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The Effects of Ankle Bracing and Fatigue on Time to Stabilization in Subjects with Chronic Ankle Instability

by

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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Master of Science Degree in Exercise Science

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An Abstract of

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It is unknown whether the application of an ankle brace can increase dynamic stability to overcome the effects of fatigue in those individuals with CAI. Ankle dynamic stability was assessed before and after a functional fatigue protocol using the Time to Stabilization (TTS) method. Prior to the functional task, dynamic stability was measured using a single leg jump landing at 50% of the subjects’ maximum vertical jump height. The functional fatigue circuit was repeated until the time it took to complete the circuit increased to 50% of the baseline time. Immediately after fatigue was reached, the single leg jump landing measures were repeated. This protocol was performed with and without an ankle brace. For APTTS, the main effect for Group was statistically significant (F=4.15; p=.05). Subjects in the CAI group (1.291±0.179s) took significantly longer to stabilize than those in the healthy group (1.191±0.10s). There were no other significant results found. The results of our study provide questions regarding the use of ankle braces for improving dynamic stability measured with TTS in both a healthy population and those with CAI. Further research, with a larger sample size should be conducted to make
a better decision regarding the effectiveness of ankle braces in improving single-leg jump landing stabilization.
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Chapter 1

Introduction

Ankle injuries are one of the most common injuries that occur in the physically active population.\textsuperscript{1-5} Lateral ankle sprains resulting from forced inversion and plantar flexion are the most frequently observed ankle injury.\textsuperscript{1} Not only can these injuries be debilitating, but with residual ankle laxity and lingering functional deficits, the rate of ankle injury recurrence is disturbingly high.\textsuperscript{6-8} Multiple ankle sprains cause instability to result in the ankle joint. Subsequently, this pathology, chronic ankle instability (CAI), is a result of both mechanical and functional instability.\textsuperscript{9} Mechanical instability can be caused by increased laxity, arthokinematic abnormalities, impingement, and degenerative changes.\textsuperscript{9} Functional instability is associated with deficits in proprioception, altered neuromuscular and postural control and strength deficits.\textsuperscript{9} These impairments may increase the risk of reinjury, which has been reported to affect 80% of individuals following an initial ankle sprain.\textsuperscript{10}

The use of prophylactic taping and bracing in preventing lateral ankle sprains has become common in clinical practice; with the typical goal in the application of these devices to provide mechanical support to stabilize the ankle. There is evidence that
bracing is effective at reducing the occurrence of ankle sprains.\textsuperscript{11-17} A systematic review of nineteen studies concluded that the use of semi-rigid braces restricted inversion ROM 21.3\% more than tape before exercise and 72.1\% after exercise.\textsuperscript{13} Additionally, in a study conducted on American football players over a seven year period, Rovere, et al\textsuperscript{12} reported that a lace up ankle brace reduced the incidence of injury by 50\%. Furthermore, a review of the literature by Verhagen, et al.\textsuperscript{18} as well as a numbers-needed-to treat analysis by Olmsted et al\textsuperscript{11} concluded that bracing is more effective at preventing ankle sprains in those individuals who have already sustained a previous sprain. These results seem to provide the clinician and athlete with many reasons to utilize ankle bracing, especially after the initial injury has occurred.

Research has shown that fatigue causes a decrease in force production, reaction times, and proprioception.\textsuperscript{19-21} Fatigue negatively effects performance in athletics, causing postural control and dynamic stability to become diminished.\textsuperscript{22-28} These alterations not only negatively effect performance, but more importantly, may cause detrimental effects on the muscles’ ability to protect the joints, which may increase the risk of sustaining a subsequent ankle sprain.\textsuperscript{29} The majority of information on the impairments in neuromuscular control caused by fatigue is related to healthy individuals. However, there is limited, but consistent evidence that fatigue causes greater deficits in subjects with CAI, especially with measures of dynamic postural control.\textsuperscript{30, 31} These previous investigations utilized the Star Excursion Balance Test (SEBT) to demonstrate the relationships between fatigue and decreased postural control. While the SEBT is a reliable\textsuperscript{32-34} and sensitive tool\textsuperscript{34, 35}, it does not require movement patterns that may more closely mimic sport and potential injury mechanisms, such as landing from a jump.
Time to stabilization (TTS) is a method of quantifying dynamic stability during a jump-landing task. TTS provides a more functional method for assessing deficits in neuromuscular control than traditional static postural control measurements. TTS requires a single-leg landing following a jump, which is a common mechanism for a lower extremity injury, with up to 45% of ankle injuries occurring during a jump-landing. It has been reported that subjects with CAI experience longer TTS compared with healthy counterparts. These deficits in TTS measurements may help identify stability impairments experienced by CAI athletes during their functional activities, helping clinicians and researchers to distinguish those with CAI and implement interventions that address their deficits.

Braces have been shown to be an effective method of improving ankle joint stability during isolated tasks, but there is limited information to support the effectiveness of ankle braces during dynamic activities, especially in pathological subjects. Shaw et al reported the Swede-O Universal lace up brace improved TTS in the anterior/posterior direction in healthy fatigued participants. Wikstrom et al demonstrated that ankle bracing can improve vertical stability, a component of the Dynamic Postural Stability Index, in subjects with functional ankle instability. The combination of detrimental factors of CAI and fatigue is common in athletic participation and can create a high risk for ankle injury. However, it is unknown whether braces can improve dynamic stabilization in individuals with CAI during a jump-landing task when fatigue is introduced.
Statement of the Problem

Chronic ankle instability commonly follows a lateral ankle sprain, leading to deficits in mechanical and functional stability. Fatigue is frequently experienced by athletes during participation and may create a decrease in joint stability and increase the risk for injury. The problems caused by fatigue coupled with the problems caused by CAI could cause an athlete to be at an even greater risk of sustaining reoccurring sprains. Ankle braces have been reported to help increase mechanical stability and reduce the occurrence of ankle sprains. Furthermore, ankle braces have shown to improve TTS in healthy individuals, before and after fatigue. However, it is not known whether the application of a brace can increase stability to overcome the effects of fatigue in those individuals with CAI.

Statement of the Purpose

The purpose of this study is to determine the effects of fatigue and ankle bracing on time to stabilization in those with chronic ankle instability. Examining what influence ankle braces can have on dynamic stabilization may help clinicians make important decisions regarding their use, especially in athletes with CAI. The intent of this project is to measure how CAI and fatigue affect dynamic stability and if those effects can be influenced by the application of an ankle brace.

Significance of the Study

Once an athlete has sustained an ankle injury, their likelihood for re-occurrence is very high, potentially leading to CAI and a decrease in joint stability. Athletes commonly
use ankle prophylactic devices to increase stability and help prevent injury. Fatigue is experienced frequently during athletic participation and may create decreases in dynamic stability, potentially exacerbating the ankle pathology. This study will examine how the application of a common lace-up style ankle brace will affect dynamic stability after fatigue in subjects with CAI. This study may help clinicians determine if ankle braces are appropriate interventions for minimizing dynamic stability deficits during landing from a jump. If the use of an ankle brace can improve dynamic stabilization during landing from a jump under fatigue in athletes with CAI, it is likely that the risk for sustaining an ankle injury may be decreased.

Research Hypotheses

1. Healthy subjects will have better dynamic postural control when compared to subjects with CAI; with shorter TTS in the no brace condition before fatigue is induced.

2. Bracing will improve TTS; with Healthy subjects and CAI subjects experiencing faster TTS with the ankle brace compared to the no-brace condition, before fatigue is induced.

3. Fatigue will impact TTS negatively; with Healthy subjects and CAI subjects experiencing faster TTS in the pre-fatigue condition compared to the post-fatigue condition.

4. Bracing will interact positively with fatigue and CAI; with the Healthy subjects and CAI subjects experiencing faster TTS with the ankle brace compared to the no-brace condition after fatigue has been induced.
Operational Definitions

CAI=Chronic Ankle Instability- a condition resulting from the occurrence of multiple ankle sprains, leading to a combination of mechanical and functional ankle instability.  

TTS=Time to Stabilization- a functional method of assessing dynamic postural stability by measuring the time required to stabilize after a single-leg jump-landing.  

APTTS=Anterior/Posterior Time to Stabilization- a TTS measure in the anterior/posterior direction.  

MLTTS=Medial/Lateral Time to Stabilization- a TTS measure in the medial/lateral direction.  

SEBT=Star Excursion Balance Test- a single-leg balance test used as a method of assessing dynamic postural control.  

FADI and FADI Sport=Functional Ankle Disability Index- a subjective instrument used to quantify functional limitations and to detect possible CAI subjects.  

Limitations

Some limitations to this study are the subjects self-reporting of their past lower extremity injury history. Subjects false reporting of this information could affect the results of the study. Also, subjects fatigue will not be measured by an objective measure, such as EMG, but rather by the time it takes for them to complete the fatigue protocol. This is a subjective way of measuring fatigue and it can only be assumed that subjects are giving their maximal effort, both during the fatigue protocol and the maximal vertical
jump. Furthermore, subjects will be asked to wear their own lace up athletic shoes, so the style will not be the same across all subjects.
Chapter 2

Literature Review

Anatomy

Bones

The ankle joint consists of three bones: the tibia, the fibula and the talus, with the talus being the key bone in the ankle joint, connecting the lower leg and the foot. The distal end of the tibia and fibula form the medial and lateral malleoli, respectively, which help to stabilize the ankle joint. The lateral malleolus extends further than the medial malleolus, thus providing more support on the lateral side of the ankle. The talus is hinged to the lower leg by the talocrural joint and to the foot by the subtalar joint.

Joints

The talocrural joint, also known as the ankle mortise joint is made of the articulations between the talus and the tibia, the medial malleolus, and the lateral malleolus. The talocrural joint allows motion primarily in the sagittal plane, through plantar flexion and
dorsiflexion. The talocrural joint receives its stability through the anterior talofibular ligament (ATFL), posterior talofibular ligament (PTFL), calcaneofibular ligament (CFL), and the deltoid ligament. The ATFL prevents the talus from excessive anterior translation and internal rotation and becomes taut as the ankle moves from dorsiflexion to plantar flexion. The CFL is responsible for limiting excessive supination of the subtalar and talocrural joints and the PTFL restricts excessive inversion and internal rotation, along with posterior translation of the talus.\(^{56}\)

The subtalar joint is made of the articulation between the talus and the calcaneus and the motions of inversion, eversion, pronation and supination occur at the joint. The ligamentous support of the subtalar joint consists of the deep ligaments, peripheral ligaments, and the retinacula. The deep ligaments include the cervical and interosseous ligaments while the peripheral ligaments include the CFL, the lateral talocalcaneal, and the fibulotalocalcaneal ligaments.\(^{56}\)

The distal tibiofibular joint is a syndesmosis consisting of the articulation between the distal tibia and fibula. This joint is supported through an interosseous membrane along with the anterior and posterior inferior tibiofibular ligaments. This syndesmosis gives a strong support to the superior aspect of the talocrural joint.\(^{56}\)

**Ligaments**

The ligaments of the ankle consist of the tibiofibular ligaments, the lateral ligaments, and the medial ligaments. As stated above, the tibiofibular ligaments consist of the anterior and posterior tibiofibular ligaments, which support the distal tibiofibular joint. The lateral ligaments consist of the ATFL, PTFL, and CFL. A grade I inversion
ankle sprain, involving the ATFL, is the most common type of sprain. A grade II inversion sprain involves injury to the ATFL and the CFL, while a grade III sprain causes damage to all three of the lateral ligaments. The PTFL is the least common ligament to be damaged with a sprain, and commonly is accompanied by a dislocation or fracture. The medial ligaments consist of the calcaneonavicular ligament, along with the deltoid ligament. The calcaneonavicular, or spring ligament, helps maintain the medial longitudinal arch. The deltoid ligament provides eversion restraint and consists of four separate ligaments: the anterior tibiotalar, tibionavicular, tibiocalcaneal, and the posterior tibiotalar.

**Muscles**

Dorsiflexion and plantar flexion occur at the talocrural joint, while inversion and eversion occur at the subtalar joint. Muscles that produce dorsiflexion are the tibialis anterior, the extensor hallucis longus, and the extensor digitorum longus. Plantar flexion is produced by the gastrocnemius and soleus muscles. The peroneus longus, brevis, and tertius are responsible for everting the ankle, while the tibialis posterior, flexor digitorum longus, and flexor hallucis longus aid in inversion. The peroneal muscles, especially the peroneus longus, have been speculated to provide dynamic protection of the ankle from excessive inversion. These muscles could serve as a last resort in protecting the ankle from an inversion sprain.

**Pathomechanics of Ankle Sprain**
Lateral ankle sprains occur when the talocrural joint is placed in excessive plantar flexion, inversion, and internal rotation. \(^{58}\) The lateral ligaments are placed under excessive strain when the rearfoot is supinated and the lower leg is externally rotated. This position, along with increased plantar flexion of the foot is the most common mechanism for lateral ankle sprain. The ankle is most stable when the foot is in dorsiflexion, because the widened shape of the anterior portion of the talus becomes fixed between the malleoli. \(^{54}\) This makes the ankle more susceptible to injury when it is not in its closed-pack position, but rather in a plantar flexed position.

When the ankle is placed in extreme positions of inversion and plantarflexion, the ligaments cannot handle the stress and thus fail to mechanically stabilize the joint. When this occurs, the ligaments become damaged. This position commonly occurs when the athlete is not anticipating a sudden change in the position of their foot, such as landing from a jump or stepping on an opposing player’s foot. A study by McKay, et al. \(^{59}\) found that 45% of all ankle injuries occur during jump landings, with 50% of those being the result of landing with half their foot on another player’s foot. When the ankle ligaments are stretched beyond their anatomical limits, a sprain occurs, with the most commonly sprained ligament being the ATFL, followed by the CFL, and finally the PTFL, which is the strongest and least likely to be sprained. A sprained ankle causes the athlete to experience pain, swelling, and loss of function. \(^{59}\) Depending on the severity of injury, these symptoms typically subside within a couple days to a few months and the athlete can return to normal function; however, when normal function has returned and the athlete returns to play, they have a greater risk of suffering from reoccurring sprains. \(^{59}\) It has been found that the primary predisposing factor of a lateral ankle sprain is the history
of a previous sprain. The changes that occur to the ankle following the initial injury are what are thought to be the cause of subsequent sprains.

**Chronic Ankle Instability**

Acute lateral ankle sprains have been found to place the athlete at a much greater risk for sustaining recurrent sprains; with 40% to 75% of individuals developing chronic ankle instability. Chronic ankle instability has been described by Hertel as the existence of an unstable ankle due to ligamentous damage, resulting in multiple ankle sprains. CAI is the result of mechanical or functional instability, or more likely a combination of the two.

**Mechanical Instability**

Mechanical instability is the cause of altered mechanics within the ankle joint. Ligamentous laxity, arthrokinematic alterations, impingement, and degenerative changes have been described as the possible causes of mechanical ankle instability. Hypermobility, or laxity, at the talocrural joint has been examined extensively as the primary alteration occurring in response to ankle sprain. The amount of laxity within the joint depends on the amount of damage to the lateral ligaments that occurred with the injury. Even though the ligaments may be fully healed after an acute injury, laxity has still been found to be present at the talocrural joint. Laxity is the result of lengthening or tearing of the ligamentous structures that act to support the joint. Increased joint laxity results in instability at the joint, causing recurring injury when the ankle is placed in positions commonly associated with injury. One theory suggests that the crimping pattern
of the ligaments becomes straight following injury, causing the collagen fibers to be laid in improper alignment.\textsuperscript{61} When these structures become laxed, access motion is allowable at the joint, thus placing further stress on the structures.\textsuperscript{56, 58} A study conducted by Hertel et al\textsuperscript{60} found those with CAI had significantly more talocrural joint laxity, both with an anterior drawer and a talar tilt test. However, Tropp et al.\textsuperscript{62} found only 42% of CAI subjects tested during their study demonstrated a positive anterior drawer test. This research demonstrates that mechanical laxity at the talocrural joint may be a common symptom experienced by those with CAI, but it may not necessarily be present in all individuals.

Arthrokinematic changes may also be present in CAI individuals, leading to re-injury of the ankle. Those with chronic ankle instability have been thought to have excess anterior and inferior translation of their distal fibula, causing the ATFL to be less taught while in a resting position and allowing the talus to experience greater range of motion before the ATFL acts to restrict movement.\textsuperscript{63} Impaired althrokinematics may also cause a reduction in dorsiflexion ROM following ankle sprain.\textsuperscript{9} Limited dorsiflexion will prevent the ankle from attaining its closed-pack position; therefore allowing easier inversion and internal rotation.\textsuperscript{9} This places the athlete in a position of increased risk of sustaining an ankle injury. Furthermore, synovial inflammation and impingement and degenerative changes in the ankle joint have been found to be potential contributors to mechanical instability.\textsuperscript{9}

**Functional Instability**
Functional instability is caused by alterations in one or more of the following: proprioception, neuromuscular control, postural control, and strength. Dynamic support of the ankle is provided by the neuromuscular system, which often experiences deficits following ankle sprains, thereby effecting the dynamic stability of the ankle and its protection against inversion sprains. Sport specific activities require athletes to rely on their sense of joint position to stabilize the joint and prevent injury. However, when a joint becomes injured, an athlete’s sense of joint position becomes hindered, thus decreasing their ability to properly stabilize the joint and prevent injury. When proprioception is lost or diminished, this ability to stabilize the joint and prevent it from going beyond anatomical limits decreases. This loss in proprioception has been shown to have an influence on why athletes are more likely to sustain reoccurring ankle sprains. Freeman et al. first speculated that proprioceptive input may be adversely affected because of the damage that occurs to the mechanoreceptors following ankle injury. Further research conducted by Lentell et al. found that ankle sprains caused significant impairments of passive motion sense, attributed to the damage occurring at the Type II mechanoreceptors following acute injury. Additionally, Konradsen and Magnusson found that individuals with functionally unstable ankles had significantly worse joint position sense when measured on their ability to replicate joint position angles. These researchers concluded that these alterations in kinesthetic awareness predispose individuals to sustaining recurrent ankle sprains.

Postural control impairments are frequently seen in individuals suffering from both acute ankle sprain and CAI and are linked to deficits in proprioception and neuromuscular control. Postural control is maintained through an “ankle strategy,”
where the foot pronates and supinates in order to keep balanced and to maintain the body’s center of gravity. However, because of changes in central neural control that occur in response to dysfunction at the ankle, individuals with CAI have been found to use the less efficient “hip strategy” in order to maintain their balance. A review of the literature conducted by McKeon and Hertel found deficits in postural control were associated with increased risk of ankle sprain. Furthermore, this study concluded that individuals suffering from acute ankle sprain had significantly greater deficits in measurements of postural control when compared to control groups of healthy individuals. Another study by Gribble et al. used the Star Excursion Balance Test, which is a measurement of dynamic postural control, and found that individuals with CAI reached significantly less in all three directions on their involved leg when compared to their uninjured side. These results further suggest alterations in neuromuscular control occur following ankle injury.

**Ankle Bracing**

The typical goal in the application of these devices is to provide mechanical support to stabilize the ankle. Much research has examined the efficacy of these devices and many researchers have focused on comparing the effectiveness of taping and bracing. These findings suggest that there are many advantages to using ankle braces. Braces not only provide quicker and easier application and do not require a qualified individual to apply, they also have been shown to be more cost effective than taping. A cost benefit analysis has shown that ankle taping can be three times more expensive than bracing over one season. Research has also shown that bracing is
significantly more effective at providing mechanical support throughout the duration of exercise. It has been reported that taping can lose its effectiveness after only twenty minutes of exercise.\textsuperscript{12, 13, 70, 71} Furthermore, bracing has been shown to be more beneficial than taping in reducing the occurrence of ankle sprains.\textsuperscript{12, 13} The results of nineteen studies have shown that the use of semi rigid braces restricted inversion ROM 21.3\% more than tape before exercise and 72.1\% after exercise.\textsuperscript{13} Additionally, in a study conducted on American football players over a seven year period, Rovere et al\textsuperscript{12} found that a lace up ankle brace reduced the incidence of injury by fifty percent. Furthermore, a review of the literature by Verhagen, et al\textsuperscript{68} found that bracing is more effective at preventing ankle sprains in those individuals who have already sustained a previous sprain. These results seem to provide the clinician and athlete with many reasons to choose ankle bracing.

**The Swede-O Universal Ankle Brace**

The Swede-O brace has been shown to be an effective brace at preventing inversion ROM both before and after exercise.\textsuperscript{70, 72} Martin and Harter\textsuperscript{70} conducted a study in which they measured healthy subjects’ active inversion ROM both before and after a vigorous 20 minute obstacle course consisting of forward sprinting, lateral movements, vertical jumping, and backward running. While wearing the Swede-O brace, subjects had significantly less inversion ROM before and after exercise compared to the control and the ankle tape groups. Similarly, Gross et al\textsuperscript{73} found the Swede-O brace to significantly reduce passive eversion and inversion ROM before exercise. Following exercise, subjects in the taping group experienced a significant increase in passive inversion, while the
Swede-O group did not. Metcalfe et al\textsuperscript{72} also conducted a study measuring ROM during a 20 min exercise protocol. Their results showed that the Swede-O brace group had significantly less inversion, plantar flexion, and dorsiflexion ROM than the group wearing no brace. Furthermore, a study performed by Shaw et al,\textsuperscript{26} used healthy subjects and compared the Swede-O brace to the Active Ankle brace at improving dynamic stability at the ankle. Subjects’ dynamic stability was measured both before and after fatigue by using TTS measurements. Their results found that the Swede-O brace was effective at preventing increases in APTTS after fatigue, where the Active Ankle and control groups both took longer to stabilize. The results of these research studies suggest that the Swede-O Universal brace may be effective at providing mechanical stability throughout exercise and also may be effective at improving dynamic stability under fatigued conditions.

**Ankle Prophylaxes and Sensorimotor Function**

The effects of ankle braces on measures of sensorimotor function, such as proprioception, peroneus longus reaction time, and postural control is not clearly understood.\textsuperscript{13} It has been speculated that by using ankle prophylactic devices, such as taping and bracing, proprioception can be enhanced and therefore ankle sprains can be prevented. This conclusion has been drawn by the fact that these external support devices can provide stimulation to the cutaneous mechanoreceptors around the ankle joint.\textsuperscript{13} These mechanoreceptors in the skin of the plantar surface of the foot provide sensory feedback regarding the positioning of the foot and ankle.\textsuperscript{71} Therefore, by using ankle braces to improve proprioceptive mechanisms, healthy athletes may be able to prevent
ankle sprains from occurring and those who have already sustained an ankle sprain may be able to prevent subsequent sprains from reoccurring. However, the literature regarding the effects of ankle prophylactic devices on proprioception seems to be inconclusive, but some research has found positive results regarding the effect of ankle bracing on proprioception. Feuerbach et al.\textsuperscript{74} measured joint position sense before and after the application of a semi-rigid brace and also after anesthetizing the ATFL and CFL. No significant differences were found between the anesthetized and nonanesthetized conditions, but they found subjects had significantly less error in matching reference points after the application of a brace. The authors concluded that the mechanoreceptors in the ligaments may not play an important role in proprioception at the ankle, however the application of an ankle brace seems to enhance the cutaneous receptors in the foot. Furthermore, Jerosch et al.\textsuperscript{75} found that the application of a lace up style brace was associated with less error in joint reposition sense when compared to a control, tape, and semi-rigid brace condition. A similar study also found less angle reproduction error in inversion and plantarflexion after the application of a lace up style brace as well as in the tape condition.\textsuperscript{76}

The peroneal muscles have an important role in providing dynamic stability against inversion, the primary mechanism for ankle injury.\textsuperscript{77} The peroneus longus is responsible for controlling excessive motion at the ankle and preventing an ankle sprain from occurring; therefore, its response time and reflex amplitude during sudden inversion are thought to be very important factors in preventing injury.\textsuperscript{77} Ashton-Miller et al.\textsuperscript{78} proposed that when the peroneal muscles are recruited, they are the best natural protection against injury because they immediately provide restraint against inversion. It
has been speculated the application of an ankle brace provides pressure around the joint, which stimulates the mechanoreceptors and the peroneus longus motoneuron, and in turn helps prevent lateral ankle injuries. However, the effects of ankle prophylactic devices on the activation and reflex amplitude of the peroneals seem to be inconsistent. Nishikawa and Grabiner, looked at the effect of a semi-rigid ankle brace on the excitability and Hoffman-reflex (H-reflex) of the peroneus longus in healthy individuals. They found that after the application of the brace, the normalized H-reflex amplitude increased by 10%. They concluded since the H-reflex is a measure of peroneal a-motoneuron excitability, the application of an ankle brace may cause the stimulation of a greater number of motoneurons. Similarly, Cordova and Ingersoll compared the peroneus longus stretch reflex amplitude following the immediate and long term application of a semi-rigid and lace-up style brace. They examined the latency of the peroneus longus by measuring the electrical activity of the muscle during a sudden inversion movement caused by the release of a trap-door mechanism. They found that immediately after the application, the lace-up style brace was associated with significantly higher stretch reflex amplitudes than the semi-rigid or control groups. They concluded that the lace-up style brace covers more area than the semi-rigid brace, thus stimulating more cutaneous receptors. The stimulation of more receptors would lead to more afferent signals being delivered to the CNS. They also found that after eight weeks of application, subjects in the semi-rigid group had significantly greater stretch reflex amplitudes than those of the lace-up group or control group. In disagreement to these results, Shima et al. also used the trap door to simulate a sudden inversion mechanism, but actually found peroneal reflex latency to be delayed after taping or bracing. These
results were found in both normal and hypermobile ankles. These results were consistent with those of Gribble et al, who looked at the activation of the peroneus longus during a dynamic lateral shuffling task. They found no differences in the activation of the muscle after the immediate application of an ankle brace. They also found no significant differences in peroneus longus activation following two weeks of constantly wearing the brace. The research regarding peroneal muscle activation following the application of ankle brace seems to provide inconclusive evidence. However, there is research providing positive effects of ankle bracing on peroneus longus function and the application of an ankle brace has not been shown to cause detrimental effects on activation of the peroneals, so their use should not be discontinued because of this reason.

The effect of ankle bracing on postural control also seems to show conflicting results in the literature. A decrease in postural control has been found be linked to an increased risk of ankle injury. If the application of an ankle brace can improve postural control, those with deficits may be able to prevent recurring sprains. Kinsey et al measured the COP trajectory in the AP and ML directions during six different modified Rhomberg tests. The application of an ankle brace did not cause a significant effect to occur in any of the measured variables. Feuerbach and Grabiner found varying results when looking at the effects of an ankle brace on postural sway during static and dynamic tasks. They used the Chattecx Balance System to measure vertical reaction forces during a single leg stance. Subjects completed static trials and then dynamic trials, where the platform they were standing on was rotated underneath them. During the static trials, subjects experienced significantly less AP and ML sway amplitude after the application of a semi-rigid brace. They also found significant decreases in the frequency of AP and
ML sway during the dynamic task after the application of the brace. This suggests that the application of an ankle brace may help to improve postural control. However, no significant differences were found in AP and ML sway amplitude during the dynamic task or in AP sway frequency during the static task.

The results of these studies seem to provide inconsistent results. Further research is needed to determine the effect of ankle braces on postural control. It should be noted that all of these studies were using healthy subjects. If CAI subjects with greater deficits in postural control had been used, the results could have differed. Additionally, these studies were conducting using static or simple dynamic task. A more challenging sport specific task would allow researchers to examine how postural control is affected during skills that are common mechanisms of ankle injury, such as landing from a jump.

**Time to Stabilization**

Static measures of postural control may not be challenging enough to examine deficits occurring in those with CAI, so a more dynamic method is needed to determine individuals with these deficits. Time to Stabilization (TTS) is a measurement of dynamic stability using a single-leg jump landing task. TTS measurements can help to identify individuals who have impaired dynamic stability and therefore help identify those at an increased risk of reinjury. TTS is a challenging task, causes high ground reaction forces (GRF), and closely mimics the demands of sport. TTS requires a single-leg landing following a jump, which is a common mechanism for a lower extremity injury, with up to 45% of ankle injuries occurring during a jump-landing. During a forward jump-landing, the muscles of the lower leg must eccentrically contract to
decelerate and stabilize the center of mass. If controlled deceleration is not achieved, the body will be forced to land with the foot flat and an extended body position, thus increasing the GRF’s and increasing injury risk. It has been suggested that eccentric strength and neuromuscular control during a jump-landing are imperative to preventing injury to the lower extremity. If TTS measurements can identify individuals with deficits in dynamic postural control, ankle sprains related to these deficits may be prevented.

The technique of calculating TTS, as reported by Ross and Guskiewicz, is used to determine dynamic postural stability in those with healthy and unstable ankles. The technique measures dynamic stability as the time it takes for the range of variation of the GRF at the beginning of the jump landing to become similar to the range of variation of the GRF in a single-leg stance. The range of variation is the smallest absolute range value of the ground reaction force AP and ML components during the single-leg stance. A horizontal line, equal to the smallest absolute range value of the AP and ML components of the ground reaction is inserted over the GRF data. The TTS value is determined where an unbound third-order polynomial intersects the range of variation line of each component.

Several studies have used TTS measurements to determine deficits in dynamic postural control in subjects with CAI. However, the results of these studies vary. All of the studies had the subjects begin at a distance 70 cm. from the force platform, jump to a height equal to 50% of the maximum vertical jump height, land on a single leg, and stabilize as quickly as possible. Ross et al examined TTS values in ten subjects with stable ankles and ten subjects with functionally unstable ankles and found subjects with
FAI to take significantly longer to stabilize than those with stable ankles (1.72 ± .58s compared to 1.35 ± .30s in the AP direction and 2.23 ± .94s compared to 1.56 ± .28s in the ML direction). Brown et al\(^40\) measured TTS, along with joint position sense and electromyography to assess functional ankle instability. They measured ten healthy subjects and compared them to ten subjects with FAI. Subjects in the FAI group took significantly longer to stabilize in the AP direction compared to healthy subjects. However, no significant differences were found in the ML direction between groups. They attributed the significance in the AP direction and not the ML direction to the damage that occurs to the ATFL following multiple ankle sprains and the AP plane of the jump. Similarly, Wikstrom et al\(^45\) compared TTS measurements of 29 individuals with FAI and 29 healthy. They also found a significant difference in APTTS between groups. The authors noted that individuals with previous injury have been shown to land in a more dorsiflexed position to protect their lateral ligaments, which causes improper landing and increased GRF. This research seems to provide strong evidence regarding the reliability of TTS measurements in detecting subjects with unstable ankles.

**Fatigue**

Fatigue has been defined as “any reduction in the maximum force generating capacity, regardless of the force required in any given situation.”\(^87\) It has been found that many injuries occur at the end of a practice or a competition when fatigue has set in.\(^88\)

Fatigue occurs from physiological mechanisms that occur at both the central and peripheral levels.\(^89\) Peripheral fatigue occurs locally, generally to only one muscle or muscle group.\(^90\) The peripheral component of fatigue is related to the reduced activity of
the muscle spindles in response to metabolites and inflammatory substances such as
bradykinin, arachidonic acid, prostaglandins, and lactic acid. Central fatigue is a more
general type of fatigue, possibly stemming from lack of drive or motivation. Another
proposed theory on the central component of fatigue is that it possibly occurs because of
the generated reflexes from the muscles’ small diameter afferents in response to the
metabolic changes.

Fatigue causes changes in the muscles function and performance, placing an
individual at an increased risk for injury due to the reduction in the muscles’ ability to
protect the joint. Jackson et al measured the response of the stretch reflex of the ankle
musculature to a sudden inversion perturbation following fatigue. The results of this
study showed that the reflex amplitude was significantly less in those who were fatigued
compared to the control subjects. They concluded that fatigue may put individuals at risk
for injury because of their decreased ability to correct for an unexpected inversion.
Furthermore, Gutierrez et al examined the changes in peak torque, peak EMG, and
median frequency of the tibialis anterior, peronues longus, and lateral gastrocnemius
following continuous concentric and eccentric inversion, eversion, plantarflexion, and
dorsiflexion. Their most interesting result was the significant decrease in median
frequency and firing rate of the peroneus longus after plantar flexion fatigue. They noted
that fatigue to the plantarflexors is common during sports requiring jumping, cutting, and
landing, and it is during these activities that ankle sprains commonly occur. If the
peroneus longus also experiences decreased firing during fatigue of the plantarflexors, it
seems that lateral stabilization by the peroneus longus would be reduced, increasing the
risk for a lateral ankle sprain.
Fatiguing protocols only using isokinetic measures traditionally consist of isolated joint movements and isolated muscle groups in the open kinetic chain.\textsuperscript{84} This method of inducing fatigue does not expose the athletes to the same demands as athletic training or competition and therefore more functional fatigue protocols should be used.\textsuperscript{84} These protocols will give researchers insight to the changes that occur with fatigue during athletic participation and will allow results to be applicable outside the laboratory in a functional setting.\textsuperscript{84} Wikstrom et al\textsuperscript{84} compared the effects of an isokinetic fatigue protocol and a functional fatigue protocol on TTS measures. They tested twenty healthy male subjects on their TTS before and after each one of the fatiguing protocols. The isokinetic protocol consisted of continuous concentric contractions of the plantarflexors and dorsiflexors until the torques of each decreased below 50\% of their peak values for 3 consecutive trials. The functional protocol consisted of six stations including: the Southeast Missouri Agility Drill, plyometric box jumps, side-to-side bounds, minitramp jumps, cocontraction arc, and a two-legged hop sequence. Subjects completed this protocol continuously until their time increased by 50\% compared to their baseline trial time. They found that after performing both protocols, subjects had significantly longer vertical TTS times and increased GRF, however, no significant results were found between the two protocols. It should be noted that these researchers used healthy subjects with no deficits in dynamic stability, so these results may not apply to subjects with unstable ankles.

It has also been demonstrated that fatigue causes changes in the biomechanics of the lower extremity.\textsuperscript{93, 94} Orishimo and Kremenic\textsuperscript{93} performed a study in which they measured the biomechanical changes that occur in response to a fatigue protocol
consisting of step-ups. They found that subjects took more time to decelerate the center of mass, resulting in significant increases in knee flexion at landing after fatigue was induced. They also found that after fatigue, the ankle remained in a dorsiflexed position throughout the landing, plantar flexion moment was significantly increased, and the ankle contributed more to the maximum total support moment increased. They concluded that because of the fatigue occurring in the proximal musculature, the ankle was forced to slow the forward progression of the center of mass and prevent lower extremity collapse.

In a study conducted by Augustsson et al, the hip moments and GRF were measured during a single-leg hop take-off and landing following fatigue. When fatigue was induced, subjects had significantly less AP GRF during take-off and were significantly worse at generating power at the hip, knee, and ankle joints and also experienced decreased joint moments at all of these joints. Fatigued subjects jumped significantly less distance, resulting in lower GRF during landing as well as decreased hip moments. These results seem to provide evidence that fatiguing proximal musculature causes altered biomechanics to occur in the lower extremity, contributing to the increased risk for injury.

Fatigue has been linked with a decrease in postural control due to the decreased activity of the muscle spindles, which play an important role in maintaining stability. Research has found that deficits in postural stability occur when individuals are in a fatigued state. Some studies have only used static or simple postural control measures such as postural sway and balance measurements and many have found deficits in postural control occurring in response to fatiguing protocols. Measures of static postural control are very simple tasks and they may not recognize deficits that occur
during demanding sport specific activities. More dynamic measure of postural stability, such as the Star Excursion Balance Test (SEBT) and Time to Stabilization, have been used to determine postural control impairments occurring with fatigue. Gribble, et al$^{30}$ used the SEBT to determine how dynamic postural control is effected by fatigue and CAI. They found that after fatigue, the injured side of the CAI group had a significantly greater reduction in maximum reaching distances, knee flexion, and hip flexion than on their uninjured side or when compared to healthy controls. This suggests that fatigue causes alterations to occur at the proximal leg musculature especially in those with CAI, resulting in a decrease in postural control and decreased performance during the task. In a study conducted by Shills, et al$^{96}$ fatigued subjects with and without CAI were used to determine deficits in dynamic stability occurring after fatigue. They found significant increases in TTS measures in both groups following the inducement of fatigue. Furthermore, Shaw et al$^{26}$ used TTS to determine how fatigue and the application of an ankle brace could influence dynamic stabilization. They put healthy subjects through a functional fatigue protocol consisting of the SEMO agility drill, stationary lunges, and quick jumps at 50% of their vertical jump maximum. They found that during the control condition and while subjects were wearing the Active Ankle brace, their APTTS increased, while the Swede-O ankle brace was effective at decreasing APTTS. This suggests that the application of a Swede-O brace may be capable of overcoming the deficits in dynamic stability caused by fatigue. However, this study used only healthy subjects, so the results cannot be applied to subjects with CAI.
Summary

According to previous research, individuals with CAI experience many deficits, most notably that of the reduction in postural control. Research has also been conducted to support the hypothesis of the negative effects of fatigue on postural control in both CAI and healthy subjects. Ankle braces have been shown to be effective interventions at preventing recurring ankle sprains. Furthermore, the application of a Swede-O Universal ankle brace has been proven to improve dynamic stability in healthy subjects after the onset of fatigue. TTS uses a single-jump landing, mimicking sport and ankle injury mechanisms and is dynamic way to measure postural control. There is currently no evidence to support the effectiveness of a Swede-O Universal brace at improving dynamic stability in those with CAI, measured by TTS, after fatigue.
Chapter 3

Experimental Design & Methods

Subjects

Twenty six physically active individuals between the ages of 18 and 35 were recruited from the university community and volunteered as subjects for the study. Thirteen of these individuals were healthy control subjects with no previous lower extremity injury (23.38462±3.90595 yr; 68.23077±3.11325 in; 71.00231±13.6844 kg). The other thirteen subjects had self-reported CAI (20.76923±1.58923 yr; 68.76923±4.51209 in; 73.89846±13.30357 kg). Subjects were matched according to age, height, sex, mass, and involved leg. CAI was defined by a history of at least one acute ankle sprain that resulted in swelling, pain, and temporary loss of function (but none in the previous 3 months); and a history of multiple episodes of the ankle “giving way” in the past 6 months. All subjects were given a questionnaire to fill out regarding their previous ankle injuries (Appendix B). Additionally, subjects with self-reported CAI filled out the Foot and Ankle Disability Index (FADI) and the FADI Sport Scale (Appendix C). These instruments have been used to determine CAI group inclusion using cut-off scores of <90% on the FADI and <80% on the FADI Sport Scale.\textsuperscript{42,43,97} Also, all subjects read
and signed an informed consent form that was approved by the University Institutional Review Board (Appendix A).

**Instrumentation**

A Vertec vertical jump tester (Sports Imports, Columbus, OH) was used to measure the subjects’ standing, maximum and 50% maximum vertical jump height. A Bertec 4060NC forceplate (Bertec, Inc., Columbus, OH) integrated with MotionMonitor™ software (Innovative Sports Technologies Inc., Chicago, IL) was used to collect ground reaction forces during the jump-landing task, sampled at 200Hz. A Monark Ergomedic 828E ergometer (Monark Exercise AB; Vansbro, Sweden) was used during the functional fatigue protocol. A Seiko DM50L Metronome (Seiko Corp., Mahwah, NJ) was used to standardize the lunge cycles during the fatigue protocol.

**Independent Variables**

1. Group
   a. Control
   b. CAI

2. Condition
   a. No brace
   b. Brace (Swede O Universal)

3. Time
   a. Pre-fatigue
   b. Post-fatigue
Dependent Variables

1. A/P TTS (sec)
2. M/L TTS (sec)

Procedures

Each subject was asked to report to the research laboratory for three separate testing sessions, with at least one week between each session. Subjects were asked to wear comfortable lace-up athletic shoes in good condition and athletic clothing for all testing sessions. Session 1 consisted of completing paperwork (informed consent, injury history, FADI instruments), recording of height and mass, establishing the maximum vertical jump height, and establishing the baseline for the functional fatigue protocol. During sessions 2 and 3, subjects completed a single-leg jump-landing task before and after the completion of the functional fatigue protocol. The subjects completed sessions 2 and 3 either with or without the application of a Swede-O Universal brace (Swede-O Inc.; North Branch, MN). The brace condition was randomized for those two sessions.

During session 1, subjects’ maximum vertical jump height was measured using the Vertec vertical jump tester. Subjects’ standing reach height was measured first by having the subject stand next to the Vertec and instructing them to reach up with one hand and touch the highest point possible while keeping both feet flat on the ground. Next, the subject’s maximum vertical jump height was measured. The subject was instructed to jump off both feet and reach up to touch the highest point possible on the Vertec. They completed three trials and their maximum height was recorded. Each
subject’s maximum vertical jump height ($\text{Vert}_{\text{max}}$) was calculated by subtracting their standing reach height from their maximum height during the jumping trials.

After the jump trials and a 5-minute rest period, subjects then established a baseline of the fatigue protocol that was used in sessions 2 and 3. Subjects were given a demonstration of the protocol. Then, they completed 3 attempts of the protocol with 5 minutes rest between each attempt. The fastest of the three attempts was used as the baseline time to complete the protocol. The fatigue protocol consisted of a five minute warm up on a stationary bike, lower extremity stretching, and the following exercises:

1. The Southeast Missouri (SEMO) Agility Drill: The SEMO agility drill is a series of a forward sprints, diagonal backpedaling, and side shuffling. This was completed in a rectangle of 12 x 12 feet $^{27}$.

2. Stationary lunges: This consisted of five forward lunges per leg from the starting position of the SEMO agility drill. Subjects lunged forward to a distance equal to their individual leg length. Pieces of tape on the floor served as the point of origin and the target reaching distance. Lunges were performed at a rate of one lunge per two seconds. A metronome was used to establish the rate of performance for the subjects. A lung cycle was defined as having the subject reach to the target, achieve approximately 90° of hip and knee flexion in the lunging leg while maintaining an upright trunk, and returning the reaching leg back to the point of origin.

3. Quick jumps done at 50% of each subject’s $\text{Vert}_{\text{max}}$: This was done near a wall and consisted of ten quick, two-footed jumps with both arms above the head
reaching for a mark on the wall equal to 50% of the previously measured maximum jump height.

The three components were completed as fast as possible in the order that is listed. The measurement was how much time (seconds) it takes to complete the entire circuit. This protocol mimics a recent study under the direction of the faculty advisor. 26 For sessions 2 and 3, after the pre-testing procedures were completed, subjects completed the functional fatigue protocol. The subjects continually ran through the protocol until the time to finish the stations increased by 50% compared with their baseline timed runs. 26, 27 Immediately following the inducement of fatigue, subjects moved back to the jump-testing area (10 feet from the finishing point) and performed three post-test trials of the single-leg jump-landing task.

During sessions 2 and 3, subjects completed the single-leg jump-landing task before and after the fatigue protocol using either the braced or no braced conditions. The jump-landing task consisted of a jump at 50% of their Vert_{max} and a single leg landing. Subjects with CAI landed on their injured leg, while healthy subjects landed on the same leg as their CAI matched subject. For example, if a CAI subject had a right side instability, the control subject that is matched (sex, age, height, mass) to that CAI subject used the right side as their testing limb. Subjects were given instructions and demonstration of the jump landing task and afforded four practice trials prior to their test trials. 98

The task began with the subject standing 70 cm away from the force platform, then they jumped with both feet and reached up to touch the indicated marker on the Vertec, which was set at 50% of their Vert_{max}. 27,42-46,86,99 They then landed on a single
leg onto the force plate. They were instructed to land on their test leg, while stabilizing as quickly as possible and placing both hands on their hips. Subjects were given four practice trials at the beginning of the second and third testing sessions to become accustomed to the task and minimize a learning effect. During the actual testing, three trials were completed both before and after the fatigue protocol. The mean of these three trials was recorded. If they subject lost their balance or touched down with the non-test leg, it was considered a failed trial and was repeated until three successful trails were completed. At the beginning of the session 2, the randomized order of bracing conditions was revealed for the sessions 2 and 3.

**Data Processing**

The TTS values in the anterior/posterior (APTTS) and medial/lateral (MLTTS) were calculated from A/P and M/L ground reaction force data, respectively, collected during the successful landing trials. Ground reaction force data, sampled at 200 Hz, was filtered with a 4th order Butterworth filter with a cutoff frequency of 14 Hz. The TTS variables were created with the sequential estimation method using an algorithm to calculate a cumulative average of the data points from the jump-landing trials in a series by successively adding one point at a time. To determine the values for the calculation of the cumulative average of the series (sequential average of the series), the first two raw data points from the trial were averaged; then the first three raw data points were averaged; then the first four data points were averaged; and so on. These sequential averages were then compared with the overall series mean. The overall series mean was mean of all the raw data points collected during the five-second period after impacting the force plate. The subject was considered to be in a stable position when the
sequential average of the series is within 0.25 standard deviations of the overall series mean.\textsuperscript{102,103}

**Statistical Analysis**

The means and standard deviations for APTTS and MLTTS from the pre- and post-test trials were used in the statistical analysis. For each of these two dependant variables, a separate 2-within (Condition, Time), 1-between (Group) repeated measures ANOVA was performed. In the event of statistically significant interactions, a Tukey’s post-hoc test was applied. Statistical significance was set \emph{a priori} at $p<.05$. All statistical analysis was performed using SPSS 15.0 (SPSS, Inc. Chicago, IL.).

**Power Analysis**

The power analysis is based on recent work from the laboratory of the faculty advisor examining the influences on TTS that we are proposing to study.

**Influence of CAI**

A recent study conducted by the faculty advisor examining the influence of CAI on dynamic postural control reports that subjects with CAI demonstrated slower APTTS measures compared to their control subject counterparts.\textsuperscript{43}

This study included 19 subjects in each group and this result was associated with an observed power level of 0.87. Therefore, 20 subjects per group would exceed this already strong reported level of power.
Influence of Fatigue and Bracing on TTS

A recent study conducted in the laboratory of the faculty advisor examining the influence of fatigue on TTS reports that the functional fatigue protocol that was used in our study disrupts this measure of dynamic postural control; but that the ankle brace that was used in our study will help to alleviate the detriments that fatigue introduces. ²⁶

Using a within subjects design, this study included 10 subjects and the results were associated with an observed power of .79. We anticipated that increasing the number of subjects will improve the statistical power.

Summary

Based on the information above, including 20 subjects in each Group would have provided a strong level of power in all planned comparisons in our current study.

Potential Health Risks

Subjects were given verbal and visual instructions and adequate practice time for the jump-landing task and fatigue protocols in order to minimize the risk of injury. Subjects were monitored closely during to make sure they were demonstrating proper technique.

Subjects may have experienced muscle soreness due to the completion of the functional fatigue protocol. They were given at least seven days to rest following the first testing session in order for this soreness to subside. If subjects experienced any adverse reactions or problems due to testing, they were able to drop out at any time.
Anticipated Outcomes

This investigation examined the influence of a combination of two factors that can increase the likelihood of injury (previous history of ankle sprain and induced fatigue) on dynamic stability and if a commonly used intervention (ankle brace) can minimize the disruption in the measure of dynamic stability. The information from this study will help clinicians and researchers to determine if the application of an ankle brace is an appropriate intervention for this specific pathological group when placed under fatigue, mimicking potential injurious factors.

First, we have hypothesized that healthy subjects will have better dynamic postural control compared to subjects with CAI. Since TTS is a functional measure of dynamic stability, we believe healthy subjects will be able to achieve stabilization more quickly than CAI subjects. We have also hypothesized that the application of a Swede-O Universal ankle brace will improve dynamic stability in healthy and CAI subjects, as measured with TTS, during a functional jump-landing task both before and after fatigue. Furthermore, we hypothesize that fatigue will cause both groups to experience longer TTS. This will help determine whether the effects of fatigue could create additional loss of dynamic stability, thus further increasing the risk for injury.

The results of this study may help clinicians and researchers make decisions regarding the effectiveness of a Swede-O Universal ankle brace at providing dynamic stability in those with CAI, especially during athletic participation when fatigue may be a factor. If the use of an ankle brace can improve dynamic stabilization during landing from a jump under fatigue in individuals with CAI, it is likely that the risk for sustaining
an injury may be decreased. We are hopeful that our results will lead to further research in this area to continue to address these ideas.
Results

Anterior/Posterior Time to Stabilization

For APTTS, the main effect for Group was statistically significant ($F= 4.15; p=.05$) (Figure 1). Subjects in the CAI group ($1.291±0.179s$) took significantly longer to stabilize than those in the healthy group ($1.191±0.10s$). The effect size and 95% CI for this relationship was $0.69 (-0.12,1.46)$.

The main effect for Time was not statistically significant ($F= 3.378; p=.078$) (Figure 2). While not significantly different, subjects took longer to stabilize in the post-fatigue condition ($1.260±0.199s$) compared to pre-fatigue ($1.222±0.105s$). The effect size and 95% CI for this relationship was $0.24 (-0.31,0.78)$.

The main effect for Condition was not statistically significant ($F=.000; p=.993$) (Figure 3). Subjects took the same amount of time to stabilize in the braced ($1.241±0.158s$) and non-braced conditions ($1.241±0.146s$). All other comparisons had effect sizes $=0$.

The Group by Time interaction was not statistically significant ($F=1.819; p=.190$) (Figure 4). While not significantly different, both CAI and control subjects took longer to stabilize in the post-fatigue condition (CAI: $1.324±0.246s$; Control: $1.196±0.112$)
compared to the pre-fatigue condition (CAI: 1.258±0.111s; Control: 1.185±0.087s). The effect size and 95% CI for the Pre-fatigue CAI vs. Control comparison was 0.73 (-0.08,1.50). The effect size and 95% CI for the Post-fatigue CAI vs. Control comparison was 0.67 (-0.14,1.44). All other comparisons had low effect sizes =0.35.

The Group by Brace interaction was not statistically significant (F=.001; p=.982) (Figure 5). Both CAI and control subjects took almost exactly the same amount of time to stabilize in the braced (CAI: 1.291±0.184s; Control: 1.190±0.111s) and non braced conditions (CAI: 1.291±0.129s; Control: 1.191±0.089s). The effect size and 95% CI for the No Brace CAI vs. Control comparison was 0.89 (0.07,1.68). The effect size and 95% CI for the Braced CAI vs. Control comparison was 0.66 (-0.14,1.43). All other comparisons had effect sizes =0.

The Time by Brace interaction was not statistically significant (F=.209; p=.651) (Figure 6). While not significantly different, subjects with and without an ankle brace took longer to stabilize in the post-fatigue condition (Braced: 1.265±0.217s; Non: 1.255±0.181s) compared to pre-fatigue (Braced: 1.217±0.099s; Non: 1.226±0.110s). All other comparisons had low effect sizes =0.28.

The Group by Time by Brace interaction was not statistically significant (F=.002; p=.965) (Figure 7). While not significantly different, CAI and control subjects with and without an ankle brace took longer to stabilize in the post-fatigue (CAI Braced: 1.329±0.265s; CAI Non: 1.318±0.228s; Control Braced: 1.200±0.137s; Control Non: 1.191±0.088s) condition compared to pre-fatigue (CAI Braced: 1.253±0.102s; CAI Non: 1.263±0.120s; Control Braced: 1.181±0.085s; Control Non: 1.190±0.089s). The effect size and 95% CI for the Pre-fatigue, No Brace CAI vs Control comparison was 0.69 (-
The effect size and 95% CI for the Pre-fatigue, Braced CAI vs Control comparison was 0.77 (-0.05, 1.54). The effect size and 95% CI for the Post-fatigue, No Brace CAI vs Control comparison was 0.73 (-0.08, 1.50). The effect size and 95% CI for the Post-fatigue, Braced CAI vs Control comparison was 0.61 (-0.19, 1.38). All other comparisons had low effect sizes =0.38.

**Medial/Lateral Time to Stabilization**

For MLTTS, the main effect for Group was not statistically significant (F= .340; p= .565) (Figure 8). While not significantly different, subjects in the CAI group (1.435±0.115s) took longer to stabilize than those in the healthy group (1.407±0.144s). The effect size for this comparison was low at 0.21 (-0.56, 0.98)

The main effect for Time was not statistically significant (F= .561; p=.461) (Figure 9). Subjects actually took longer to stabilize in the pre-fatigue condition (1.424±0.132s) compared to post-fatigue (1.417±0.130s). The effect size for this comparison was low at 0.05 (-0.72, 0.82).

The main effect for Condition was not statistically significant (F=.1.941; p=.176) (Figure 10). While not significantly different, subjects took less time to stabilize in the braced condition (1.408±0.113s) compared to the non-braced condition (1.433±0.148s). The effect size for this comparison was low at 0.19 (-0.59, 0.95)

The Group by Time interaction was not statistically significant (F=.031; p=.862) (Figure 11). Both CAI and control subjects actually took less time to stabilize in the post-fatigue condition (CAI: 1.431±0.113s; Control: 1.404±0.146s) compared to the pre-
fatigue condition (CAI: 1.439±0.117s; Control: 1.409±0.141s). All comparisons for this interaction had low effect sizes =0.23.

The Group by Brace interaction was not statistically significant (F=.453; p=.507) (Figure 12). While not significantly different, both CAI and control subjects took less time to stabilize in the braced condition (CAI: 1.428±0.124s; Control: 1.388±0.102s) compared to the non-braced condition (CAI: 1.441±0.106s; Control: 1.425±0.186s). All comparisons for this interaction had low effect sizes =0.35.

The Time by Brace interaction was not statistically significant (F=.000; p=.994) (Figure 13). Both in the braced and non-braced conditions, subjects actually took less to stabilize in the post-fatigue condition (Braced: 1.405±0.113s; Non: 1.430±0.147s) compared to pre-fatigue (Braced: 1.412±0.113s; Non: 1.436±0.150s). All comparisons for this interaction had low effect sizes =0.19.

The Group by Time by Brace interaction was not statistically significant (F=1.220; p=.280) (Figure 14). While not significantly different, control subjects with an ankle brace took longer to stabilize in the post-fatigue (1.390±0.112s) condition compared to pre-fatigue condition (1.387±0.091s). Control subjects not wearing an ankle brace actually took less time to stabilize in the post-fatigue condition (1.418±0.181s) compared to the pre-fatigue condition (1.432±0.191s). CAI subjects wearing an ankle brace actually took less time to stabilize in the post-fatigue condition (1.420±0.117s) compared to pre-fatigue (1.437±0.130s). CAI subjects not wearing an ankle brace took the same amount of time to stabilize in the pre-fatigue (1.441±0.104s) and post-fatigue (1.441±0.109s). All comparisons for this interaction had low effect sizes =0.30.
Table 4-1. Subject Demographics

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<tr>
<td>20.76923±1.58923 yr</td>
<td>23.38462±3.90595 yr</td>
<td>68.76923±4.51209 in</td>
<td>68.23077±3.11325 in</td>
<td>73.89846±13.30357 kg</td>
<td>71.00231±13.6844 kg</td>
</tr>
</tbody>
</table>
Figure 4-1. APTTS Group Main Effect

$F = 4.150; p = .05$
Figure 4-2. APTTS Time Main Effect

F= 3.378; p=.078
Figure 4-3. APTTS Condition Main Effect

F=.000; p=.993
Figure 4-4. APTTS Group by Time Interaction

F=1.819; p=.190
Figure 4-5. APTTS Group by Brace Interaction

F=.001; p=.982
Figure 4-6. APTSS Time by Brace Interaction

$F = 0.209; p = 0.651$
Figure 4-7. APTTS Group by Time by Brace Interaction

$F = .453$;

$p = .507$
Figure 4-8. MLTTS Group Main Effect

F = .340; p = .565
Figure 4-9. MLTTS Time Main Effect

F=.561; p=.461
Figure 4-10. MLTTS Condition Main Effect

F=1.941; p=.176
Figure 4-11. MLTTS Group by Time Interaction

$F=0.031; p=0.862$
Figure 4-12. MLTTS Group by Brace Interaction

$F = .453; \ p = .507$
Figure 4-13. MLTTS Time by Brace Interaction

F=.000; p=.994
Figure 4-14. MLTTS Group by Time by Brace Interaction

F=1.220; p=.280
Chapter 5

Discussion

The purpose of this study was to determine if the application of a Swede-O Universal ankle brace could overcome the effects of fatigue and CAI and improve dynamic stability, measured by Time to Stabilization after a single leg jump landing. First, we hypothesized that healthy subjects would have better dynamic postural control compared to subjects with CAI. Previous research conducted by Ross et al. found subjects with FAI to take significantly longer to stabilize than those with stable ankles. Similarly, Brown et al. and Wikstrom et al. found subjects with unstable ankles to take significantly longer to stabilize in the AP direction compared to healthy subjects. However, no significant differences were found in the ML direction between groups. They concluded that the AP plane of the jump and the damage to the ATFL following ankle sprain were the reasons that AP differences were seen and ML differences were not. The results of our study are in agreement with the findings of decreased dynamic stabilization in the CAI group in the A/P direction, but not in the M/L direction. TTS was measured following a single leg jump landing from a jump in a forward direction, possibly explaining why no ML differences were seen.
Furthermore, we hypothesized that fatigue would cause dynamic stability to diminish and both groups would experience longer TTS times. Wikstrom et al.\textsuperscript{84} found that after performing both an isokinetic and a functional fatigue protocol, subjects had significantly longer vertical TTS times and increased GRF. Also, the results of a studies conducted by Gribble, et al.\textsuperscript{30} and Shills, et al.\textsuperscript{96} using the SEBT and TTS found decreases in dynamic postural control following the inducement of fatigue. Fatigue has been linked with a decrease in postural control due to the decreased activity of the muscle spindles, which play an important role in maintaining stability.\textsuperscript{90} Previous research, along with the results we have found agree that deficits in postural stability occur when individuals are in a fatigued state.\textsuperscript{95} Both healthy subjects and those with CAI took longer to stabilize in the AP direction after fatigue. While the main effect result was not statistically significant between the pre and post-fatigue conditions, it did approach significance (p=0.078). However, the effect size for this relationship was low (\(d=0.24\)). One possibility for the lack of significance between pre and post-fatigue trials is the large number of thrown out trials that occurred during the post-fatigue jumps. Fifteen of the twenty six subjects failed at least one post trial after fatigue without a brace, with seven of those being CAI subjects. Eighteen of the twenty six subjects failed at least one post trial with a brace, with nine of those being CAI subjects. A trial was considered failed if the subject lost their balance and had to touch down with their other leg. This possibly suggests that the subjects had such diminished dynamic stability that they couldn’t even hold a single leg landing. If the subjects failed a trial, it allowed for them to have extra time to reset themselves and have more rest. This possibly could have been enough time for the effects of fatigue to wear off, considering subjects failed as many as six post-fatigue trials.
We had also hypothesized that the application of a Swede-O Universal ankle brace would improve dynamic stability in healthy and CAI subjects, both before and after fatigue. The results of our study found no significant differences in APTTS or MLTTS once an ankle brace was applied in either the control group or the CAI group. This is similar to the results of a study conducted by Wikstrom, et al\(^\text{37}\) where no differences were found in any measures of dynamic stability between the braced and no braced conditions in subjects with functionally unstable ankles. Similarly, Gribble et al\(^\text{104}\), using subjects with CAI, did not observe differences in TTS with or without the application of the same ankle brace used in this current study. These results suggest that the application of an ankle brace may not improve dynamic stability in either healthy subjects or those with unstable ankles. Another possibility is that the TTS method may not be the best way to determine the effects of an ankle brace. TTS has been a proven method in detecting those with unstable ankles.\(^\text{40,45}\) However, TTS may not be able to measure the effectiveness of ankle braces at preventing ankle sprains. TTS is a measure of dynamic stability after a single leg jump landing, which is a functional task, but does not put the subject into an injurious inversion mechanism. The results of our study show that ankle braces may not improve dynamic stability after a single leg jump landing, but these results may not be applicable to their effectiveness at preventing ankle sprains.

It is possible that the application of an ankle brace may not be as important to dynamic stability as proper muscle pre-activation. Gribble et al\(^\text{57}\) determined that the application of an ankle brace had no effects on peroneal muscle activation on a lateral shuffling movement among healthy tennis players. Additionally, Shima et al\(^\text{80}\) actually found peroneal reflex latency to be delayed after taping or bracing in healthy and unstable...
ankles. This could possibly mean that ankle braces do not contribute to muscle pre-activation and thus may not help protect against injurious mechanisms. The effects of ankle bracing on postural control also seem to be inconclusive.\textsuperscript{74,82} The results of these studies seem to suggest that more research should be conducted regarding the effects of ankle braces on measures of sensorimotor function, peroneus longus activation, and postural control.

Even though some of our hypotheses were not supported, there are still some clinical implications that can be taken from this study. One possible reason for the lack of significant results could be from the sample size. Our initial power analysis determined that twenty subjects in each group would be needed. However, due to time constraints and subject compliance we were only able to test thirteen subjects in each group. This left us with post-hoc power between 0.050-0.498 for APTTS comparisons and 0.050-0.267 for MLTTS.

For the APTTS data, there are several interesting relationships that are associated with moderate or strong effect sizes ranging between 0.61-0.89. In these main effects and interactions, Group seems to be the underlying factor that drives these relationships. This goes back to our first stated finding, which was statistically worse dynamic APTTS for the CAI group. The main effect for Group had a moderate effect size, which is expected. Interactions with Group, Time and Brace were also observed, but many of these effect sizes had confidence intervals that crossed zero, diminishing the strength of these comparisons. The strongest effect was in the No Brace condition among the Group by Brace interaction in which the CAI-Control Group differences were associated with an effect size of 0.89 with a confidence interval that did not cross zero. This relationship
seems to summarize what we have discussed above, which is there was no important influences of fatigue or brace on the performance on dynamic stability, while Group seems to be the most important factor.

Limitations

There were several limitations we have realized could have possibly altered the results of our study. The first possible limitation being the large number of failed trials after fatigue. When subjects failed trials they were able to have more rest and time before their recorded trials, possibly allowing time for the effects of fatigue to be reversed. This would have caused changes in the post-fatigue TTS times. Along these lines, subjects fatigue was based on their performance time, not measured by an objective measure, such as EMG. This could have caused subjects to quit before they were truly “fatigued” and caused their post-fatigue trials to be altered. Another possible limitation was the lack of familiarity subjects had with wearing ankle braces. Subjects commented on the uncomfortable feeling they had while wearing the brace and how they felt it changed their movements and jumping. The presence of an ankle brace could have caused subjects to concentrate more on the brace then on the jump-landing task.

Future Directions

Although our study did not prove any significant results regarding the effects of an ankle brace on dynamic stability we feel that future research should be conducted to come to a more solid conclusion. We feel that significant results could be seen with the addition of more subjects.
Also, our study brings up very important questions regarding ankle braces and their effectiveness at providing stability during a jump-landing. It seems we could have seen different results had subjects not failed so many post-fatigue trials. This in itself brings up questions for researchers and clinicians. It seems there needs to be a better way to measure dynamic stability immediately after fatigue for more accurate results. We feel more significant results would possibly be seen if this occurred.

It also could be speculated that the TTS measurement may not be the best way to measure the effectiveness of applying an ankle brace on preventing ankle sprains. Future research should be aimed at determining if the brace truly has no effect on dynamic stability or rather if there is another measure that may be more accurate at detecting the difference.

**Conclusion**

This study was conducted to determine if the application of ankle braces, specifically the Swede-O Universal, are effective in helping athletes, specifically those with CAI, stabilize from a jump landing. Consistent with previous research, we found subjects with CAI to take significantly longer to stabilize in the Anterior/Posterior direction from a single leg jump landing. Although, not statistically significant, we found that fatigue did negatively affect dynamic stability, with subjects taking longer to stabilize in the AP direction during the post-fatigue trials compared to pre-fatigue; but fatigue did not have as great an influence as we expected. Contradictory to our hypotheses, we did not find the application of a Swede-O Universal ankle brace to provide any significant changes to jump landing stabilization. We found no TTS changes
for healthy or CAI subjects in either the pre or post fatigue trials once an ankle brace was applied. The effects of ankle braces in preventing ankle sprains and providing mechanical stability seem to be well understood. However, the results of our study provide questions regarding the use of ankle braces for improving dynamic stability measured with TTS in both a healthy population and those with CAI. Further research, with a larger sample size should be conducted to make a better decision regarding the effectiveness of ankle braces in improving single-leg jump landing stabilization.
References


42. Gribble PA, Robinson RH. Differences in spatiotemporal landing variables during a dynamic stability task in subjects with CAI. Scandinavian Journal Medicine and Science in Sports. in press.


Appendix A

Human Subjects Consent Form

INFORMED CONSENT FORM FOR HUMAN RESEARCH STUDY
University of Toledo

Title of Project: Effects of ankle bracing and fatigue on time to stabilization among those with chronic ankle instability

Person in Charge: Sari Cattoni
University of Toledo
Athletic Training
2801 W Bancroft St.
Toledo, OH 43606
Office Phone: (419) 530-4303
Email: saricattoni@yahoo.com

1. This section provides an explanation of the study in which you will be participating:

   A. The study in which I am participating is part of research intended to assess the effects of ankle bracing and fatigue on time to stabilization after a jump-landing task in subjects with chronic ankle instability.

   B. If I agree to take part in this research, I certify that I have not had any injury, specifically to the ankle or head, that has not caused me to miss a significant amount of time in my sport, and that I am not suffering from any diseases or illnesses that would prevent me from performing the study.

   C. I will be asked to report to the Athletic Training Research lab in the Health and Human Services building on the campus of the University of Toledo on two separate occasions. The first session will comprise of filling out a health history questionnaire, measurement of my vertical maximum jump, a familiarization with and timed run through of the functional fatigue
protocol, and a familiarization with the jump-landing protocol. I will then do three trials of the jump-landing task at 50% of my vertical jump maximum, complete the fatigue protocol and then immediately complete three more jump-landing trials. I will complete the trials under either one of the following conditions: brace or no brace.

D. I will report back to the Athletic Training Research lab for one more testing session, at least seven days after my first session. I will complete the same procedures listed above under the other condition: brace or no brace.

E. The functional fatigue protocol will consist of the following stations:
1. The Southeast Missouri (SEMO) Agility Drill. The SEMO agility drill is a series of a forward sprints, diagonal backpedaling, and side shuffling. This will be completed in a rectangle of 12 x 19 feet.

2. Stationary lunges. This will consist of five forward lunges per leg from the starting position of the SEMO agility drill.

3. Quick jumps done at 50% of each subject’s Vert_{max}. This will be done near a wall and will consist of ten quick, two-footed jumps with both arms above the head reaching for a mark on the wall.

I will continue to run through each station until fatigue is induced. Fatigue will be determined as the point at which the time it takes me 50% longer to finish the stations compared to the baseline timed run.

2. This section describes your rights as a research participant:

A. I understand that I may ask the investigator any questions about the research procedures, and these questions will be answered.

B. My participation in this research is confidential. Only the person in charge will have access to my identity and information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed. To make sure my participation is confidential, only a code number will appear on the data collection sheet. Only the researchers can match my name with my code number.

C. My participation is voluntary. I am free to stop participating in the research at any time, or to decline to answer any specific questions without penalty.
D. I may contact the Office for Research, 2300 University Hall, University of Toledo, Toledo, OH 43606, (419) 530-2844, for additional information concerning my right as a research participant.

3. This section indicates that you are giving your informed consent to participate in the research:

**Participant:**

I agree to participate in the scientific investigation described above, as an authorized part of the education and research program of the University of Toledo.

I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge and belief, I have no physical or mental illness or difficulties that would increase the risk to me of participation in this study.

I understand that my participation in this study does not entitle me to any compensation, financial or otherwise.

I understand that my participation in this research is voluntary, and that I may withdraw from this study at any time by notifying the person in charge.

I am 18 years of age or older.

I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

I understand that I will receive a signed copy of this consent form.

_____________________________________________ ____________
Signature        Date

**Researcher:**

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

_____________________________________________ ____________
Signature        Date
Appendix B:

Health History Questionnaire

1. Age: __________
2. Height: _________
3. Weight: __________
4. What sport do you play: __________________
5. Have you sprained your non-kicking ankle in the past twelve months?:
   Yes_______ No_______
6. Which foot do you kick a ball with?: Right_______ Left_______
7. Have you ever had an injury that has caused you to miss a significant amount of time in your sport?: Yes_______ No_______
8. If yes, Explain:
   __________________________________________________________
   __________________________________________________________
9. Have you had a concussion in the past twelve months?: Yes_______
    No_______
10. If yes, explain:
    __________________________________________________________
    __________________________________________________________
11. Have you ever had a grade III concussion?: Yes_______ No_______
12. Do you suffer from vertigo, or any other neurological disorders?: Yes_______
    No_______
13. If yes, explain:
    __________________________________________________________
    __________________________________________________________
14. Are you currently suffering from the effects of a cold or flu?: Yes_______
    No_______

80
Appendix C

Functional Ankle Disability Index (FADI) and Functional Ankle Disability Index Sport (FADI Sport)

<table>
<thead>
<tr>
<th>Foot and Ankle Disability Index Items</th>
<th>Foot and Ankle Disability Index Sport Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>Running</td>
</tr>
<tr>
<td>Walking on even ground</td>
<td>Jumping</td>
</tr>
<tr>
<td>Walking on even ground without shoes</td>
<td>Landing</td>
</tr>
<tr>
<td>Walking up hills</td>
<td>Squatting and stopping quickly</td>
</tr>
<tr>
<td>Walking down hills</td>
<td>Cutting, lateral movements</td>
</tr>
<tr>
<td>Going up stairs</td>
<td>Low-impact activities</td>
</tr>
<tr>
<td>Going down stairs</td>
<td>Ability to perform activity with your normal technique</td>
</tr>
<tr>
<td>Walking on uneven ground</td>
<td>Ability to participate in your desired sport as long as you would like</td>
</tr>
<tr>
<td>Stepping up and down curves</td>
<td></td>
</tr>
<tr>
<td>Squatting</td>
<td></td>
</tr>
<tr>
<td>Sleeping</td>
<td></td>
</tr>
<tr>
<td>Coming up on your toes</td>
<td></td>
</tr>
<tr>
<td>Walking initially</td>
<td></td>
</tr>
<tr>
<td>Walking 5 minutes or less</td>
<td></td>
</tr>
<tr>
<td>Walking approximately 10 minutes</td>
<td></td>
</tr>
<tr>
<td>Walking 15 minutes or greater</td>
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<tr>
<td>Home responsibilities</td>
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</tr>
<tr>
<td>Activities of daily living</td>
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</tr>
<tr>
<td>Personal care</td>
<td></td>
</tr>
<tr>
<td>Light to moderate work (standing, walking)</td>
<td></td>
</tr>
<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
<td></td>
</tr>
<tr>
<td>Recreational activities</td>
<td></td>
</tr>
<tr>
<td>General level of pain</td>
<td></td>
</tr>
<tr>
<td>Pain at rest</td>
<td></td>
</tr>
<tr>
<td>Pain during your normal activity</td>
<td></td>
</tr>
<tr>
<td>Pain first thing in the morning</td>
<td></td>
</tr>
</tbody>
</table>

*Subjects were given the following instructions: “Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark N/A.” Subjects rate the activity as no difficulty at all (4 points), slight difficulty (3 points), moderate difficulty (2 points), extreme difficulty (1 point), unable to do (0 points), or N/A (not applicable). For pain related to the foot and ankle, subjects select no pain (4 points), mild (3 points), moderate (2 points), severe (1 point), or unbearable (0 points). The Foot and Ankle Disability Index scores are recorded as a percentage of 104 points. The Foot and Ankle Disability Index Sport scores are recorded as a percentage of 32 points.
Subject Information Form

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Foot</th>
<th>Height</th>
<th>Weight</th>
<th>Standing Reach</th>
<th>Jump Max</th>
<th>$\text{Vert}_{\text{max}}$</th>
<th>50% $\text{Vert}_{\text{max}}$</th>
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</thead>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>4</td>
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Appendix E

Functional Fatigue Protocol

SEMO Agility Drill

<p>| | |</p>
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Forward Sprint</td>
<td>Side shuffle</td>
</tr>
</tbody>
</table>

(right foot pivot, turn)  

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Backpedal</td>
<td>Side shuffle</td>
</tr>
</tbody>
</table>

(left foot pivot, turn)  

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Forward Sprint</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
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<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Backpedal</td>
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(right foot pivot, turn)
Appendix F

Data Collection Form

<table>
<thead>
<tr>
<th>Subject #: ___________</th>
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</thead>
<tbody>
<tr>
<td>Condition: Brace No Brace</td>
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<td>Group: CAI Healthy</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial</th>
<th>NF A/P</th>
<th>NF M/L</th>
<th>F A/P</th>
<th>F M/L</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
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<td>3</td>
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<tr>
<td>Avg.</td>
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</table>

Key:
- NF = No Fatigue
- F = Fatigue
- A/P = Anterior/Posterior TTS
- M/L = Medial/Lateral TTS