al., 2009). When using the term CAI, authors highlight the functional instability and ignore the mechanical aspect. To be described as having CAI, an individual needs to meet certain criteria including: a correlating score on associated surveys, repetitive sprains (at least three), 'giving way' with activity, and difficulty performing functional tasks (Brown et al., 2008; Hubbard et al.; Monaghan et al.; Sefton et al.). Several authors often do not assess the mechanical instability, but still classify individuals as having CAI if they meet the above criteria (Forkin et al., 1996; Monaghan et al.; Willems et al., 2002). No authors have required all subjects to have mechanical instability to be classified as having CAI.

Functional ankle instability (FAI).

Another term used to describe the phenomena of repetitive ankle sprains is functional ankle instability (FAI) (Brown et al., 2004; Freeman, 1965; Freeman et al., 1965; Lee & Lin, 2008). Freeman first described the condition of FAI in 1965. Freeman (1965) listed several possible causes of FAI including: deficits in proprioception, joint adhesion formation, and mechanical instability. Further research has included other potential causes of FAI including: strength deficits, longer time to stabilization, and altered gait mechanics (Brown et al., 2004; Brown et al., 2008; Lee & Lin, 2008; Lin et al., 2008). Research is still inconclusive about one specific underlying cause of FAI (Hertel, 2002). FAI has changed from the original definition to exclude mechanical laxity (De Noronha, Refshauge, Kilbreath, & Crosbie, 2007; Kidgell, Horvath, Jackson, & Seymour, 2007; Lee & Lin; Yokoyama et al., 2008). Subjects classified as having FAI are described as having repetitive ankle sprains, a sensation of 'giving way' with functional activity, no history of a fracture, and no existing mechanical laxity (Lee & Lin; Yokoyama et al.).

Mechanical ankle instability (MAI).

Another distinct type of ankle instability is mechanical ankle instability (MAI) (Brown et al., 2008; Brown et al., 2009; Hubbard et al., 2004). Mechanical instability is often used in conjunction with the term 'laxity' (Hertel, 2002). Laxity, also known as mechanical laxity, is described as the stretching of connective tissue past its physiological limit (Liu et al., 2001). Mechanical 'laxity' in the ankle can be assessed using manual tests, or with the use of an ankle-specific arthrometer (Hubbard et al., 2004; Kovaleski, Hollis, Heitman, Gurchiek, & Pearsall, 2002). Ankle stress tests such as the anterior drawer, inversion talar tilt, and eversion talar tilt yield excessive motion when there is ligamentous laxity in the anterior talofibular ligament, calcaneofibular ligament, posterior talofibular ligament, or medial deltoid ligaments (Brown et al., 2008; Brown et al., 2009; Hubbard & Hicks-Little, 2008). Ankle arthrometers apply a consistent external load to the ankle to quantify the rotational laxity associated with inversion and eversion and the displacement associated with an anterior and posterior force (Hubbard et al., 2004; Liu et al., 2001). This laxity may be congenital, caused by an acute injury, or chronic from repetitive damage over time (Freeman, 1965).

In an otherwise healthy, symptom-free ankle, an increase in laxity changes how pressure is absorbed by the foot (Barber Foss et al., 2009). Midfoot pressure becomes greater compared to those who do not have an increased laxity (Barber Foss et al.). Midfoot pressure also changes the mechanical advantage of the peroneus longus muscle causing a strength decrease in eversion (Barber Foss et al.; Ledoux & Hillstrom, 2002). Laxity is a contributing factor to injury: athletes with an increase in mechanical laxity have a higher rate of injury to the ankle (Decoster et al., 1999). When there is an increase in laxity, that joint is considered mechanically instable. Ankles can also be classified as having MAI if there are degenerative or synovial changes within the joint causing an increase in range of motion (Hubbard et al., 2004).

Although there is a debate within the literature about different classifications of ankle instability, current literature has separated MAI into its own category. Based upon an investigation of functional skills, Hubbard et al., 2007 stated that FAI and MAI are not completely separate and should be assessed together. Conversely, Brown et al. (2008) has shown there to be a difference in the gait pattern of individuals with MAI compared to FAI. In a follow up study, Brown et al. (2009) further shows individuals with MAI have biomechanical differences during a jump stop. In support of classifying MAI separately from FAI, Hubbard et al. (2004) stated that it was important to distinguish a mechanical instability in ankles with recurring sprains in order to better understand the cause of the overall ankle instability. Research has been devoted to determining the underlying pathology of ankle instability. Individuals with ankle instability have been found to have a deficit in neurological proprioception.

Neurological Proprioception

When first addressing the idea of ankle instability, Freeman (1965) cited a lack of proprioception as a potential cause. Proprioceptive deficits are also a valuable predictor of ankle injury (Payne et al., 1997). Proprioception is a sensory system used to help regulate muscle action and contributes to joint stability (Refshauge, 2003). A deficit in proprioception can lead to impairment in other aspects of functional movement such as gait (Payne et al.; Willems et al., 2005). Individuals with ankle instability have been shown to have altered kinematics while walking and running compared to healthy controls (Brown et al., 2008; Brown et al., 2009; Drewes et al., 2009). Compared to healthy controls, individuals with ankle instability position the foot with significantly more internal rotation during the terminal swing phase of gait and at the initial contact (Drewes et al.; Monaghan et al., 2006). Joint coupling is also altered: there is variability in the coupling of rear foot movement and shank rotation in individuals with ankle instability (Drews et al.; McKeon et al., 2009). A deficit in proprioception affects the perception of foot position in individuals with ankle instability (Konradsen, 2002; Willems et al.). The position of the foot right before heel strike and other kinematic differences place individuals with ankle instability at a higher risk for repetitive sprains (Brown et al., 2008; Drews et al.; Willems et al.).

Freeman, Dean, & Hanham's (1965) original hypothesis about the cause of proprioceptive deficits remains accepted in the current literature (Deshpande et al., 2003; Lee & Lin, 2008). This hypothesis states that damage to the lateral ligament also causes a disruption to the surrounding mechanoreceptors leading to joint deafferentation. Joint afferents are large contributors to overall proprioception and this proposed disruption results in impaired proprioception. Proprioception can be further broken down into two parts: kinesthesia and joint position sense (JPS) (Hertel, 2002; Holmes & Delahunt, 2009; Lee & Lin). Some researchers state both sensations need to be assessed to declare an overall proprioceptive deficit (de Jong et al., 2005; Refshauge, 2003), yet most other researchers are more liberal in the definition, and a deficit in either kinesthesia or JPS is sufficient to declare an overall proprioceptive deficit (Forkin et al., 1996; Hertel; Liu, Jeng, &Lee, 2005; Willems et al., 2002).

Kinesthesia.

Kinesthesia is the ability to detect motion through movement sense and discrimination (Deshpande et al., 2003; de Jong et al., 2005). This is an important aspect of proprioception because a disruption in sensory input would change how an individual responds to an unstable surface by making postural adjustments through reflexes and motor control (Forkin et al., 1996). When assessing kinesthesia, a passive movement is applied to the foot. To determine movement sense, the participant must inform the researcher when that movement was felt (Deshpande et al.; Forkin et al.). To determine movement discrimination, the participant must inform the researcher of the direction to which the movement occurred (Deshpande et al.; de Jong et al.). Movements can be applied to the ankle in plantar flexion, inversion and plantar flexion, or inversion and eversion (Deshpande et al.; Forkin et al.; de Jong et al.; de Noronha et al.).

When assessing kinesthesia in relation to ankle instability, there are mixed results (de Jong et al., 2005; Forkin et al., 1996; de Noronha et al., 2007). De Noronha et al. did not find a significant deficit of kinesthesia for people with ankle instability. However, de Jong et al. found unstable ankles had a small deficit in detecting active movement discrimination, but not in passive movement detection. Forkin et al. also found a deficit in kinesthesia for active individuals with ankle instability. A more applicable way to assess proprioception and ankle instability is by assessing JPS because of the importance of foot and ankle position during gait (Konradsen, 2002; Willems et al., 2005; Wright et al., 2000).

Joint position sense (JPS).

Joint position sense (JPS) is an individual's perception of the arrangement of a joint in relation to the surroundings (Holmes & Delahunt, 2009). A deficit in JPS is described as an error in joint angle replication. There are three types of error in JPS: constant error, variable error, and absolute error (Willems et al., 2002; Yokoyama et al., 2008). Constant error is the directional difference of the perceived angle from the reference angle. A positive number represents an overestimation and a negative number denotes an underestimation (Konradsen & Magnusson, 2000; Yokoyama et al.) Variable error is the standard deviation from the constant error; it shows the variation in error indicating random error (Willems et al.). Absolute error is the absolute difference from the perceived angle to the reference angle (Brown et al., 2004; Ghani Zadeh Hesar et al., 2008; Kynsburg et al., 2006; Lee & Lin, 2008). When determining error in relation to ankle instability, only three previous authors have differentiated between the types of error (Konradsen & Magnusson; Willems et al.; Yokoyama et al.), while most other authors measure just the absolute error (Brown et al., 2004; Ghani Zadeh Hesar et al.; Kynsburg et al.; Lee & Lin; Liu et al., 2005).

JPS is more accurate when assessed in a weight bearing position due to an increase in muscle involvement over multiple joints. A weight bearing position increases articulation causing a stimulation of more mechanoreceptors responsible for proprioceptive awareness (Harrington, 2005; Stillman & McMeeken, 2001). Although a weight bearing assessment leads to less error, a non-weight bearing assessment is more applicable to gait when assessing JPS in relation to ankle instability (Konradsen, 2002; Willems et al., 2005). During the terminal swing phase of gait, the foot is not in contact with the ground therefore there is not additional stimulation of mechanoreceptors and JPS needs to be assessed in a non-weight bearing position (Liu, Jeng, & Lee, 2005; Konradsen; Spanos et al., 2008; Yokoyama et al.). Errors in JPS can be evaluated through passive joint angle replication or active joint angle replication (Brown et al., 2004; Liu, Jeng, & Lee; Sefton et al., 2009).

Passive JPS.

Passive ankle joint angle replication is assessed when a participant is placed in a reference angle the verbally instructs the researcher about the perception of the reference angle to determine error (Brown et al., 2004; Kynsburg et al., 2006; Lin et al., 2008; Yokoyama et al., 2008). Current literature is conflicted about the relationship between passive JPS and ankle instability (Sefton et al., 2009). Brown et al. (2004), assessed JPS in individuals with ankle instability only with passive JPS and found no difference between healthy ankles and unstable ankles. Willems et al. (2002), assessed JPS in individuals with ankle instability with both an active and passive JPS and found no difference in passive JPS. Liu, Jeng, & Lee (2005), also assessed JPS in individuals with ankle instability using both an active and passive JPS and did find significantly more error with passive JPS in unstable ankles. Yokoyama et al., 2008 found significant error in passive JPS only in the sagittal plane. Conflicting results with a passive joint replication and ankle instability may be because an active joint replication is more applicable to the proposed biomechanical mechanism for repetitive ankle injuries (Brown et al., 2004; Konradsen, 2002; Wright et al., 2000).

Active JPS.

During the crucial terminal swing phase of gait, an individual must actively position the foot to ensure proper contact with the ground (Konradsen, 2002; Wright et al., 2000). If there is an error in active JPS, then an individual may unknowingly place the foot in a vulnerable position for ankle sprains (Knoradsen; Willems et al., 2005; Yokoyama et al., 2008). Active JPS is assessed by the participant being shown a specific joint angle, and then the participant must actively replicate the reference angle to determine error (Liu et al., 2005; Payne et al., 1997; Sefton et al., 2009).

Most current literature supports an error in active JPS in relation to ankle instability (Hertel, 2002). Sefton et al. (2009), assessed different factors found in the literature to predict ankle instability and determined that, compared to healthy controls, individuals with ankle instability did not have an increase in active JPS error. Payne, Berg, & Latin (1997), found that when there was an active JPS error, that individual had a higher ankle injury rate. Liu, Jeng, & Lee (2005) and Willems et al. (2002), assessed both active and passive JPS in individuals with ankle instability, and both studies found in increase in active JPS error for the unstable ankle. Other researchers also support a significant increase in active JPS error in unstable ankles compared to stable controls (Konradsen & Magnusson, 2000). The current literature supports proprioceptive deficits in individuals with CAI and FAI (Forkin et al., 1996; Freeman et al., 1965; Konradsen & Magnusson; Liu et al.; Yokoyama et al., 2008). Despite all the literature about proprioception and ankle instability, proprioception, more specifically JPS, has not been assessed in individuals exhibiting MAI.

Summary

The purpose of this research was to examine the relationship between MAI and JPS. Chapter two has covered the current literature surrounding injury, ankle injury, ankle instability, and neurological proprioception. This literature review has shown that FAI and MAI are two distinctly different types of ankle instability and that CAI is considered a combination of FAI and MAI. This review has also shown a link between proprioceptive deficits and CAI and FAI and yet there is a gap in the literature about the relationship between MAI and proprioception.

Chapter 3

Methods

The purpose of this research was to exam the relationship between mechanical ankle instability (MAI) and active joint position sense (JPS). Chapter three will review the protocol that was used to study this relationship. This review will include a discussion of the participants and their selection, the instrument protocol followed, procedures for gathering the data, and the statistical methods used to analyze the data.

Participants.

A sample size of 13 participants was used for data collection. This sample size fits into the range of most current ankle JPS studies (Brown et al., 2004; Deshpande et al.; 2003; Kidgell et al., 2007; Lee & Lin, 2008). To ensure only MAI was assessed (not CAI or FAI), participants were required to have a bilateral score on the Cumberland Ankle Instability Tool (CAIT) greater than 28, and an increased mechanical laxity in only one ankle as assessed by an ankle arthrometer (Blue Bay Research, Inc., Milton, FL) (Brown et al., 2008; Brown et al., 2009; Hubbard, Kovaleski, & Kaminski, 2003; Liu et al., 2001). Exclusion criteria included a CAIT score of 27 or lower, previous history of lower extremity fracture or surgery, any acute signs of trauma (redness, swelling, or ecchymosis), bilateral instability, any ankle sprain within the past six weeks, or any disease or disorder that may impair neurological or vestibular function (de Jong et al., 2005; McKeon et al., 2009; de Noronha et al., 2007; Wingert, Burton, Sinclair, Brunstrom, & Damiano, 2009; Yokoyama et al., 2008). These criteria were assessed with a pre-participation health questionnaire (Appendix A) administered at the same time as the CAIT (Appendix B).

Participants were recruited from a regional university in the Pacific Northwest. It was a convenience sample of males and females aged 18-39 years. Deshpande et al. (2003), and Kaplan et al. (1985), demonstrated that individuals over 39 years of age have greater error in active JPS. Participants were approached verbally by the researcher. Further, participants were required to have unilateral MAI allowing the participants to serve as their own control. A gender affect did not need to be addressed since the participant served as his/her own control.

Instrumentation.

Functional ankle instability was assessed through the use of the Cumberland Ankle Instability Tool (CAIT; see Appendix B). The CAIT is a reliable and valid measurement for identifying individuals with FAI (Hiller et al., 2006). Validity showed a strong correlation (p =.76) between the CAIT and a previously existing measurement of FAI. Reliability showed the CAIT to have excellent test-retest reliability with an intraclass correlation coefficient of .96 (Hiller et al., 2006). A perfect score of 30 on the CAIT reflects no functional instability in the ankle. An individual is considered to have FAI if they score 27 or lower on the questionnaire, and the lower the score the more severe the ankle instability (Hiller et al., 2006). This instrument was chosen over other ankle instability questionnaires such as the Foot and Ankle Disability Index (FADI), the FADI-sport, or the Ankle Instability Instrument, because of the reliability and validity of the tool, as well as the tool's ability to detect a presence of FAI regardless of the participant's activity level (Docherty, Gansneder, Arnold, & Hurwitz, 2006; Hale & Hertel, 2005; Hiller et al.).

Mechanical instability was established based upon measurements taken with a portable ankle arthrometer (Blue Bay Research, Inc., Milton, FL) (Hubbard et al., 2003; Liu et al., 2001). The portable ankle arthrometer measured total anterior/posterior load displacement in millimeters, and measured total inversion/eversion rotational laxity in degrees of range of motion (Hubbard et al., 2004; Kovaleski et al., 2002). The foot was attached to an adjustable plate with an attached load-measuring handle to apply an external load. There was a reference pad attached to the tibia referred to as the tibial pad. The footplate was attached to the tibial pad by a six degree of freedom (3 rotations and 3 translations) spatial kinematic linkage. Laxity was measured by the relative motion between the ankle arthrometer's footplate and tibial pad as assessed by the spatial kinematic linkage (Hubbard & Cordova, 2009; Hubbard et al., 2003). A computer with an analog-to-digital convertor (National Instruments Corp, Austin, TX) was used to calculate and record the displacement.

The ankle arthrometer has been shown to have a strong relationship between tibial-calacaneal bone motion and arthrometric measurements in both anterior-posterior displacement and internal and external rotation (r=.878, P =.001 and r=.858, P =.001 respectively) (Kovaleski et al., 2002). Intertester and intratester reliability from measurements of an instrumented ankle arthrometer show the portable ankle arthrometer to be reliable with an intraclass correlation coefficient ranging from .80 to .99 (Hubbard et al., 2003). The standard error of measurement of the portable ankle arthrometer was found to be .89 mm for anterior/posterior displacement and .98^{o} for inversion/eversion rotation (Hubbard et al., 2004). In previous research, ankle laxity was established using passive range of motion measurements with an anterior drawer test, talar tilt stress test, and eversion stress test performed by a current clinician (Brown et al., 2008; Brown et al., 2009; Liu et al., 2001). By utilizing an ankle arthrometer, this study had a valid, objective measurement for ankle laxity and produced a more accurate sample of individuals with MAI.

JPS was analyzed using a non-weight bearing active-to-active joint position replication in the frontal and sagittal plane. A Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, New York) with universal foot attachment assessed the absolute error in JPS (Brown et al., 2004; Lee & Lin, 2008; Lin et al., 2008; Willems et al., 2002). The Biodex was chosen because, in the current literature, it is the most common method of assessing JPS in an active-to-active replication (Ghani Zadeh Hesar et al., 2008; Lee & Lin, 2008; Liu et al., 2005; Willems et al., 2002). The Biodex has been shown to be a valid measurement for angular positioning with an intraclass correlation coefficient of .99 (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004). The Biodex was also shown to have reproducible angular position measurements on separate days (intraclass correlation coefficient of .99) (Drouin et al.). The Biodex was calibrated before data collection. As according to the Biodex manual: the researcher used a universal goniometer to manually calibrate talar neutral at the beginning of each test position. Sagittal plane movements were measured with dorsiflexion and plantar flexion; frontal plane movements were measured with inversion. Participants were blindfolded to eliminate visual cues (Ghani Zadeh Hesar et al., 2008; Spanos et al., 2008; Willems et al., 2002; Yokoyama et al., 2008). Participants were also barefoot to reduce cutaneous receptor input and because previous research has shown that the thickness of the sole of a shoe effects the dorsiflexion JPS (Sekizawa, Sandrey, Ingersoll, & Cordova, 2001; Spanos et al.).

Procedures.

The University's Institutional Review Board approved all experimental methods prior to subject recruitment and data collection. Due to the explorative definition of the MAI sample, a pilot study was conducted before official data collection to determine how many individuals have MAI without the presence of a functional instability. Subjects of the pilot study were approached in an education course in the university's Physical Education, Health, & Recreation Department. With permission from the instructor, the researcher explained the purpose and methods of the main study and pilot study. The researcher answered any questions and handed out the informed consent, health and CAIT questionnaires. The students were allowed 24 hours to read over the informed consent form, and complete the questionnaires. The researcher then returned to the class and collected the questionnaires. Participants scoring a 28 or higher on the CAIT were assessed using the ankle arthrometer. Based on findings in the pilot study, classification of having an MAI was changed from an anterior/posterior displacement > 1mm or inversion/eversion rotation >1° to an anterior/posterior displacement > 2.65 mm or inversion/eversion rotation > 6.5° compared to the opposite side. The displacement and rotation criteria were changed to make a more rigorous guide for classifying a participant as having MAI. Participants from the pilot study were not used in the main study.

Subjects for the study were inquired through direct communication in the athletic and sports medicine department where the researcher worked, as well as during an athletic training education specific class. Interested participants were given a packet explaining the research process and containing the informed consent, health questionnaire, and CAIT. Participants were given 24 hours to read the research process and give consent. Participants were informed that completion of the packet did not automatically include them in the present study. If a participant wished to continue with the process, then he/she scheduled a follow up meeting with the researcher.

At the follow up meeting, the participant returned the completed consent form, health history questionnaire, and CAIT. If the participant voluntarily signed the consent form, did not have any relevant health issues, and had a score greater than 28 on the CAIT then they were assessed using the ankle arthrometer. If the participant did not meet the above criteria, then they were excluded from the study.

The final inclusion step was the presence of unilateral mechanical laxity as established through an ankle arthrometer (Blue Bay Research, Inc., Milton, FL). Procedures for using the ankle arthrometer followed the outlined protocol in Hubbard & Cordova, 2009; Hubbard et al., 2003; Hubbard et al., 2004; and Kovaleski et al., 2002 as well as the user guide included with the arthrometer. Participants were supine on a table with his/her foot off of the edge of the table. The plantar aspect of the participant's foot was in good contact with the arthometer and then secured onto the footplate after adjusting the heel and dorsal clamps attached the arthrometer. The dorsal clamp secured the foot to the footplate, and the heel clamp prevented calcaneal rotation. A restraining strap was placed 1 cm above the malleoli, and restricted lower leg movement. The tibial pad was secured to the lower leg, and was positioned 5 cm above the malleoli. The ankle was held in a neutral position (0° of flexion) as assessed by the portable computer (National Instruments, Austin, TX) attached to the ankle arthrometer. Laxity assessment was measured in anterior/posterior displacement before inversion/eversion rotation. To assess total anterior/posterior displacement, an external force of 125 N anterior load was applied to the ankle followed by a posterior load of the same force. Total displacement was the combination of the anterior and posterior displacement. To assess total inversion/eversion rotation, an external torque of 4 N-m was applied to the ankle for inversion followed by eversion. Total rotation was the combination of the inversion rotation and the eversion rotation. A computer monitor was used to maintain a consistent force and torque (Hubbard & Cordova; Hubbard et al., 2003; Hubbard et al., 2004; and Kovaleski et al.). Participants who had increased laxity compared to the opposite ankle were included for data collection. These participants were then scheduled for JPS collection.

JPS data was collected in the Human Movement Laboratory at the University. Participants were not allowed to consume alcohol or any other substance that might affect JPS on the day of testing. Joint position sense was measured with a non-weight-bearing, active-to-active joint replication using the Biodex System 3 dynamometer with universal foot attachment. Although a weight-bearing assessment of JPS leads to less error (Herrington, 2005; Stillman & McMeeken, 2001), a non-weight-bearing assessment is more applicable to the proposed biomechanical model of an ankle sprain (Konradsen, 2002; Willems, Witvrouw, Delbaere, Philippaerts, et al., 2005). The terminal swing phase of gait is the most important aspect of gait in relation to frequent ankle sprains. This is the phase when an individual will position the foot before contact with the ground and determine if the ankle is in a vulnerable or stable position for contact. During this crucial terminal swing phase, the involved leg is non-weight-bearing and the individual has to actively position the foot before contact with the ground (Liu et al.; Konradsen; Spanos et al., 2007; Yokoyama et al.). Participants were seated on the Biodex with knees and hips flexed. Participants were barefoot and strapped to the Biodex. The straps were used for participant comfort and to ensure only ankle ROM was assessed. Straps were applied on the distal thigh, the proximal tibia, and the distal meta-tarsals. The foot was attached to the movable footplate with a thin Velcro strap to reduce stimulation of cutaneous receptors that increase proprioceptive accuracy (Spanos et al.). Participants were given the hand-held comfort stop button in case he/she wished to stop the testing. Participants were also given the hand-held hold/pause button to record estimate angles. The buttons were placed in opposite hands. To eliminate confusion between the two buttons, the stop button was red and placed in the participant's non-dominant hand, while the hold/pause button was black and placed in the participant's dominant hand.

The participants were allowed to freely move the ankle through full range of motion (ROM) because the Biodex allowed the ankle to move at a speed of 180 deg/s. The participant was asked to place his/her ankle at the first testing angle: this was the test position. Once the ankle reached the test position, the Biodex did not allow for movement and held the ankle at the angle for five sec (Deshpande et al., 2003; Kohe et al., 2007; Lee & Lin, 2008; Lin et al., 2008; Sekizawa et al.,). This starting position was held to allow for familiarization of the position. After five seconds, the ankle was allowed to move freely through full ROM without any resistance, and the participant was asked to go through full ROM twice (Sefton et al., 2009). The subject was then asked to actively replicate the test position. Once the subject felt his/her ankle was back in the test position, he/she pressed the hold/pause button. This was known as the estimate angle.

Absolute error was measured in degrees and was calculated as the absolute difference between the test position and the estimate angle (Brown et al., 2004; Ghani Zadeh Hesar et al., 2008; Kynsburg et al., 2006; Lee & Lin).

Participants were allowed two ‘warm-up’ repetitions in each plane to allow participant comfort and familiarization with the testing process (Brown et al., 2004; Liu et al., 2007; Payne et al., 1997). The ‘warm-up’ test position was not one of the 5 angles used for statistical analysis. After the ‘warm-up’ the participant was blindfolded to eliminate any visual cues and begin testing (Ghani Zadeh Hesar et al., 2008; Spanos et al., 2008; Willems et al., 2002; Yokoyama et al., 2008). Between the frontal and sagittal planes, there were 5 test positions assessed for statistical analysis. Positions were assessed in the frontal plane at 5^0 of inversion, and 20^0 of inversion (Kohne et al., 2007; Lin et al., 2008; Spanos et al., 2007; Yokoyama et al., 2008). Positions were assessed in the sagittal plane at 5^0 of dorsiflexion, 10^0 of plantar flexion, and 30^0 of plantar flexion (Deshpande et al., 2003; Kohne et al., 2007; Spanos et al., 2007; Yokoyama et al., 2008). Absolute error in degrees was assessed 3 times at each test angle (Brown et al.; Ghandi Zadeh Hesar et al., 2008; Liu et al.; Payne et al.). The starting test position was block randomized in each plane (Brown et al.; Payne et al.; Willems et al., 2002). These positions were the most commonly used within the literature and were chosen to avoid the extremes of range of motion in order to minimize sensory input from cutaneous receptors (Deshpande et al.).

Statistical Analysis.

A within-subject design was utilized in order to minimize error and maximize treatment effect. With the within-subject design, the unstable ankle was the ankle with

MAI and the stable ankle was the healthy control. Twelve participants were included in the statistical analysis of this study; therefore there were 12 ankles with MAI and 12 stable control ankles.

Before the absolute error at each test angle could be averaged for each participant, reliability analysis with a repeated measures ANOVA was used to determine the reliability of the test trials. For an angle to be considered reliable, Cronbach's Alpha needed to be $\geq .70$ and a significance $\geq .05$.

Two factorial ANOVAs were used to assess JPS in the frontal plane and the sagittal plane. The frontal plane was assessed with a 2x2 factorial ANOVA, and the sagittal plane was assessed with a 2x3 factorial ANOVA. For the 2x3 factorial ANOVA the independent variables were condition (MAI, control) and sagittal plane joint angle (-5°, 10°, 30°), and absolute error in degrees was the dependent variable. There were 3 null hypotheses tested with this statistical analysis: a) there will be no significant difference in absolute error due to condition; b) there will be no significant difference in absolute error due to sagittal plane joint angle; c) there will be no significant interaction between condition and sagittal plane joint angle on absolute error. For the 2x2 factorial ANOVA, condition and frontal plane joint angle (5° inversion, 20° inversion) were the independent variables and the dependent variable measured was absolute error in degrees. There were 3 null hypotheses tested with this statistical analysis: a) there will be no significant difference in absolute error due to condition; b) there will be no significant difference in absolute error due to frontal plane joint angle; c) there will be no significant interaction between condition and frontal plane joint angle on absolute error. The independent variable of treatment group had two levels: MAI, and a stable control condition.

The independent variable of sagittal plane joint angle had three levels: 5° of dorsiflexion, 10° of plantar flexion, and 30° of plantar flexion (Deshpande et al., 2003; Kohne et al., 2007; Spanos et al., 2007; Yokoyama et al., 2008). The independent variable of frontal plane joint angle had 2 levels: 5° of inversion, and 20° of inversion (Kohne et al., 2007; Lin et al., 2008; Spanos et al., 2007; Yokoyama et al., 2008). ANOVA assumptions were assessed through a Shapiro-Wilk significance score with an alpha confidence set at .05. The level of significance for the entire data set was set at an alpha of .05. Tukey HSD post hoc analysis was used as a follow up test to determine significant difference between each group because it determines a significant difference while also correcting for the probability of making a type 1 error (Kerr, Hall, & Kozub, 2002).

The purpose of this study was to examine the relationship between MAI and active JPS. Participants were selected based upon a subjective instability scored with a CAIT and an objective score of 'laxity' using an ankle arthrometer. JPS was assessed with a non-weight-bearing, active-to-active joint replication. The absolute error was measured with a Biodex System 3 dynamometer. Statistical analysis had planned on using a 2x2 and a 2x3 factorial ANOVA.

Chapter 4

Results

The purpose of this study was to examine the relationship between mechanical ankle instability (MAI) and active joint position sense (JPS). It was hypothesized that the MAI group would have greater absolute error in JPS than the control group. Chapter four will report the results of the current study including the descriptive statistics, analysis of variance, and JPS absolute error analysis.

Descriptive statistics.

A total of 61 people (22 males and 39 females) completed the informed consent packet including the health history questionnaire and Cumberland Ankle Instability Tool (CAIT). The average age of the 61 people who completed the packet was 21.68 ± 2.97 years. The average left CAIT score was 26.39 ± 3.85. The average right CAIT score was 25.86 ± 3.84. Forty-one of the 61 individuals completing the packets were excluded based upon the results from the questionnaires in the packet. Seven individuals had right FAI, two individuals had left FAI, and 22 individuals had bilateral FAI. Four individuals bilaterally scored ≥ 27 on the CAIT but were excluded due to previous relevant health history such as lower extremity fracture or surgery. Five individuals were excluded from the study because the packet was incomplete.

The remaining twenty individuals (6 male and 14 female) were assessed by the portable ankle arthrometer for MAI. The average age of this group was 20.89 ± 1.49 years. The average left CAIT score was 29.40 ± .82, and the average right CAIT score was 29.25 ± .97. Average anterior/posterior displacement for the left and right ankle were 10.16 ± 2.95 mm and 9.04 ± 2.39 mm respectively. Average inversion/eversion rotation for the left and right ankle were 40.36 ± 8.91° and 36.98 ± 11.25° respectively. Based upon the results of the ankle arthrometer measurements, seven of the 20 individuals were excluded.

Thirteen participants (6 male and 7 female) were found eligible to participate in JPS testing (10 with left MAI and 3 with right MAI). Of the 13 participants found eligible to participate in JPS testing, 4 identified their left leg as the dominant leg and 9 identified their right leg as the dominant leg. Just before JPS testing, one of the male participants sprained his ankle and was removed from the pool giving a final *n* of 12 participants (5 males and 7 females). The average age of the final 12 participants was 20.54 ± 1.20 years. The average left CAIT score was 29.31 ± .85, and the average right CAIT score was 29.31 ± .85. Average anterior/posterior displacement for the left and right ankle were 10.43 ± 2.88 mm and 8.60 ± 2.36 mm respectively. Average inversion/eversion rotation for the left and right ankle were 42.91 ± 8.09° and 38.57 ± 11.20° respectively.

JPS reliability analysis.

Before each test angle was averaged, a reliability analysis and ANOVA were used to determine if there was a significant difference between each trial. Table 1 and table 2 show Cronbach's alpha and significance for each test angle in the sagittal plane and frontal plane respectively.

Table 1

Cronbach's alpha and significance in the sagittal plane

	Control		MAI	
Angle	Cronbach's α*	Significance**	Cronbach's α*	Significance**
-5	.722	.131	.628	.099
10	-.639	.906	-.106	.784
30	.175	.046	.742	.170

**Cronbach's α acceptable >.700 **Significance p <.05*

Table 2

Cronbach's alpha and significance in the frontal plane

	Control		MAI	
Angle	Cronbach's α*	Significance**	Cronbach's α*	Significance**
-5	.889	.029	.781	.827
-20	.888	.536	.487	.681

**Cronbach's α acceptable >.700 **Significance p <.05*

Because Chronbach's α fell below .700, the data for the sagittal plane was deemed unreliable and the research question could not be answered.

Frontal plane joint angles.

Based on Cronbach's α and significance, both the measurement 20 degrees of inversion for the stable ankle and 5 degrees of inversion for the ankle with MAI were found to be acceptable trails. For those angles, the absolute error was not significantly different across the three test trials. Since there was not a difference between the trials, the three trials at 20 degrees of inversion for the stable ankle and 5 degrees of inversion for the ankle with MAI were averaged for statistical analysis. Although Cronbach's α at 5 degrees of inversion is greater than .700, the significance showed that there was a difference between the three trials. Because the significance was less than .05, the three test trials could not be averaged. At 20 degrees of inversion, Cronbach's α was weak, therefore the three trials could not be averaged. The two unreliable angles could be salvaged by deleting one of the test angle replications. Table 3 shows Cronbach's alpha if a given trial is deleted.

Table 3

Cronbach's alpha after deletion of replication

	-5 stable	-20 MAI
	Cronbach's alpha*	Cronbach's alpha*
1st replication deleted	.885	.056
2nd replication deleted	.863	.343
3rd replication deleted	.786	.798

**Cronbach's α acceptable >.700*

For the ankle with MAI at 20 degrees of inversion, the third trial was deleted because Cronbach's α was greater than .700. The first two trials were averaged for further statistical analysis. Although it had a weaker Cronbach's α, the third trial in stable ankle at 5 degrees of inversion was deleted. This decision was based upon the least variance of coefficient. To determine the variance, separate reliability analysis were conducted comparing the first and second trials, first and third trials, and second and third trials. When the first trial was deleted (compared the second and third trial) Cronbach's α was .885 and the significance was .208. The F ratio was 1.79 and the standard deviation was larger than the mean for the third replication (5.42 $\pm$ 6.04). When the second trial was deleted Cronbach's α was .863. The significance however was .01 therefore there was a significant difference between the two trials. When the third trial was deleted, Cronbach's α was .786 and the significance was .174. The F ratio was 2.11 and the average error for the first and second replications were 9.75 $\pm$ 7.78 and 7.08 $\pm$ 7.34 respectively. The first two trials were averaged for further statistical analysis due to the least variance of coefficients.

ANOVA.

The sagittal plane 2x3 factorial ANOVA was not conducted due to unreliable data. The mean absolute error and standard deviation for the frontal plane 2x2 factorial ANOVA are shown in table 4.

Table 4

Descriptive Statistics

	Mean	Std. Deviation	Skewness*	N
Stable Frontal -5	8.4167	6.86504	1.359	12
Stable Frontal -20	6.3058	5.06485	1.175	12
MAI Frontal -5	8.8617	7.73612	2.244	12
MAI Frontal -20	6.6750	4.4126	.687	12

**zskew acceptable if < ±1.96*

The assumptions of an ANOVA were not met at 5 degrees of inversion in the MAI ankle where the data were positively skewed. Because the data did not meet the normal assumptions of an ANOVA, the research question could not be answered in the frontal plane either. A post-hoc analysis was not used because the data could not be analyzed with an ANOVA.

Summary.

The purpose of this research was to examine the relationship between MAI and active JPS. It was hypothesized that ankles exhibiting MAI would have greater absolute error in JPS than stable ankles in both the sagittal and frontal plane. Data in the sagittal plane was found to be unreliable and the data in the frontal plane did not meet the assumptions of an ANOVA to show if there was or was not a significant difference between the ankles in the frontal plane.

Chapter 5

Discussion

The purpose of this study was to examine the relationship between mechanical ankle instability (MAI) and active joint position sense (JPS). It was hypothesized that ankles with MAI would have greater error in JPS than stable ankles. The research question could not be answered. Chapter five will discuss the findings of the current study, potential problems with the current study, and suggestions for future research.

Findings of the current study.

Although the research question could not be answered, there are other findings to the current study. It is of interest to note that a small pocket of individuals, 13 out of 61, did meet the criteria of MAI exclusive of any associated FAI does exist. The current research proposed to change the definition of MAI to exclude the presence of FAI because the way it is currently defined in some research does not differ from CAI (Brown et al., 2008; Brown et al., 2009; Hubbard et al., 2007). Previous researchers may have chosen not to exclude FAI from the definition of MAI because of the limited potential for eligible subjects. The results of the pilot study, as well as the overall study, show that there are individuals who do not consider themselves to have FAI, yet one ankle has greater laxity as compared to the other ankle. The sample for the current study did pull from a younger, more active population so the number of individuals with MAI outside of that population is still unknown. While evaluating this population, the ankle arthrometer proved to be a valuable tool for providing an objective assessment of MAI that could potentially lead to objectifying laxity in the ankle.

Through personal experience, it was assumed the ankle of the dominant leg would have more freedom of movement and therefore more laxity, but 10 out of 13 participants were found to have the greatest stability in the dominant leg. Although this was an interesting trend, because of the small sample size in the current study and the lack of reporting leg dominance in other studies, it is unknown if leg dominance makes a difference in MAI or CAI.

Improvements to the current study.

Because of the lack of findings in the current study, there are some things that could have been changed in order to conduct a more valid study. When using the ankle arthrometer for the inclusion process, the average of three trials was used for the comparison between ankles. A reliability analysis was not performed before taking the average. It wasn't until the reliability analysis for JPS testing that we realized a similar analysis for the ankle arthrometer could have been beneficial to create a more valid study.

While collecting JPS data, multiple participants complained of transient parasthesia, mainly in the sagittal plane. This may have been from an increased time in the Biodex due to the number of trials in the sagittal plane. The numbness and tingling may also have been due to tightness from the strap securing the participant's foot to the Biodex. Decreasing the amount of time the participant was required to be seated in the Biodex could have prevented the transient parasthesia. Therefore, it is suggested that in future studies, researchers consider the possibility of cutting the repetitions from 3 to 2 or splitting the data collection into two days to avoid the possibility.

Although the Biodex was calibrated before data collection, it still resisted participants randomly in the sagittal plane during the familiarization process to find the test angle. After the participant found the test angle and the Biodex completed the 5 second hold, it did allow for the participants to move freely throughout the range of motion and data collection was completed as planned. Based on the 2005 study by Huston, Sandrey, Lively, & Kotsko, fatigue should not have made a difference in JPS error, but because we did not account for this variable, it is hard to determine in the current study if this extra level of unexpected fatigue may have affected the JPS error. Because the participants did not know that finding the testing position could be a challenging process, it may have altered their motivation or focus in the ability to replicate the angle.

Areas of inconsistency in the literature.

Even though the current study did not produce reliable data that could be analyzed, we identified considerations that could be valuable for future research. While reviewing the literature, we found that there were areas of inconsistency in the definition of ankle instability, the definition of MAI, as well as the instruments used to collect JPS data.

Ankle instability definitions in the literature.

Ankle instability has been and continues to be a popular topic for researchers but there is controversy surrounding why an individual may suffer from repetitive ankle sprains. Previous research has been devoted to different factors that may affect ankle instability such as: proprioception, gait strategies, muscle activation, postural stabilization, and more (Hamlyn, Docherty, & Klosser, 2012; Wilkstrom & Hass, 2012; Wright & Arnold, 2012). Even though authors agree that there is more than one factor that may cause an individual to have repetitive ankle sprains, the factors involved have conflicting results (Hiller, Killbreath, & Refshauge, 2011; Sefton et al., 2009; Wikstrom et al., 2012). Some of this controversy may be due in part to the lack of consistency in the definition of ankle instability.

The Hertel model (Hertel, 2002), is commonly accepted in the current literature. This model suggests that CAI is the combination of FAI and MAI, but the application of this model continues to vary (Brown et al., 2008; Brown et al., 2009; Hubbard et al., 2007). While examining FAI, some researchers have made an effort to exclude the mechanical aspect (Lee & Lin, 2008; Liu et al., 2005; Yokoyama et al., 2008), while other researchers only sought to identify a functional instability as part of the inclusion criteria and did not make an effort to exclude those with an increase in laxity (Brown et al., 2004; Sefton et al., 2009). Mechanical ankle instability (MAI) has been defined as repetitive ankle sprains in addition to the presence of ligamentous ‘laxity’ (Brown et al., 2008; Brown et al., 2009, Hubbard et al., 2007). According to the commonly accepted Hertel definition, this is CAI, not MAI. The current study was the first to exclude FAI from the definition of MAI.

To confound research further, some research suggests the use of copers over stable ankles for control groups (Brown et al., 2008; Brown et al., 2009; Wikstrom et al., 2012). Copers are individuals who have previously sprained an ankle, but did not develop any subsequent instability. Previous authors have suggested that it is important to study copers to understand any difference as to why those individuals did not develop a subsequent instability.

Researchers continue to define the types of ankle instability in different ways. Hiller, Kilbreath, & Refshauge (2011), felt the commonly accepted Hertel model was not inclusive enough of a definition of ankle instability so they proposed an evolution of the Hertel model. In the evolved model, Hiller et al. suggest 7 sub-categories to define the terms of ankle sprain research. With the new model, Hiller et al. was able to identify all 108 sprained ankles examined in their study. The Hertel model was only able to identify 56% of the 108 ankle sprains. Future research would benefit from the selection and/or creation of consistent terminology and inclusion criteria used in the research about ankle instability.

Definition of MAI.

When selecting a standard on terminology and inclusion criteria, future researchers could choose to include MAI exclusive of FAI as a classification. Another difficulty of this study was the explorative nature of the participants selected. It was unsure if a population of individuals with unilateral MAI exclusive of FAI even existed, so a pilot study was conducted. The pilot study showed that a population meeting the criteria does exist, but we felt our chosen definition ($\geq$ 1mm A/P displacement, or $\geq 1^{o}$ I/E rotation) was not rigorous enough in its inclusion criteria. Our original definition was based upon the standard error of measurement (SEM) of the ankle arthrometer. We increased the difference based upon the standard deviation from previous studies validating the ankle arthrometer because there were no previous studies that had established a standard of what constitutes laxity within the ankle (Hubbard et al., 2003; Kovaleski et al., 2002). Future studies could benefit from a standardized value of laxity in the ankle to help create a more homogenous testing group of individuals with MAI.

JPS testing instruments.

One of the other interesting findings in conducting this research was the large number of different instruments used in evaluating JPS. The Biodex System 3 Dynamometer was chosen for the current study due to its use in previous studies and the study done by Drouin et al. (2004), which found the Biodex System 3 dynamometer to be accurate and reliable at measuring angular positions. However, the data collected from the current study in the sagittal plane was found to be unreliable. The reliability study by Drouin et al. was not validated on human subjects and there is no reliability analysis for the Biodex specific to ankle JPS testing.

Yokoyma et al., 2008 used a 3D ankle position analysis system and conducted a reliability analysis before averaging and analyzing the data. The authors reported that the reliability analysis showed good intra and inter rater reliability. There was a stronger intra and inter rater reliability of plantarflexion angles at 0 degrees of inversion (ICC was .917 and .825 respectively) than of plantarflexion angles at 20 degrees of inversion (ICC was .747 and .624 respectively). Interestingly, the ICC at 20 degrees of inversion wasn't as strong, but that is where the authors found significance in an underestimation in JPS.

Other authors have used an electric goniometer to evaluate JPS, but even the types of goniometers vary. Huston et al. (2005), used a custom made device with an electric goniometer, while Spanos et al. (2007) used an electric goniometer taped directly to the participant. The variations of different instruments used make it difficult to draw reliable comparisons between different studies. Future research could seek to identify and validate a standardized tool used for ankle JPS testing.

Summary.

The purpose of this research was to examine the relationship between MAI and active JPS. It was hypothesized that individuals with MAI would have greater errors in active JPS than controls in the frontal and sagittal plane. The research question could not be assessed. The pilot study showed that there was a small population of individuals with unilateral MAI exclusive of FAI. The current study could have been improved with a reliability analysis of the ankle arthrometer data; decreasing the amount of time the participant spent in the Biodex; and by ensuring the Biodex provided true, unrestricted range of motion during data collection. Future studies should seek to standardize the definitions and instrumentation used in research about ankle instability. I am not citing the inconsistencies as causation for the problems in the current study, but clarity and standardization within the ankle instability literature might facilitate future research.

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Appendix A

Health History Questionnaire.

Please answer the questions and check the relevant boxes
Age:
Gender: ☐Male ☐Female

How many times have you sprained your ankle?

Right:

Left:

When was your most recent ankle sprain?

Right:
☐Less than 6 weeks ago ☐More than 6 weeks ago ☐I've never sprained this ankle

Left:
☐Less than 6 weeks ago ☐More than 6 weeks ago ☐I've never sprained this ankle

Have you ever had a lower extremity fracture or surgery?
☐Yes ☐No

Do you have diabetes, epilepsy, vertigo, multiple sclerosis, cerebral palsy, or altered sensation in your lower extremity?
☐Yes ☐No

Have you ever had a stroke?
☐Yes ☐No

Are you currently experiencing dizziness?
☐Yes ☐No

Are you currently experiencing symptoms associated with a concussion?
☐Yes ☐No

Appendix B

The CAIT Questionnaire

Please pick the ONE statement in EACH question that BEST describes your ankles.

		Left	Right
1.	**I have pain in my ankle**		
	Never	☐	☐
	During sport	☐	☐
	Running on uneven surfaces	☐	☐
	Running on level surfaces	☐	☐
	Walking on uneven surfaces	☐	☐
	Walking on level surfaces	☐	☐
2.	**My ankle feels UNSTABLE**		
	Never	☐	☐
	Sometimes during sport (not every time)	☐	☐
	Frequently during sport (every time)	☐	☐
	Sometimes during daily activity	☐	☐
	Frequently during daily activity	☐	☐
3.	**When I make SHARP turns, my ankle feels UNSTABLE**		
	Never	☐	☐
	Sometimes when running	☐	☐
	Often when running	☐	☐
	When walking	☐	☐
4.	**When going down the stairs, my ankle feels UNSTABLE**		
	Never	☐	☐
	If I go fast	☐	☐
	Occasionally	☐	☐
	Always	☐	☐
5.	**My ankle feels UNSTABLE when standing on ONE leg**		
	Never	☐	☐
	On the ball of my foot	☐	☐
	With my foot flat	☐	☐
6.	**My ankle feels UNSTABLE when**		
	Never	☐	☐
	I hop from side to side	☐	☐
	I hop on the spot	☐	☐
	When I jump	☐	☐
7.	**My ankle feels UNSTABLE when**		
	Never	☐	☐
	I run on uneven surfaces	☐	☐
	I jog on uneven surfaces	☐	☐
	I walk on uneven surfaces	☐	☐
	I walk on flat surfaces	☐	☐
8.	**TYPICALLY, when I start to roll over (or "twist") on my ankle, I can stop it**		
	Immediately	☐	☐
	Often	☐	☐
	Sometimes	☐	☐
	Never	☐	☐
	I have never rolled over on my ankle	☐	☐
9.	**After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal"**		
	Almost immediately	☐	☐
	Less than one day	☐	☐
	1-2 days	☐	☐
	More than 2 days	☐	☐
	I have never rolled over on my ankle	☐	☐

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