Effects of External Ankle Support on Ankle Kinematics and Kinetics When Performing a Drop-Cut Maneuver

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A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Exercise & Sport Sciences in the College of Arts & Sciences

Chapel Hill
2010

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ABSTRACT

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(Under the direction of Dr. Steven M. Zinder)

Objective: To compare the effect of clinically used external ankle support (EAS) conditions on ankle kinematics and kinetics between those with stable ankles and those with unstable ankles. **Design:** A repeated-measures, counter-balanced research design was used to compare a stable group and an unstable group under three conditions of EAS (no support, athletic tape, and athletic brace). **Subjects:** Twelve subjects with stable ankles and twelve subjects with a history of unstable ankles volunteered to participate. **Measurements:** Sagittal plane ankle angles at initial contact, frontal plane ankle angles at initial contact, peak vertical ground reaction force, and time to peak vertical ground reaction force were the measured while completing a drop-cut maneuver. A mixed model ANOVA was used for statistical analyses for each dependent variable. Post-hoc testing was done with Tukey's HSD. **Results:** A significant main effect for EAS was found for sagittal plane ankle angle at initial contact ($F_{2,44}$=4.278, P=0.020). Pairwise comparisons revealed that the athletic tape condition landed in less plantar flexion than did athletic brace. There was also a significant Ankle Stability x EAS interaction effect ($F_{2,44}$=3.273, P=0.047). Pairwise comparisons revealed that the unstable-athletic tape condition landed in less plantar flexion than did the unstable-athletic brace condition. There were no other significant main or interaction effects. **Conclusions:** While athletic tape did limit plantar-flexion better then athletic brace, the use of EAS cannot be supported by the current project as athletic tape and athletic brace did not limit plantar flexion when compared to no support. Unstable ankles did not alter kinematics when compared to stable ankles. EAS use did not have a significant impact on the kinetics of the drop-cut maneuver. Clinicians are encouraged to consult the larger body of research related to ankle instability and EAS when making clinical decisions.

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LIST OF ABBREVIATIONS & SYMBOLS

CAI: Chronic Ankle Instability

FAI: Functional Ankle Instability

MAI: Mechanical Ankle Instability

AS: Ankle Stability

EAS: External Ankle Supports

PVGRF: Peak Vertical Ground Reaction Force

ATFL: Anterior Talo-Fibular Ligament

CFL: Calcaneo-fibular Ligament

PTFL: Posterior Talo-Fibular Ligament

CHAPTER 1

Introduction

Reports suggest that within the general population, ankle sprains are a significant problem, as they occur at a rate of 37/1,000 people per year in the United States (Boruta, Bishop, Braly, & Tullos, 1990). This would indicate that there are approximately 30,000 ankle sprains every day in the United States alone. Ankle sprains result in 12 to 43 days of lost occupational or athletic activity (Beynnon, Renstrom, Haugh, Uh, & Barker, 2006; Jones & Amendola, 2007), with cost of treatment estimated between $318 to $914 per sprain, resulting in two billion dollars spent in the United States (Soboroff, Pappius, & Komaroff, 1984). However, these costs have most certainly escalated in the years since this study was conducted in 1984. Over half of all ankle sprains do not receive any professional medical treatment (McKay, Goldie, Payne, & Oakes, 2001) and over 70% of ankle sprains will re-occur (Yeung, Chan, So, & Yuan, 1994).

Specifically in athletes, the lateral ligament complex of the ankle is the single most injured structure in the body (Garrick, 1977; Hootman, Dick, & Agel, 2007). Injury data reported to the NCAA Injury Surveillance System indicates that ankle sprains accounted for 14.9% of all injuries across all sports (Hootman, et al., 2007) which is in agreement with past research into ankle sprains (Garrick, 1977). It was estimated that there are 11,000 ankle sprains each year in collegiate athletics and ankle sprains are a common problem in all levels of collegiate athletics (Hootman, et al., 2007).

Acutely, ankle sprains typically occur as a result of excessive inversion and plantar flexion, which damages the lateral ligament complex, or eversion, which can lead to damage of the deltoid ligament (Prentice, 2006). In sports, ankle sprains can commonly occur when landing from a jump on another player's foot such as in basketball (Garrick, 1977). This can lead to pain, disuse and loss of function of the lower extremity. Over time and repeated sprains, the ankle can become unstable as a result of mechanical changes of supportive structures and/or a decrease in the neuromuscular control of the lower extremity. This phenomenon is termed Chronic Ankle Instability (CAI) (J Hertel, 2002). There is also evidence to suggest that repeated ankle sprains can lead to alterations further up the lower extremity which may lead to increased risk for further ankle sprains, or other injury to the lower extremity (Bullock-Saxton, 1994; Friel, McLean, Myers, & Caceres, 2006).

External ankle support (EAS) has been identified as one of the four methods that may be used to treat ankle sprains in athletes. The other methods are rule changes, technical training, and proprioceptive training (Bahr, Lian, & Bahr, 1997). External ankle support use has been investigated through several means: injury outcome studies, functional performance, and range of motion (ROM) restriction. Injury outcome studies have consistently demonstrated a protective effect of EAS especially in subjects with a history of ankle sprains (Garrick & Requa, 1973; Mickel, et al., 2006; Rovere, Clarke, Yates, & Burley, 1988; Sharpe, Knapik, & Jones, 1997; Simon, 1969; Sitler, et al., 1994; Stasinopoulos, 2004; Surve, Schwellnus, Noakes, & Lombard, 1994; Tropp, Askling, & Gillquist, 1985). Researchers have concluded that EAS has a non-significant decrease in functional performance. However, any decrease in performance is offset by the protective effect of EAS (Cordova, Scott, Ingersoll, & LeBlanc, 2005; M. T. Gross & Liu, 2003). Range of motion restriction studies tend to indicate that most EAS provide significant pre-activity ROM restriction, but quickly lose their restrictive characteristics after the initiation of activity (Cordova, Ingersoll, & LeBlanc, 2000).

The research generally indicates that EAS provide protection from ankle injuries, through avoiding pathological motion, while having a non-significant impact on performance. At this time it is appropriate to examine the effect that EAS has during dynamic tasks in those with stable and those with unstable ankle. This will provide information to assist clinicians in making the best treatment choice to prevent and treat ankle sprains.

Statement of the Problem

Applying an EAS is one of the most common practices in athletic training, yet clinicians hardly have a complete understanding of their effects. Historically, the choice of EAS has been based on anecdotal evidence or personal preference of the clinician, athletes, and coaches. One could say that clinical practice has advanced beyond what can be substantiated in the literature. There are three significant areas that are lacking in the literature presently. First, while we may have an understanding of what occurs statically at the ankle when EAS is applied, dynamic movements that occur in sports have not been investigated. Secondly, there are many clinical methods of EAS, most of which have not undergone much evaluation. Lastly, healthy subjects have been the most common population in EAS research. As identified by injury outcome studies and narrative reviews, subjects with a history of ankle sprains, or those with chronically unstable ankles, will benefit the most from the use of EAS, and warrant studying as a separate group.

Therefore, the purpose of this study was to evaluate the effect of clinically used EAS conditions on the ankle kinematics and kinetics in a healthy population and those identified as experiencing CAI. This will be accomplished by measuring the kinematics of the ankle and vertical ground reaction force while performing a dynamic drop-cut maneuver under different conditions of EAS.

Independent & Dependent Variables

Independent variables:

1) Ankle Stability (AS)
    a. Stable
    b. Unstable
2) External Ankle Support (EAS)
    a. No Support
    b. Athletic Tape
    c. Athletic Brace

Dependent variables:

1) Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground
2) Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground
3) Peak vertical ground reaction force
4) Time to peak vertical ground reaction force

Research Questions

1) Is there an AS by EAS interaction among kinematic and kinetic variables?
    a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground

b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground
c. Peak vertical ground reaction force
d. Time to peak vertical ground reaction force

2) Is there a significant difference between AS, regardless of EAS, among kinematic and kinetic variables?
    a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground
    b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground
    c. Peak vertical ground reaction force
    d. Time to peak vertical ground reaction force
3) Is there a significant difference between EAS, regardless of AS, among kinematic and kinetic variables?
    a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground
    b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground
    c. Peak vertical ground reaction force
    d. Time to peak vertical ground reaction force

Research Hypotheses

1) There will be a significant AS by EAS interaction among kinematic and kinetic variables.

a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground will be significantly greater in the no support condition. Specifically, the unstable-no support condition will be greater than the stable-no support condition.

b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground will be significantly greater in the no support condition. Specifically, the unstable-no support condition will be greater than the stable-no support condition.

c. Peak vertical ground reaction force will be significantly greater in the unstable group. Specifically, the athletic tape-unstable will be higher than the athletic brace-unstable, which will be higher than the no support-unstable.

d. Time to peak vertical ground reaction force will be shorter in the unstable group. Specifically, the athletic tape-unstable condition will be shorter than the athletic brace-unstable condition, which will be shorter than the no support-unstable condition.

2) There will be a significant difference between AS, regardless of EAS, among kinematic and kinetic variables.

a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground will be significantly greater (more inversion) in the unstable group when compared to the stable group

b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground will be significantly greater (more plantar-flexion) in the unstable group than the stable group

c. Peak vertical ground reaction force will be higher in the unstable group than the stable group
d. Time to peak vertical ground reaction force will be shorter in the unstable group than the stable group

3) There will be a significant difference between EAS, regardless of AS, among kinematic and kinetic variables.
    a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground will be significantly greater (more inversion) in the no support condition than either the athletic tape or athletic brace condition
    b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground will be greater (more plantar-flexion) in the no support condition than either the athletic tape or athletic brace condition
    c. Peak vertical ground reaction force will be higher in the athletic tape and athletic brace conditions than the no support condition
    d. Time to peak vertical ground reaction force will be shorter in the athletic tape and athletic brace conditions than the no support condition

Null Hypotheses

1) There will be no significant AS by EAS interaction among kinematic and kinetic variables.
    a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground
    b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground

c. Peak vertical ground reaction force

d. Time to peak vertical ground reaction force

2) There will be no significant differences between AS, regardless of EAS, among kinematic and kinetic variables.

a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground

b. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact with the ground

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a. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground

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c. Peak vertical ground reaction force

d. Time to peak vertical ground reaction force

Operational Definitions

1. External ankle support (EAS) will be 3 conditions: 1) no external ankle support 2) Tape: athletic tape applied in a traditional closed basket weave and consists of tape adherent, friction pads, and under wrap with traditional cloth tape applied in 3

alternating stirrups and horseshoes, 1 figure 8, 4 heel locks applied over and three cover strips 3) Brace: ASO lace-up brace applied per the manufacturer's instructions

2. Initial ground contact time is defined as the point where the ground reaction forces exceed 10 Newtons as measured by the Bertec force platform system. At this point the ankle position will be noted.
3. Frontal plane motion will be defined as inversion and eversion of the ankle as measured by the Flock of Birds electromagnetic motion analysis system.
4. Sagittal plane motion will be defined as plantar-flexion and dorsi-flexion of the ankle as measured by the Flock of Birds electromagnetic motion analysis system.
5. Peak vertical ground reaction force will be defined as the maximum value as measured by the Bertec force platform system.
6. Time to peak vertical ground reaction force will be defined as the time between initial ground contact and the peak vertical ground reaction force.
7. End of the loading phase will be marked by peak knee flexion angle that occurs during the stance phase. At this point frontal and sagittal plane kinematics will be noted.
8. Ankle stability (AS) will be composed of two groups: 1) unstable ankles and 2) stable ankles
9. Unstable ankles will be defined as those subjects who self report symptoms of CAI which is specifically composed of 1) a history of ankle sprain with pain and/or limping for more than one day, 2) chronic weakness, pain, or instability that they attributed to the initial injury, and a 3) sensation of giving way of the ankle in the last 6 months.

10. Stable ankles will be defined as subjects with no history of the ankle giving way over the last six months.
11. Lower extremity dominance will be based upon which foot a subject would kick a ball with. The side the subject would kick a ball with will be considered the dominant one, while the other side will be considered the non-dominant foot.
12. Cutting maneuver will be a drop-cut task in which subjects will drop onto the force platform from a 30 cm high box, placed 10 cm away, on the leg of interest and then cut in a 45-degree angle in the opposite direction of the leg landed on.

Assumptions

1) The Flock of Birds electromagnetic motion analysis system is a valid and reliable instrument to measure frontal and sagittal plane motions at the ankle
2) The Bertec force platforms are valid and reliable instruments to measure ground reaction forces.

Limitations

1) Sample may not represent all types of active individuals that may use external ankle support. Subjects used in this study may not demonstrate the same speed, strength, and agility ability seen in high-level athletes.
2) Results will be difficult to generalize to injured athletes of all levels, due to unknown effects of injury on lower extremity speed, strength, power, etc.
3) Results from this study may not be applied to other situations where EAS are used (i.e. differences in application of tape, different braces, etc.)
4) Electromagnetic markers that are placed on subjects may not truly represent the motions that are occurring at the foot and ankle

5) Some subjects may have a previous history of EAS, which may predispose them to one type versus the other.
6) Determining CAI is based on subjective complaints, which may not be accurate.

Delimitations

1) Subjects will be recreational athletes age 18 to 30 years old from the UNC-CH campus.
2) Subjects will be tested only on the stated drop-cut maneuver, with the stated methods of EAS.
3) Testing will only take place over one session.

Significance of the Study

The time lost and future complications due to ankle injuries are significant problems in daily life and sports. It should be the goal of every clinician to use treatment methods that are grounded in solid theory and supported by research. This study will provide clinicians with a more complete understanding of what is occurring at the ankle during dynamic situations in stable and unstable ankles while wearing EAS. This information will allow clinicians to select one type of EAS over another to ensure that the most appropriate is used.

CHAPTER 2

Review of Literature

Introduction

Ankle sprains are the most common injury encountered in sports (Garrick, 1977). Unfortunately, the common perception is that any non-fractured ankle is “just an ankle sprain”. Ruth in 1961, first remarked that ankle sprains are disabling injuries that result in significant consequences and time lost, and their complications are compounded by the “it’s just a sprain” attitude (Ruth, 1961). It is ironic that the same sentiments are still shared by clinicians and researchers today, even in the face of mounting scientific evidence to the contrary.

Acutely, ankle sprains can lead to pain, disuse, significant loss of activity, and significant financial costs (Beynnon, et al., 2006; Jones & Amendola, 2007; Soboroff, et al., 1984). Chronically, ankle sprains have an insidious effect on the entire lower extremity. This is partly due to a low rate of medical care of the sprained ankle (McKay, et al., 2001), which may be a result of the “just a sprain” mindset. Ankle sprains are also associated with the development of chronic ankle instability (CAI) and negative changes that are seen further up the lower extremity (Bullock-Saxton, 1994; Friel, et al., 2006).

To fully understand the relationship between ankle sprains and EAS, several topics will be reviewed. First the relevant anatomy of the ankle region will be presented with a particular emphasis on the structures associated with ankle sprains. Next the topic of ankle sprains will be covered, with sections on epidemiology, etiology, and consequences with a particular emphasis on CAI. Next, the topic of External Ankle Supports (EAS) will be presented with sections on injury outcomes, range of motion restriction, functional performance, and practical considerations. Finally methodological considerations will be discussed that are relevant to this study.

Ankle Anatomy

Ankle stability is provided by 3 major contributors: congruity of the articulating surfaces when the joints are loaded, static ligamentous restraints, and the musculotendinous units which provide dynamic stability (J Hertel, 2002). Each of these aspects will be discussed with a particular interest towards stability and EAS. As a brief overview, the ankle complex is composed of four major bones the tibia, fibula, talus, and calcaneus. These four bones then meet to form three articulations: the distal tibiofibular syndesmosis, talocrural joint, and the subtalar joint. All three of these joints work together to accomplish all of the movements and stability of the ankle (J Hertel, 2002).

Articular Anatomy

The distal tibiofibular syndesmosis is a fibrous union of the tibia and fibula by the interosseous membrane, the anterior tibiofibular ligament, and the posterior tibiofibular ligaments. The role of this articulation in stability is to firmly attach the lateral malleolus into its position in the mortise. Only slight movement is allowed at this joint. Its function is to accommodates the wedging of the trochlea of the talus between the malleoli during dorsiflexion of the talocrural joint (Moore, Dalley, & Agur, 2006).

The talocrural and subtalar joint are considered the true ankle complex. The talocrural joint is formed by the articulation of the dome of the talus, the medial malleolus, the tibial plafond, and the lateral malleolus. This articulation can also be called a “mortise” joint. It is a hinge joint that allows the motions of plantar-flexion and dorsiflexion in the sagittal plane (McConkey, 1987). The subtalar joint is formed by the articulation between the talus and the calcaneus. This joint allows for inversion and eversion in the frontal plane. Congruity of the articulating surfaces of the ankle is of special note when the ankle is not in a neutral position. When plantar-flexed and inverted the overall bony stability of the ankle complex decreases for two reasons: first, the talus fits poorly in its mortise in this position, secondly, the lateral malleolus extends further distally than the medial malleolus, allowing excessive inversion (McConkey, 1987). This indicates that there is extra boney stability supporting the deltoid ligament, which puts the lateral ligaments at risk for injury.

The ligamentous support provided to both the talocrural and subtalar joint should be considered together for several reasons. First, anatomically they are not constrained to one joint. The medial and lateral ligaments of the ankle cross and are involved with motions occurring at both the talocrural and subtalar joints. Second, the mechanism of injury at the ankle is a result of multi-planar motion that involves both joints and therefore requires a more holistic approach to understand. The ankle receives ligamentous support from the lateral ligament complex, which is composed of three parts: the anterior talo-fibular ligament (ATFL), the posterior talo-fibular (PTFL), and calcaneofibular (CFL) ligament. These ligaments act limit the amount of inversion at the ankle. Medially, the deltoid ligament, which has four parts, stabilizes the ankle. The four parts of the deltoid ligament are the tibionavicular, the tibiocalcaneal, the anterior tibiotalar, and the posterior tibiotalar ligaments. The deltoid ligament prevents excessive eversion (J Hertel, 2002; Moore, et al., 2006).

The joint capsule of the ankle also provides some stability to the ankle joint, however in a limited fashion only (McConkey, 1987). The ATFL is the smallest of the ligaments and is primarily responsible for preventing anterior translation of the foot relative to the fibula. The CFL is the largest and is best positioned to resist inversion in the neutral position, however as plantar-flexion increases the ability to resist inversion decreases. The PTFL is poorly positioned to resist inversion at any position of the foot. It mainly prevents posterior motion of the tibia on the ankle and foot. It is injured in only the most serious of inversion sprains (McConkey, 1987).

During plantar-flexion, the nature of the lateral ligament complex changes such that there is an increase in tension and poor positioning of all three ligaments to resist inversion. When the foot is placed in plantar flexion the lateral ligaments are placed at a much greater risk for injury (Wright, Neptune, van den Bogert, & Nigg, 2000). Given that increased plantar-flexion has been identified as the motion that increases the risk for lateral ankle sprains, this motion should be the primary concern when investigating the kinematics of the ankle.

The mechanical properties of the lateral ligaments also predispose them to injury. The approximate load to failure of the ATFL is 140 Newtons, 345 Newtons for the CFL, 260 Newtons for the PTFL, and 713 Newtons for the deltoid (Attarian, McCrackin, DeVito, McElhaney, & Garrett, 1985). This results in approximately 750-800 Newtons of combined force of the lateral ligaments, which is far less than the force of landing from a half-meter jump. This may explain the high rate of injury that they experience (Mann, et al., 2002).

The subtalar joint has 2 separate joint cavities not associated with the talocrural joint. This articulation also consists of numerous ligaments however two merit discussion. The cervical ligament (CR) lies within the sinus tarsi and resists inversion. The lateral talocalcaneal ligament (LTC) runs parallel and anterior to the CFL. The LTC is smaller and weaker than the CFL, however, it still resists inversion of the subtalar joint. The ligaments of the subtalar joint are rarely injured due to their strength and configuration within the joint. Even though it may be the excessive motion at this joint (inversion or eversion) that is mostly responsible for the pathology, it is the weaker medial (deltoid) and lateral (ATFL, CFL, PTFL) ligaments that are injured (J Hertel, 2002).

Musculotendinous Units

There are no muscles contained solely within the ankle, therefore the muscles of the leg are most directly responsible for the dynamic control of the foot and ankle. There are four fascial compartments of the leg, which house the muscles of the leg. The four compartments are the anterior, lateral, deep posterior, and the superficial posterior. Dynamic stability of the foot and ankle is primarily provided by the lateral and the deep posterior compartments (J Hertel, 2002). The lateral compartment contains the fibularis longus and brevis, which evert the foot, or control inversion eccentrically during the contact phase of gait. The deep posterior compartment contains: flexor hallucis longus, flexor digitorum longus, and tibialis posterior. Tibialis posterior is the best invertor of this group and can control eversion eccentrically (Moore, et al., 2006).

The anterior compartment contains the tibialis anterior, the extensor hallucis longus, and the extensor digitorum. Collectively these muscles are responsible for dorsi-flexion of the ankle. These muscles can also come into play with eccentric control of plantar-flexion during initial heel strike of gait. The last compartment is the superficial posterior compartment, which contains the gastrocnemius, soleus, and the plantaris. These muscles collectively act through the Achilles tendon on the calcaneus to plantar-flex the ankle (Moore, et al., 2006).

Ankle Sprains

Epidemiology (Incidence/Prevalence)

Within the general population, ankle sprains are a significant problem as reports indicate that the incidence of injuries to the lateral ligaments of the ankle is 37/1,000 people per year in the united states (Boruta, Bishop, Braly, & Tullos, 1990). This would indicate that there are approximately 30,000 ankle sprains every day in the United States alone. With an estimated cost of treatment typically of $318 to $914 per sprain, the annual cost is up to two billion dollars for ankle sprains (Soboroff, et al., 1984). In an epidemiological study performed in a casualty ward of a Denmark hospital it was determined that 45% of ankle injuries were the result of sports participation, 20% during play, and 16% during work activities (Holmer, Sondergaard, Konradsen, Nielsen, & Jorgensen, 1994).

Garrick (1977) first described the occurrence of ankle sprains and reported that ankle sprains account for 85% of all injuries at the ankle. Approximately 85% of these sprains are of the inversion type, affecting the lateral ligament complex. Garrick further reported that one-sixth of all time lost due to injuries is a result of ankle sprains (Garrick, 1977). The ankle sprain has been identified as the most common injury in volleyball accounting for 41% of all injuries, and an incidence of 1.0 injuries per 1000 player hours (Verhagen, Van der Beek, Bouter, Bahr, & Van Mechelen, 2004). Marshall et al., (2002) reported that the injury rate per 1000 player games in American football was 6.40. Only the knee had a higher injury rate in that study (Marshall, et al., 2002). The ankle sprain is reported to account for 10-15% of all athletic injuries (Garrick, 1977; Lofvenberg & Karrholm, 1993) and typically result in 7 athlete-sessions lost per ankle sprain and can account for one-sixth of all time lost in athletics (Garrick, 1977; Kofotolis, Kellis, & Vlachopoulos, 2007).

Hootman et al (Hootman, et al., 2007), conducted one of the most insightful looks into the injury rates of college athletics through the NCAA Injury Surveillance System. This study took place over 16 years with 15% of NCAA member schools submitting data on the injuries encountered during athletic activities. The data from this study indicated that injuries to the lower extremity were a significant problem, accounting for more than 50% of all injuries. Ankle sprains were highlighted as one of three specific injuries that are a common problem across all levels and sports in college. The study found that ankle sprains accounted for 14.9% of all injuries and it was estimated that there are 11,000 ankle sprains as a result of athletic participation at the college level. It was also of note that the injury rate for ankle sprains (.83 injuries per 1,000 athlete-exposure) was approximately three times higher than concussions (.28 injuries per 1,000 athlete-exposures) and approximately 5 times higher than anterior cruciate ligament injuries (.15 injuries per 1,000 athlete-exposures), the other two injuries of note (Hootman, et al., 2007).

Etiology

A sprain is a traumatic joint injury that is the result of a sudden, pathological movement that stretches and/or tears the stabilizing tissues of that joint (Prentice, 2006). The common mechanism of injury for an inversion ankle sprain has been reported as excessive plantar flexion and internal rotation. This can result from poor foot placement during cutting maneuvers which puts the ankle over the base of support of the foot. It can also occur from landing on an irregular surface, such as another player’s foot or an uneven playing surface

(Garrick, 1977; Kristiansen, 1981). In an inversion ankle sprain, the lateral ligament complex is the stabilizing structure that is exposed to trauma.

The basic anatomy of the ankle complex provides several reasons for a higher rate of inversion ankle sprains compared to eversion mechanisms. The lateral malleolus extends more distally than the medial malleolus, which limits the amount of eversion possible at the ankle. Another reason the lateral ligaments are more frequently injured is that the deltoid ligaments on the medial aspect of the ankle complex are stronger than the lateral ligament. The irregular wedge shape of the talus also plays a role in the stability of the ankle. During dorsi-flexion, the wider anterior portion of the talus brings the ankle mortise into a closed pack position and increases the articular congruency within the talocrural joint, making the joint more stable. Conversely, during plantar-flexion, the narrower posterior portion of the talus rests in the ankle mortise, thus decreasing articular congruency and making the joint more unstable (Moore, et al., 2006).

The predisposing factors of ankle sprains need to be discussed before any interventions are carried out. These factors can be divided into two groups: intrinsic and extrinsic factors. The intrinsic factors that have been identified in the literature have been anthropometrics, foot type, ankle joint characteristics, and postural sway. A review of the literature on predictive factors for lateral ankle sprains determined that previous sprain, height and weight, limb dominance, foot type, and ankle joint characteristics were either not predictive, or there was conflicting evidence in the literature (Beynnon, Murphy, & Alosa, 2002).

The idea that a previous history of ankle sprains does not increase the risk of future ankle sprains seems to be at odds with the clinical phenomenon of CAI. One of the first prospective studies of ankle sprain risk found that there was an increased risk as a result of having a previous ankle sprain in soccer athletes (Ekstrand & Gillquist, 1983). Other studies in soccer, basketball athletes, and military personnel support these findings (Ekstrand, Gillquist, Moller, Oberg, & Liljedahl, 1983; McKay, et al., 2001; Milgrom, et al., 1991; Surve, et al., 1994; Tropp, Askling, et al., 1985).

However, there are an equal number of studies that have found no increase in risk with a previous history of ankle sprain (Barrett, et al., 1993; Baumhauer, et al., 1995; Sitler, et al., 1994; Tropp, Ekstrand, & Gillquist, 1984). One explanation for the differences in findings is the lack of any way to determine the amount of recovery that has occurred after the initial ankle sprain (Beynnon, et al., 2002). It would be very difficult to standardize the amount of damage from the ankle sprain, and the recovery from the initial injury.

There is another explanation for the different findings that should be considered. It is possible that some of the subjects within the studies that demonstrated increased risk with previous history of ankle sprain were undergoing some pathological process. This process led to their development and expression of CAI, which resulted in increased risk of repeated ankle sprains. Those that did not experience an increased risk with a history of ankle sprain may simply not have developed CAI. The process of development and expression of CAI is an area that needs further explanation so that these results may be put in proper context.

Other intrinsic risk factors that have been investigated are gender and ROM. It has been noted that there is a trend toward a difference between the rates of lateral ankle injuries between males and females, but these differences are not significant (Beynnon, et al., 2002; Beynnon, et al., 2006; Hootman, et al., 2007). There is conflicting evidence in the literature as to the impact the limited range of motion has on the rates of ankle sprains. It has been demonstrated that children with limited dorsiflexion range of motion are predisposed to ankle sprains (Tabrizi, McIntyre, Quesnel, & Howard, 2000), while other studies have shown that range of motion has no impact on ankle sprains in athletes, and dancers (Beynnon, Renstrom, Alosa, Baumhauer, & Vacek, 2001; Wiesler, Hunter, Martin, Curl, & Hoen, 1996). Theoretically, limited dorsiflexion range of motion is a predisposing factor as this would prevent the talocrural joint from reaching a closed packed position while in a closed kinetic chain position, limited dorsiflexion could lead to compensation of increased subtalar pronation (J Hertel, 2002).

Beynnon et al (Beynnon, et al., 2002) also investigated the role of extrinsic factors in ankle sprains. Those factors included EAS, shoe type, and characteristics of the sport or activity. There has been limited research into shoe type, but it has demonstrated that there are certain characteristics of shoes that affect injury rate. Reduced cleat length in field sports has been associated with a decrease in ankle and leg injuries (Torg & Quedenfeld, 1971). Air cells in the heel area of shoes has also been found to adversely affect ankle injuries rates (McKay, et al., 2001).

The characteristics of the activity have been linked to increased injury rate, with a consistent finding of increased injuries in a game compared to practice (Arnason, Gudmundsson, Dahl, & Johannsson, 1996; Ekstrand & Gillquist, 1983; Ekstrand, et al., 1983; Hootman, et al., 2007). When reviewing the literature on EAS there was a consistent finding that individuals with a history of ankle sprains who use EAS experience a lower incidence of re-injury (Beynnon, et al., 2002; McKay, et al., 2001; Sitler, et al., 1994; Surve, et al., 1994; Tropp, Askling, et al., 1985). This is of particular interest as a history of ankle sprain is also linked to CAI, which may indicate a protective effect for those experiencing CAI.

Acute Consequences

Mann et al (Mann, et al., 2002), identified three practical negative consequences that have been associated with acute ankle sprains: pain, swelling and the inability to walk (loss of function). The inability to walk can at least partially be explained by the consistent finding that postural control when in single leg stance decreases significantly (Bullock-Saxton, 1995; Freeman, 1965; Freeman, Dean, & Hanham, 1965; J. Hertel, Buckley, & Denegar, 2001; J. Hertel, Denegar, Buckley, Sharkey, & Stokes, 2001). Ankle sprains can also be associated with fractures to the bones of the ankle or the fifth metatarsal (Jensen, Andresen, Mencke, & Nielsen, 1998), decreased muscular strength (Willems, Witvrouw, Verstuyft, Vaes, & De Clercq, 2002), proprioception (Fu & Hui-Chan, 2005), and range of mobility of the ankle (Airaksinen, 1989). A single lateral ankle injury can lead to any where between seven (Kofotolis, et al., 2007) and 43 days (Beynnon, et al., 2006; Jones & Amendola, 2007) of time lost from activity. In 1984 it was estimated that each ankle sprain cost between $318 to $914 resulting in over 2 billion dollars of costs in that year (Soboroff, et al., 1984). It is a reasonable conclusion that costs have risen since then.

Chronic Consequences

It is reported that over half of ankle sprains do not receive any professional medical treatment (McKay, et al., 2001), likely a result of the mentality that it is “just a sprain”. This likely plays a role in the high re-occurrence of ankle injuries as it has been reported that over 70% of ankle sprains will have a re-occurrence (Yeung, et al., 1994). Articular degeneration of the joints of the ankle has been associated with ankle sprains (P. Gross & Marti, 1999; Harrington, 1979).

The high re-occurrence rate of ankle sprains can transform into a pathological condition where there is repeated bouts of lateral ankle instability known as chronic ankle instability (CAI) (J Hertel, 2002). This phenomenon and its outcomes will be examined in the following section.

Chronic Ankle Instability

The lack of professional medical treatment (McKay, et al., 2001), combined with a high re-occurrence rate (Yeung, et al., 1994) of ankle sprains, can eventually lead to the crossover into a pathological condition of repeated bouts of lateral ankle instability, known as chronic ankle instability (CAI) (J Hertel, 2002). To provide an understanding of this phenomenon the spectrum of CAI, the impact of CAI on kinematics, kinetics, and performance will be discussed.

Spectrum of CAI

There exists confusion within the literature and clinical practice to the terms that are used to refer to instabilities of the ankle. For clarity sake the following definitions will be used as proposed by Hertel (2002). Chronic ankle instability (CAI) refers to the occurrence of repetitive bouts of lateral ankle instability. CAI encompasses two clinical components: mechanical ankle instability and functional ankle instability, which may occur independently or in combination. Mechanical ankle instability (MAI) refers to the anatomical changes that can occur as a result of ankle sprain. Functional ankle instability (FAI) refers to the neuromuscular deficits that can occur as a result of ankle sprain. With the level of confusion that is present today with respect to the presented terminology, it is important to reinforce that either of the instabilities can exist exclusive of each other or in combination. They should be viewed as contributing factors to the expression of CAI, and not discrete clinical entities (J Hertel, 2002).

With a general understanding of the clinical components of CAI, it would be useful to illustrate the clinical progression associated with instabilities and further label groups for clarification in research. Those people who have never experienced an ankle sprain would be labeled as a control group, as they have not been exposed to any pathology-inducing event. Once a person has suffered an ankle sprain sufficient enough to cause limping for more than one day they can go on develop instability, or have no episodes of giving way. In the latter case they would be termed “copers”: those with a history of ankle sprains but no instability. The copers are useful as a group because they can help illustrate what changes that lead to the development of instability when compared to those who develop instability (J. Hertel & Kaminski, 2005). If the person who sprains their ankle develops anatomical changes that lead to instability, they would fall into the MAI. If after the sprain the person develops neuromuscular deficits, they would fall into the FAI group (J Hertel, 2002).

These categories of instability have been determined to be more than conceptual entities. Brown, et al determined that those with MAI tend to demonstrate different movement patterns at the ankle than FAI and copers in a number of tasks, while there was very little difference between the FAI and the copers. All groups had experienced an episode of ankle sprain the resulted in at least three days of immobilization. The coper group complained of no bouts of instability, while the FAI, and MAI did. These groups were separated based on orthopedic exam using the talar tilt and anterior drawer tests (C. Brown, Padua, Marshall, & Guskiewicz, 2008). These findings highlight the need to separate groups based on the specific spectrum of instability that they fall into. Past research which has not done this grouping must have their results reconsidered based on this. While this classification system is a step forward, it does not allow for the discrimination between isolated MAI, or a combination of MAI and FAI. Again, it must be emphasized that these are instabilities may exist in combination, and more research needed to identify combined instabilities.

With this research presented, it is clear that the labeling of CAI is not detailed enough. The clinical manifestations of CAI are best explained by some relationship between MAI, FAI, and combined MAI & FAI (J Hertel, 2002; Hubbard, Kramer, Denegar, & Hertel, 2007). To gain a complete understanding of MAI and FAI, the contributing factors to each instability will be discussed in the following sections.

Mechanical Ankle Instability

The category of MAI is composed of the anatomic changes that are a result of ankle sprain that predispose one to further episodes of instability (J Hertel, 2002). These anatomic changes include pathologic laxity, impaired arthrokinematics, synovial changes, and the development of degenerative joint disease. Pathologic laxity is a result of the ligamentous damage from the pathological motion, thus removing the normal mechanical restraints around the joints of the ankle (J Hertel, 2002).

While impaired arthrokinematics of any of the three joints of the ankle complex can lead to CAI (J Hertel, 2002), the prime arthrokinematic impairment that has been suggested is a positional fault of the fibula (Mulligan, 2006). Studies have indicated that there is both an anterior (Hubbard, Hertel, & Sherbondy, 2006; Kavanagh, 1999; Mavi, Yildirim, Gunes, Pestamalci, & Gumusburun, 2002) and posterior (Berkowitz & Kim, 2004; Eren, Kucukkaya, Kabukcuoglu, & Kuzgun, 2003; Scranton, McDermott, & Rogers, 2000) positional fault of the fibula relative to the tibia in subjects with ankle instability. Regardless of direction, the positional fault would change the position of the ATFL and prevent it from limiting the inversion of the ankle (J Hertel, 2002).

While it is not known if these positional faults of the fibula are the result of inversion ankle injuries, or a pre-existing, pre-disposing condition (Hubbard, et al., 2006) it appears that there is conclusive evidence to include them as part of the MAI phenomenon. To address the issue of fibular positioning, new taping and manual therapy methods have been developed to return the fibula to its proper position (Kiesel; Mulligan, 2006). There is limited evidence in the literature that supports this type of treatment, but what is available is promising. Tape applied over the fibula to reposition it, or fibular repositioning tape (FRT) has been reported to reduce pain and disability (Hetherington, 1996), improved landing mechanics in those with CAI (East, Blackburn, DiStefano, Zinder, & Norcross, 2010), as well as a lower injury rate when compared to conventional EAS use during activity (Moiler, Hall, & Robinson, 2006). With regards to the present literature review, it presents a clear area for future research to investigate the use of FRT as a targeted treatment strategy to MAI sufferers.

While the fibular positional fault may be the prime characteristic of MAI, it is not apparent on physical exam and therefore only useful in the treatment (Mulligan, 2006). As a means to identify those with MAI, it has been suggested that the anterior drawer test and the talar tilt to inversion test be used during physical exam (C. Brown, et al., 2008; Ryan, 1994). Those who experience ankle instability and have positive tests would be classified as MAI, while those with negative tests would be classified as FAI.

Functional Ankle Instability

Functional ankle instability (FAI) can contribute to the development of CAI instability through impairments to the neuromuscular system, which provides dynamic control of the ankle (J Hertel, 2002). Freeman et al (Freeman, 1965; Freeman, et al., 1965) were the first to describe the phenomenon of FAI in 1965 when they attributed the deficits in balance after ankle sprain to damage of the mechanoreceptors in the lateral ankle ligaments resulting in proprioceptive deficits. The concept of FAI has been expanded since its inception to completely reflect the role that the neuromuscular system plays in preventing injuries to the ankle (Lephart, Pincivero, & Rozzi, 1998). Within FAI, impaired proprioception and sensation, neuromuscular functioning, postural control, and strength deficits all contribute to CAI (J Hertel, 2002).

Hubbard et al. (2002) provided a clinical definition of the functionally unstable ankle based on subjective reports of patients. Patients with FAI self report that the initial injury required casts or crutches, the injured ankle is described as weaker or looser, and there are periods of the ankle giving out. The person experiencing FAI will attribute the present instability to the previous injuries and at this time has no limp. The patient must also be clear of instability under physical exam through anterior drawer test and talar tilt test (Hubbard & Kaminski, 2002).

Those people who experience FAI have been found to have decreased kinesthesia (Forkin, Koczur, Battle, & Newton, 1996; Garn & Newton, 1988; Lentell, et al., 1995), decreased active replication of joint angles (Docherty, Moore, & Arnold, 1998; Glencross & Thornton, 1981; Konradsen & Magnusson, 2000), impaired cutaneous sensation (Bullock-Saxton, 1994, 1995; Nitz, Dobner, & Kersey, 1985; Stoff & Greene, 1982), and decreased nerve conduction velocity (Kleinrensink, et al., 1994; Nitz, et al., 1985). While these deficits are consistent in the literature, it is not known if these factors can be changed through any intervention (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001). With this in mind, it would be important to pursue practices that limit the rates of ankle sprains (such as EAS) to avoid these impairments.

The neuromuscular functioning of people with a history of repetitive ankle sprains has also been found to be impaired. When measured by peroneal muscle response times, there is conflicting evidence within the literature. Some studies have demonstrated that there is a delay in ability of the peroneal muscles to respond to perturbation (Brunt, et al., 1992; Bullock-Saxton, 1995; Karlsson & Andreasson, 1992; Konradsen & Ravn, 1990; Lofvenberg, Karrholm, Sundelin, & Ahlgren, 1995; Lynch, Eklund, Gottlieb, Renstrom, & Beynnon, 1996), while others have not found these impairments (Ebig, Lephart, Burdett, Miller, & Pincivero, 1997; Fernandes, Allison, & Hopper, 2000; Johnson & Johnson, 1993; Konradsen, Olesen, & Hansen, 1998; Nawoczenski, Cook, & Saltzman, 1995). There also exists evidence for a central neural adaptation as indicated by weakness in the gluteus maximus and hip abductors of those individuals who had severe ankle sprains (Bullock-Saxton, 1994; Friel, et al., 2006; J Hertel, 2002).

Besides a central neural adaptation these changes could be attributed to impaired proprioception and/or decreased nerve conduction velocity (J Hertel, 2002). The concept of a central adaptation is important because the deficits associated with could potentially increase the risk for lower extremity injuries, including ankle sprains. To avoid the potential for developing this central adaptation; the use of EAS as a preventative measure should be emphasized.

FAI has also been found to negatively affect postural control (Forkin, et al., 1996; Garn & Newton, 1988; Gauffin, Tropp, & Odenrick, 1988; Lentell, Katzman, & Walters, 1990; Perrin, Bene, Perrin, & Durupt, 1997; Rozzi, Lephart, Sterner, & Kuligowski, 1999; Tropp & Odenrick, 1988; Tropp, Odenrick, & Gillquist, 1985). This may be attributed to impaired proprioception and neuromuscular control which leads to an alteration in the strategy that is used to maintain balance (J Hertel, 2002). Normally, to maintain postural control in single leg balance the foot pronates and supinates in an effort to keep the body's center of gravity over the base of support. This has been termed the "ankle strategy" of postural control. Those individuals with FAI tend to use a "hip strategy" to maintain postural control, which is less efficient (Pintsaar, Brynhildsen, & Tropp, 1996).

It is unclear exactly what role strength deficits play in the development of FAI. The literature has conflicting reports of its existence. Some research has demonstrated that there is a deficit in eversion strength (Bosien, Staples, & Russell, 1955; Hartsell & Spaulding, 1999; Tropp, 1986) and inversion strength (Hartsell & Spaulding, 1999; Ryan, 1994), while other reports contradict these findings (Bernier, Perrin, & Rijke, 1997; Kaminski, Perrin, & Gansneder, 1999; Lentell, et al., 1995; Lentell, et al., 1990).

Assuming that strength deficits do play a role in FAI, there is no clear understanding of what this role is. Possible explanations include altered neuromuscular control as a result of the altered ankle joint functioning, muscle damage presumably from the same mechanism that injured the ankle, or atrophy (J Hertel, 2002). The role of muscle strength in the expression of FAI is not clear from the literature however it is a common recommendation to perform strengthening exercises for the ankle in all of the cardinal planes (Mattacola & Dwyer, 2002). Further research should focus on the role that strength plays in both FAI and

MAI, however the implication is that prevention of CAI would eliminate any possible complications of muscle strength.

Research has not yet explained all of the interaction between the chronic consequences of ankle sprains, both MAI and FAI. However it should be emphasized that what has been presented above is the spectrum of factors that can contribute to CAI and not discrete clinical impressions. With that in mind, comprehensive programs aimed at treating the deficiencies that are present in a person who experiences repetitive bouts of lateral ankle instability must be implemented (J Hertel, 2002). Those programs should include strength training in the cardinal planes, proprioceptive exercises, sports specific exercises, EAS use (Mattacola & Dwyer, 2002), and manual therapy techniques (Kiesel; Mulligan, 2006).

CAI & Kinematics

It appears that CAI is associated with alterations in the kinematics that are associated with several tasks (Delahunt, Monaghan, & Caulfield, 2006, 2007; Monaghan, Delahunt, & Caulfield, 2006). Those with CAI tend to land in more inversion and invert at a higher rate immediately before, and after heel strike during walking than those without CAI. This finding indicates that CAI subjects are unable to control movement, absorb forces safely, and puts the ankle at risk for further injury (Delahunt, et al., 2006; Monaghan, et al., 2006). It was also noted that knee and hip kinematics of those with CAI did not differ from controls (Monaghan, et al., 2006). Indicating that the alterations that account for the phenomenon of CAI may be local, at least in terms of the kinematics.

Other investigations have examined kinematics in higher demand tasks such as medial-lateral hopping (Delahunt, et al., 2007). Similar results were found, in that CAI subjects were more inverted position before, at, and after initial contact than controls. All of these studies support the idea that repeated bouts of lateral instability associated with CAI can be partly explained by poor foot positioning around the time of initial contact. The more inverted the foot position, the more likely it is to cross over into a pathological region that reflex systems would not be able to prevent (Konradsen, Voigt, & Hojsgaard, 1997).

However, these studies were conducted while subjects completed relatively low demand tasks. Tasks that use higher speed and/or incorporate changes of direction may result in different findings due to the increase in forces that must be accommodated by the lower extremity. In fact, other studies have found no difference in frontal plane ankle kinematics with drop landings, concluding that the task was not stressful enough to elicit changes (Delahunt, O'Driscoll, & Moran, 2009). With this in mind higher stress tasks, such as the drop-cut maneuver should be considered in future studies.

CAI & Kinetics

The ankle plays a vital in dissipating the forces experienced at ground contact through the distal motion that occurs at the ankle (T. S. Gross & Nelson, 1988). Because of the restriction to ankle ROM in the sagittal plane, EAS may have a detrimental effect on the attenuation of vertical ground reaction forces, resulting in excessive vertical ground reaction forces (McCaw & Cerullo, 1999; Riemann, Schmitz, Gale, & McCaw, 2002). High ground reaction forces have been identified as a predisposing factor for injury of the lower extremity, in particular the knee (Chappell, et al., 2005; Chappell, Yu, Kirkendall, & Garrett, 2002; Decker, Torry, Wyland, Sterett, & Richard Steadman, 2003; Yu, Lin, & Garrett, 2006).

As a result of this it has been a clinical concern that alterations in ground reaction forces that are the result of EAS use, could predispose individuals to knee injuries. While the evidence is limited, it appears as though people with CAI have alterations in the timing of ground reaction forces (Caulfield & Garrett, 2004; Dayakidis & Boudolos, 2006) magnitude of ground reaction forces (Dayakidis & Boudolos, 2006; Delahunt, et al., 2007), and differences in the distribution of forces under the foot during walking (Nyska, et al., 2003).

Caulfield, et al found that the magnitude of ground reaction forces were not different, however there are significant changes to the timing of ground reaction forces with those with FAI reaching their peak in the lateral and anterior direction sooner than healthy controls (Caulfield & Garrett, 2004). Dayakidis, et al found that the vertical component of peak vertical ground reaction force (PVGRF) was significantly higher and the time to PVGRF was sooner in FAI (Dayakidis & Boudolos, 2006). However, Delahunt, et al found that kinetics were only altered in the posterior ground reaction force magnitude and no other direction. Vertical ground reaction forces were the same between CAI and controls (Delahunt, et al., 2007). Nyska, et al found that those with CAI spend a larger portion of the stance phase on the heel in order to avoid plantar-flexed positions, and had a lateral shift of body weight during toe off (Nyska, et al., 2003). This change in kinetics may help to explain the mechanism of repeated lateral ankle sprains.

Given the findings in the literature regarding vertical ground reaction forces; it would be appropriate to re-visit this issue in those with CAI. It would also prove useful to include EAS in the investigation to determine its role in vertical ground reaction forces as well as any interactions with CAI.

CAI & Performance

One of the primary concerns of athletes is the affect of a condition on performance of athletic tasks. Several studies have attempted to investigate the affects that CAI has on performance of lower extremity tasks with varying results. Several studies have not found any difference in the ability to complete tasks (Demeritt, Shultz, Docherty, Gansneder, & Perrin, 2002), while others have determined that there are measurable deficits when a person with CAI completes a task (Buchanan, Docherty, & Schrader, 2008; Caffrey, Docherty, Schrader, & Klossner, 2009). Given this disagreement among the literature it is important to consider other research that has found a performance increase when those with CAI complete a task with EAS applied (Hals, Sitler, & Mattacola, 2000). This last study is particularly interesting as it indicates a performance effect of as a result of the interaction between CAI and EAS. Investigating this interaction may lead to being able to target specific EAS types to those who would benefit the most.

External Ankle Support Research

The role of EAS is to resist motion in the free fall phase before the foot touches down and is loaded under the weight of the body. This is due to the theoretical explanation of ankle injuries as a result of a larger inversion (Eils & Rosenbaum, 2003) and plantar-flexion (Wright, et al., 2000) angles during free fall leading to an increased moment arm at the subtalar joint at ground contact and thus higher torque when the body weight is applied. This mechanical aspect is underscored by the determination that placebo tape had no effect on performance and the mechanical effects of the application of tape were what resulted in improvements (Sawkins, Refshauge, Kilbreath, & Raymond, 2007).

However, it is important to remember that there is a poor understanding of what the effects of EAS during motion, in particular the critical time right before initial contact. To provide a background for future investigation the injury outcome, performance, kinematic, and kinetic studies involving EAS will be discussed.

Injury Outcome Studies

Ten published studies exist in the literature that have compared the different conditions of EAS and have reported injury rates (prevalence or incidence) as the outcome measure (Garrick & Requa, 1973; Mickel, et al., 2006; Moiler, et al., 2006; Rovere, et al., 1988; Sharpe, et al., 1997; Simon, 1969; Sitler, et al., 1994; Stasinopoulos, 2004; Surve, et al., 1994; Tropp, Askling, et al., 1985). These studies all have similar conclusions that EAS does limit the ankle sprain injury rate and are most useful in people with a history of ankle sprain. These studies due have their limitations and flaws, especially the lack of any study that compares across the different types of EAS. In the absence of any study it is difficult to justify the use of one type of EAS over another. However, taken individually there is evidence to support the use of different types of EAS. With regards to the evidence to support the use of EAS, the lack of a high quality study that examines that use of athletic brace, athletic tape, along with a control group, will always be needed.

EAS & Kinematics

Cordova, Ingersoll, and LeBlanc (2000) performed a meta-analysis to compare the ROM restriction of three different EAS conditions: athletic tape, athletic lace-up brace, and semirigid brace before and after exercise (Cordova, et al., 2000). The conclusions drawn from this analysis were that the semirigid orthosis offered greater restriction before exercise, mostly due to the materials that it was constructed from. But more importantly is that the semirigid orthosis maintained its restriction over time, while tape and lace-up brace loosened with time. The loss of restriction is again attributed to the material that the lace-up and tape are made out of (Cordova, et al., 2000).

The authors recommend that tape or a lace-up brace may be used in an unimpaired ankle, since these methods are a good blend of restriction and mobility. However, the person with a history of chronic ankle sprains or recovering from an ankle sprain will benefit most from the use of a semirigid stabilizer (Cordova, et al., 2000). It is important to consider these findings with common clinical practice, which is to emphasize the use of lace-up braces due to clinician preference and perceived comfort. With this in mind, lace-up braces should be investigated in more detail.

However, the dynamic restriction to motion provided by EAS is a more valuable piece of information to explain the affect of EAS. A limited number of studies have examined this (Delahunt, et al., 2009; DiStefano, Padua, Brown, & Guskiewicz, 2008). It has been found that athletic braces limit the amount of plantar-flexion at initial contact in stable ankles (DiStefano, et al., 2008). A more interesting finding is that applying athletic tape to unstable ankles lead to a decrease in plantar-flexion before and at initial contact (Delahunt, et al., 2009). This finding is important as it demonstrates a protective effect from a position associated with injury (Wright, et al., 2000), and leads to ask more questions about how kinematics would change with other types of EAS. Another important point is that both of these studies measured angles during functional activity, which is more clinically useful information and should be used in future research.

EAS & Kinetics

Kinetics associated with ground contact has been a topic of interest as it has been associated with lower extremity injuries (Chappell, et al., 2005; Chappell, et al., 2002; Decker, et al., 2003; Yu, et al., 2006), as was previously discussed. Therefore it is important to present the relevant information associated with the affect of EAS on ground reaction forces, especially if a patient had other factors that may make them susceptible to other lower extremity injuries.

There have been a limited number of studies that examine the changes that occur in ground reaction force as a result of EAS use. DiStefano, et al, found that athletic braces had no affect on the magnitude and timing of PVGRF when compared to no support. The authors also observed a significant increase in the amount of knee flexion at initial contact and an increase in the knee joint displacement when the athletic braces were worn. This increase in knee kinematics was hypothesized to be a compensation from the plantar-flexion restriction, which allowed the bodies center of mass to travel over the same distance and allow the PVGRF to remain constant (DiStefano, et al., 2008).

Sacco Ide, et al, found that magnitude and timing of PVGRF were not affected by either athletic tape or athletic brace. However, these researchers did find alterations in the timing of peak horizontal ground reaction forces, with both tape and brace significantly greater than no support. These findings indicate that the use of EAS may force the body to experience higher than normal medial/lateral or inversion/eversion forces than normal. The authors concluded that this may be detrimental over time (Sacco Ide, et al., 2006). These studies agree with the idea that the use of EAS will not alter PVGRF, but there is the possibility that horizontal forces may be affected. However, with such limited information on the subject, and its importance it is vital to continue to build the knowledge base on this subject.

EAS & Performance

The effect of EAS on functional performance is another issue that must be addressed when choosing the best method of support. Athletes will typically have concerns that EAS will negatively influence athletic performance and be uncomfortable. This can affect the athletes' compliance with using the EAS, and may have an overall psychological impact on the effectiveness of the treatment.

Cordova, Scott, Ingersoll, and LeBlanc (2005) performed a meta-analysis of the literature that examined EAS and performance. The conclusions drawn from this were that EAS was most likely to negatively impact sprint speed but by approximately 1% only. Agility was not deemed to be negatively affected by EAS, as the effect size was deemed to be trivial. EAS use was also not likely to improve performance in vertical jump, but not likely to impair it either. Overall, the authors made the conclusion that EAS is a viable option for injury prevention, while taking into consideration individual differences of the athlete. One consideration that must be kept in mind is that these studies did not use elite athletes, where performance impairment may be more pronounced, and any decrease is of major concern (Cordova, et al., 2005).

The notion that EAS will negatively affect performance, should no longer play a concern in the clinicians mind as the risk of injury should far outweigh any trivial performance decrease (Cordova, et al., 2005). Clinicians should use this information as an educational tool to enhance compliance of EAS use. Any athlete with the concern that their performance will suffer with EAS use should have this information brought to their attention.

Practical Considerations

In the only examination of its kind, Olmsted, Vela, Denegar, and Hertel (2004) performed an evaluation of taping and bracing by performing a numbers-needed-to-treat (NNT) and cost benefit analysis. NNT was used to present a simple clinical number that can indicate the rate of prevention of a pathological event so that the cost benefit analysis could be done. The authors assumed that the cost of tape was, $1.37 per roll and the cost of an Air Cast stirrup brace was $35.00 (Olmsted, Vela, Denegar, & Hertel, 2004).

The authors applied the numbers-needed-to-treat formula to the results of three articles that reported injury rates, used athletic tape and athletic brace as the intervention, and had a control group (Garrick & Requa, 1973; Sitler, et al., 1994; Surve, et al., 1994). The main highlights of the cost-benefit analysis were that it could cost $15,280.98 to tape a team for an entire season, while it would only cost $5,005.00 if braces were used for the same time period. The authors concluded that it was 3.05 times more expensive to tape an ankle for the entire season, as it was to brace the ankle for a season. The authors then recommended bracing is a superior method of EAS based on cost and time considerations (Olmsted, et al., 2004).

This study is vital to the discussion of what method of EAS is appropriate. We must consider the total impact of injury outcomes, ROM restriction, functional performance, as well as cost, and time associated with each method of support. The financial data is clearly indicating that bracing is superior.

Another aspect of the choice of external ankle support is the time-benefit. While the literature is scarce on this topic, the time the clinician must put into preventing ankle sprains must be considered. Mickel et al., (2006) were the first to present any of these findings on EAS. It was estimated that it would take 3 hours and 14 minutes to tape both ankles for an entire season for high school football. There was no data presented on how long it took to fit and instruct a subject on athletic brace usage, only that is was minimal by comparison to the time it takes for taping (Mickel, et al., 2006). This information is critical for the clinician to have access to when deciding what are the priorities in daily practice.

With a lack of research examining all of these variable common sense must be used. If the athletes all apply their own braces the athletic trainer is then free to perform other duties, such as rehabilitation, equipment fitting, environmental assessments, proper injury evaluations, administrative duties, etc.

Methodological Considerations

Agility/Cutting Maneuvers

Past research on EAS and functional performance have dealt with tests that demonstrate some set of movement skills. The rationale behind using agility tests is that they are accurate reflections of the demands of sports, in particular court and field sports that require significant changes of direction (Sheppard & Young, 2006). These type of tests have been used because it is an easy way to communicate with coaches and athletes the affect that EAS has on performance due to the necessity of changing direction in athletics.

There have been many studies that examine cutting maneuvers as the task. However, these studies have mostly examined the effect that the cutting maneuver has on the hip and/or knee with the outcome measure being the kinematics, kinetics, or the activation of the muscles around these joints (Besier, Lloyd, & Ackland, 2003; Besier, Lloyd, Ackland, & Cochrane, 2001; Besier, Lloyd, Cochrane, & Ackland, 2001; Cowley, Ford, Myer, Kernozek, & Hewett, 2006; Ford, Myer, Toms, & Hewett, 2005; Landry, McKean, Hubley-Kozey, Stanish, & Deluzio, 2007; McLean, Walker, & van den Bogert, 2005; Pollard, Davis, & Hamill, 2004; Pollard, Sigward, & Powers, 2007; S. Sigward & C. M. Powers, 2006; S. M. Sigward & C. M. Powers, 2006; Sigward & Powers, 2007). Kinematics of the ankle has not been examined sufficiently to provide evidence for one use of EAS over another. It will be a very informative to determine the changes at the ankle with different EAS conditions, and use this information to chose the best method of support.

EAS Conditions

The vast majority of EAS conditions, athletic tape, lace-up athletic brace, and semi-rigid athletic brace, have been studied in some way (Cordova, et al., 2000; Cordova, et al., 2005). However, the specific applications of each type of EAS need to be investigated, as clinical practice is moving faster than research can support. With this in mind new lace-up athletic braces that are common clinical methods should be compared to tape, which is most likely the most common form of EAS.

Kinematic Research

Kinematic research is regularly undertaken to examine the effects that certain variables, interventions, or characteristics have on motion (Bishop, Fiolkowski, Conrad, Brunt, & Horodyski, 2006; Nishikawa, Kurosaka, Mizuno, & Grabiner, 2000; Pollard, et al., 2007). The Flock of Birds has been shown to be a reliable and valid measure of joint kinematics. It has previously been shown to effective for measuring shoulder (Meskers, Fraterman, van der Helm, Vermeulen, & Rozing, 1999), first metatarsophalangeal joint (Umberger, Nawoczenski, & Baumhauer, 1999), and elbow kinematics (Stokdijk, et al., 2000).

Force Platform

Force plates are also typically used in kinematic research to determine the specific points of ground contact and the resulting forces associated with ground contact. The typical sampling frequencies of these forces plates is such that it is in sequence with what ever kinematic system is being used (i.e. The Flock of Birds) (Pollard, et al., 2007; Ross, Guskiewicz, & Yu, 2005).

Power Analysis

Between the dependent measures that are going to be recorded during this investigation, an ankle angle at initial contact is the one best suited to determine sample size. Time to complete an agility previous literature has demonstrated that there is no effect of EAS on agility courses (effect sizes -0.01 and 0.03 for tape and lace-up brace respectively) (Cordova, et al., 2005), and therefore not useful in determining a sample size. Ankle ROM restriction is also not the best method of determining a sample size as it will not represent the critical measure of position before and at initial contact.

Ankle angle position at initial contact has been identified as the variable of primary concern when evaluating the potential for injury (Eils & Rosenbaum, 2003; Wright, et al., 2000). Ankle angle at initial contact has been researched in several studies. It will provide a clear effect size that will allow for a clear indication of an appropriate sample size to demonstrate a difference between subjects. Delahunt, et al, examined the kinematics of walking in those with FAI and a control group. Based on their findings and the scope of the current study, the most conservative effect size found is 0.77 for dorsiflexion (Delahunt, et al., 2006). This is the effect size that will be used in the power analysis to determine how many subjects will be needed to achieve a power of .80.

CHAPTER 3

Methodology

Research Design

In order to address our research questions, we employed, a repeated-measures, counter-balanced design. Two groups of subjects based on AS (stable & unstable ankles) completed the same task (drop-cut maneuver) under the different conditions of EAS (no support, athletic tape, & athletic brace) that were used in this study. During this task, frontal and sagittal plane position of the ankle at initial ground contact were measured, as well as peak vertical ground reaction force and time to peak vertical ground reaction force.

Subjects

Subjects for this study were eligible to take part if they were recreationally active and associated with The University of North Carolina at Chapel Hill. Potential subjects were 18 to 30 years old, and took part in activity at least 3 sessions per week for at least 30 minutes per session. Two groups of subjects based on AS were used during the investigation. The first were those with unstable ankles, who complained of CAI symptoms. Subjects in the unstable ankle group self reported the following (Delahunt, et al., 2006, 2007; Hale & Hertel, 2005):

1) History of ankle sprain with pain and/or limping for more than one day

2) Chronic weakness, pain, or instability that they attributed to the initial injury

3) Sensation or experiencing giving way of the ankle in the last 6 months.

The second group was those with stable ankles that did not self-report any of the above problems. The subjects in the stable group were matched to the unstable group based on their foot dominance.

Subjects were excluded from participation in this study if they had any of the following:

1) History of ankle fracture

2) Injury to either lower extremity within the last 3 months

3) History of balance disorders

4) Current participation in formal physical therapy of the lower extremity

5) Any medical condition that might affect or be compromised by participation in this study.

A power analysis was performed *a priori* to determine the number of subjects we needed to enroll in the study to achieve a power of at least 0.80. Based on a conservative estimate of dorsi-flexion range of motion restriction effect size (d = 0.77) previously published (Delahunt, et al., 2006), it was determined that at least 8 subjects in each group (stable and unstable) were needed to achieve a power of 0.80 based on a two-way repeated measures ANOVA with two degrees of freedom. However, in this research study, there were 12 subjects in each group for a total of 24 subjects.

Measurement & Instrumentation

EAS Materials

The materials that were used for the conditions of EAS in this study were athletic tape and athletic brace. Athletic tape that was used for this study was Johnson & Johnson Zonas plain adhesive tape, 1 ½ inch x 15 yards (Johnson & Johnson model # 5189). The athletic tape was applied over heel and lace pads (Cramer Heel & Lace Pads Model # 28052M), skin lubricant (Cramer Skin Lube Model # 192542), foam underwrap (Cramer Tape Underwrap Model # 214507), and tape adherent (Cramer QDA Taping Base Model # 171531).

The athletic brace that was used in this study was the ASO ankle stabilizer (Model # 264014). This brace has nylon strapping that replicates the heel locks and figure eight of ankle taping, and elastic cuff closures that decrease the amount of inversion possible, as indicated by the manufacturer (Medical Specialties, Inc., 4600-K Lebanon Rd, Charlotte, NC 28227)

3-D Kinematic Data Collection

Kinematic data were collected using A Flock of Birds (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by Motion Monitor (Innovative Sports Training, Inc., Chicago, IL) data acquisition computer software. Kinematic data were sampled at a rate of 100 Hz.

Force Platform Data Collection

Ground contact information was collected from the Bertec non-conductive force plate, (Model 4060-08, Bertec Corp, Worthington, OH). The force plate was interfaced with a computer using a 12-bit, 32-channel analog to digital (A/D) converter board (DT3010/32; Data Translation, INC.; Marlboro, MA, USA). Force platform data was collected at 1000 Hz.

Procedures

The general order of procedures remained the same for all subjects throughout the proposed study: subject data collection, electromagnetic sensor application & limb digitization, drop-cut maneuver practice, and EAS application & data collection. All testing was completed in the Neuromuscular Research Laboratory at The University of North

Carolina at Chapel Hill. Subjects reported in athletic attire (shorts and a t-shirt) for a testing session that lasted approximately 60 minutes. Upon reporting for testing, subjects were made aware of the purpose of the study; participants read and signed a University Institutional Review Board approved informed consent form prior to any test procedures.

Subject Data Collection

Subjects completed a questionnaire to collect demographic, ankle stability, lower extremity dominance, test order and determine lower extremity of interest. The questionnaire can be found in Appendix C. Demographic data were obtained from the subjects. Such data included the subject's height (cm), mass (kg), age (years), and gender (Table 1). Ankle stability was determined by having the subjects answer yes or no to the following three questions:

1) History of ankle sprain with pain and/or limping for more than one day?
2) Affected ankle is less functional (weakness, pain, or instability) since the initial ankle sprain?
3) Sensation or experiencing giving way of the ankle in the last 6 months?

Lower extremity dominance was determined by asking the subject what foot they would chose to kick a ball with. This side was determined to be the dominant lower extremity, while the other side was the non-dominant lower extremity. Subjects were randomly assigned without replacement to one of six counterbalanced test orders by drawing out of a hat. These testing orders were pre-established and were based on the order of EAS worn.

The lower extremity of interest was the side of the unstable ankle in the unstable group. For the stable group the lower extremity of interest was determined by matching them to an unstable subject based on dominance. Matching was accomplished by matching a stable subject to the unstable subject that they most closely resembled in demographic data. The stable subject then had the same lower extremity tested as the unstable subject, either dominant or non-dominant. This was done to control for any effect that foot dominance may have.

Electromagnetic Sensor Application & Limb Digitization

The lower extremity of interest had electromagnetic sensors applied. To apply the electromagnetic sensors the subjects were required to remove their shoes and leave them off for the duration of the testing session. The sensors were placed on the dorsum of the foot and the tibia. Both sensors were placed in an area with as little soft-tissue as possible to minimize potential artifact induced by muscle contraction. Electromagnetic sensors were applied using double sided tape, foam underwrap, and athletic tape.

After the electromagnetic sensors were attached, the limb was digitized using Motion Monitor software. The subject stood in a neutral and relaxed stance. The following bony landmarks were palpated and digitized by a moveable sensor attached to a wooden stylus: medial and lateral epicondyle of the femur, medial and lateral malleoli of the ankle, and the most distal portion of the second phalanx.

Drop-Cut Maneuver Practice

Subjects were shown and instructed on how to perform the drop-cut maneuver by the primary investigator and then completed three practice trials. The drop-cut maneuver required the subject to stand barefoot, on his/her unmarked limb on a box 30 centimeters high placed 10 centimeters from the edge of a force plate with marked limb relaxed and non-weight bearing. Subjects then dropped from the box, landing on the marked limb on the middle of the force plate and then cut in a 45° angle to the opposite direction of the limb that was landed on. For example, if the subject's right limb is marked, the subject will stand on top of the box with the left foot, landed on the right foot in the middle of the force plate, and then cut in a 45° angle to the left. A diagram of the drop-cut maneuver can be found in Figure 1.

EAS Application & Data Collection

Subjects then sat on a stool for application of the first EAS condition for 5 minutes. During this time the primary investigator either applied the athletic tape, or instructed the subjects on how to apply the athletic brace. In the case of the no support condition, the subject sat on the stool for 5 minutes. The two experimental EAS conditions were applied as follows:

- ASO lace-up brace: subjects were instructed in the proper way to apply the brace per manufacturer's instructions. A picture can be found in Figure 2.
- Athletic tape was applied over heel and lace pads, and pre-wrap in a closed basket-weave fashion. Three anchor strips were applied first, then three alternating stirrups and horseshoes. The stirrup was applied first running from medial to lateral to resist against inversion. The horseshoe was applied next so that it covers the lace area running from the medial midfoot to the lateral midfoot covering the Achilles. The subsequent stirrups were applied such that they overlap each other by half moving in an anterior direction. Horseshoes also overlapped by half, and moved in a superior direction. Heel locks were applied next. Two lateral, two medial heel locks, and a figure of eight were applied to complete the tape job. A picture can be found in Figure 3.

After the appropriate EAS had been applied, the subject completed five trials of the drop-cut maneuver with 30 seconds of rest between trials to minimize the risk of fatigue. Trials with incorrect landings or errors in data collection were considered invalid, and a new trial performed. Incorrect landings were those in which the subject's marked limb did not land completely on the force platform or the subject did not cut in the correct angle. After the five successful trials of the first EAS the subject returned to the stool to have the second EAS application, then completed five more successful trials of the drop-cut task, and then repeated for the third EAS condition.

Data Reduction

Raw kinematic data were converted to the aligned anatomical coordinate axes. The three dimensional global and local coordinate systems were defined as follows: the positive x-axis was the direction the subject faced, the positive y-axis was to the left of the subject, and the positive z-axis was directed upward. The Motion Monitor software processed the raw sensor data, and a Butterworth low pass filter (4th order, zero phase lag) smoothed the data at a frequency of 10 Hz. Ankle angles in the frontal and sagittal plane at initial ground contact and at the end of the loading phase, peak vertical ground reaction force, and time to peak vertical ground reaction force were determined through customized software in MatLab (The Mathworks, Inc., Natick, MA). Peak vertical ground reaction force was normalized to the body mass of each subject.

In the original conception of the this project it had been planned to examine the position of the ankle during the end of the loading phase to compare the effects that ankle stability and EAS had on kinematics while the foot was in contact with the ground. However, upon examination the kinematic data was not used due to errors. Specifically, the kinematic data was well beyond physiological limits. These errors are most likely due to motion artifact as a result of electromagnetic sensor movement upon soft tissue. The kinematic data at the end of the loading phase were not used in the statistical analysis for this reason. The kinematic data for the ankle angles in the frontal and sagittal plane at initial contact did not have these same errors and was used in the statistical analysis.

Statistical Analysis

A mixed model repeated measures ANOVA with one within subjects factor (3 levels: no support, athletic tape, & athletic brace) and one between subjects factor (2 levels: stable & unstable) was used to compare the groups and testing sessions for each of the four dependent variables, 1. Frontal plane position of the ankle (inversion/eversion) at initial contact with the ground, 2. Sagittal plane position of the ankle (plantar-flexion/dorsi-flexion) at initial contact, 3. Peak vertical ground reaction force, and 4. Time to peak vertical ground reaction force. Post-hoc analyses were conducted with Tukey's HSD. All data were analyzed with SPSS Statistics, version 18.0 statistical software (SPSS, Inc., Chicago, IL) with an *a priori* alpha level set at 0.05.

Based on the means and standard deviations, effect sizes were calculated for the post-hoc pairwise comparisons using Excel (Microsoft Corporation, Redmond, WA). Effect sizes were calculated using Cohen's d. The interpretation of the calculated effect sizes followed the scale provided in previous research of small (d=.2), moderate (d=.5), and large (d=.8) effect sizes (Cohen & Quade, 1977). A post-hoc power analysis was conducted in situations where there were no significant findings to determine if sample size was adequate. The post-hoc power analyses were conducted using the differences in means and standard deviations of the results.

CHAPTER 4

Results

Frontal Plane Ankle Angles

Means, standard deviations, and 95% confidence intervals for ankle angles at initial contact in the frontal plane are presented in Table 2. Effect sizes calculated from the means and standard deviations of ankle angles at initial contact in the frontal plane are presented in Table 6. A 2 (AS) x 3 (EAS) mixed-model ANOVA was calculated to examine the effects of AS (stable and unstable ankles) and EAS (no support, athletic tape, and athletic brace) on position of the ankle joint in the frontal plane at initial contact while performing a drop-cut maneuver. No significant main or interaction effects were found. The main effect for EAS (no support: -3.30º ± 21.43, tape: -3.25º ± 18.48, d=0.00, brace: -3.01º ± 14.34, d=0.01, $F_{2,44}$=0.010, P=0.990, observed power=.051), the main effect for AS (stable:-6.34º ± 19.22, unstable: -0.03º ± 16.56, d=0.45 $F_{1,22}$=0.785, P=0.385, observed power=.136), and the AS x EAS interaction effect (stable-no support: -7.45º ± 24.13, stable-tape: -5.23º ± 19.78, d=0.09, stable-brace: -6.34º ± 14.13, d=0.05, unstable-no support: 0.86º ± 18.69, d=0.34, unstable-tape: -1.28º ± 17.73, d=0.26, unstable-brace: 0.32º ± 14.37, d=0.32, $F_{2,44}$=0.533, P=0.591, observed power=.132) were all not significant. Neither AS nor EAS influenced ankle position in the frontal plane at initial contact.

Sagittal Plane Ankle Angles

Means, standard deviations, and 95% confidence intervals for ankle angles at initial contact in the sagittal plane are presented in Table 3. Effect sizes calculated from the means and standard deviations of the ankle angles at initial contact in the sagittal plane are presented in Table 7. 95% confidence intervals for the difference in means of the ankle angles at initial contact in the sagittal plane of the significant findings can be found in Table 10. A 2 (AS) x 3 (EAS) mixed-model ANOVA was calculated to examine the effects of AS (stable and unstable ankles) and EAS (no support, athletic tape, and athletic brace) on position of the ankle joint in the sagittal plane at initial contact while performing a drop-cut maneuver. A significant main effect for EAS was present (no support: -5.69º ± 22.04, tape: -6.41º ± 20.20, d=-0.03, brace: -3.10º ± 20.05, d=0.12, $F_{2,44}$=4.278, *P*=0.020, observed power=.717). In addition, a significant AS x EAS interaction was present (stable-no support: -6.35º ± 22.03, stable-tape: -5.04º ± 20.18, d=0.06, stable-brace: -4.71º ± 20.48, d=0.07, unstable-no support: -5.04º ± 23.02, d=0.06, unstable-tape: -7.78º ± 21.01, d=-0.06, unstable-brace: -1.48º ± 20.38, d=0.22, $F_{2,44}$=3.273, *P*=0.047, observed power=.593). The main effect for AS (stable: -5.37º ± 20.32, unstable: -4.77º ± 21.04, d=0.03, $F_{1,22}$=.005, *P*=0.944, observed power=.205) was not significant.

Pairwise comparisons of the main effect of EAS revealed that there was a significant difference between athletic tape and athletic brace, with the athletic tape condition landing in significantly less plantar flexion than the braced condition. No other significant differences were found. Pairwise comparisons of the AS x EAS interaction effect revealed that there was a significant difference between the unstable-athletic tape condition and the unstable-athletic brace condition, with the unstable-athletic tape condition landing in significantly less plantar flexion. AS did not influence ankle position in the sagittal plane at initial contact.

The 95% confidence interval of the mean difference for the athletic tape – athletic brace is -0.62° to -6.01°. The 95% confidence interval of the mean difference for the unstable-athletic tape – unstable-athletic brace is -1.49° to -11.13°.

Peak Vertical Ground Reaction Force

Means, standard deviations, and 95% confidence intervals for peak vertical ground reaction force are presented in Table 4. Effect sizes calculated from the means and standard deviations of the peak vertical ground reaction force data are presented in Table 8. A 2 (AS) x 3 (EAS) mixed-model ANOVA was calculated to examine the effects of AS (stable and unstable ankles) and EAS (no support, athletic tape, and athletic brace) on peak vertical ground reaction force while performing a drop-cut maneuver. No significant main or interaction effects were found. The main effect for EAS (no support: 227.49% ± 23.90, tape: 224.97% ± 27.41, d=-0.11, brace: 223.80% ± 18.80, d=-0.15, $F_{2,44}$=0.933, *P*=0.401, observed power=.201), the main effect for AS (stable: 220.84% ± 20.12, unstable: 230.00% ± 25.66, d=0.46, $F_{1,22}$=1.017, *P*=0.324, observed power=.162), and the AS x EAS interaction (stable-no support: 221.72.% ± 19.36, stable-tape: 218.55% ± 22.84, d=-0.16, stable-brace: 222.25% ± 19.55, d=0.03, unstable-no support: 233.26% ± 27.33, d=0.60, unstable-tape: 231.39% ± 30.97, d=0.50, unstable-brace: 225.36% ± 18.75, d=0.19, $F_{2,44}$=1.829, *P*=0.173, observed power=.316) were all not significant. Neither AS nor EAS influenced peak vertical ground reaction force.

Time to Peak Vertical Ground Reaction Force

Means, standard deviations, and 95% confidence intervals for time to peak vertical ground reaction force are presented in Table 5. Effect sizes calculated from the means and standard deviations of the time to peak vertical ground reaction force data are presented in Table 13. A 2 (AS) x 3 (EAS) mixed-model ANOVA was calculated to examine the effects of AS (stable and unstable ankles) and EAS (no support, athletic tape, and athletic brace) on time to peak vertical ground reaction force while performing a drop-cut maneuver. No significant main effects or interactions were found. The main effect for EAS (no support: 110.93 ms ± 29.48, athletic tape: 110.58 ms ± 39.45, d=-0.01, athletic brace: 104.78 ms ± 28.38, d=-0.21, $F_{2,44}$=0.605, *P*=0.551, observed power=.144), the main effect for AS (stable: 109.65 ms ± 34.08, unstable: 107.88 ms ± 31.24, d=-0.05, $F_{1,22}$=0.024, *P*=0.879, observed power=.052), and the AS x EAS interaction effect (stable-no support: 110.31 ms ± 23.44, stable-tape: 116.23 ms ± 45.19, d=0.25, stable-brace: 102.41 ms ± 31.62, d=-0.34, unstable-no support: 111.55 ms ± 35.59, d=0.05, unstable-tape: 104.94 ms ± 33.81, d=-0.23, unstable-brace: 107.15 ms ± 25.92, d=-0.13, $F_{2,44}$=0.900, *P*=0.414, observed power=.195) were all not significant. Neither AS nor EAS influenced time to peak vertical ground reaction force.

CHAPTER 5

Discussion

The principal findings in this study were that athletic tape limited plantar-flexion better than athletic brace, particularly in those with unstable ankles. However neither athletic tape nor athletic brace limited kinematics of the ankle in the sagittal and frontal plane at initial contact when compared with no support. We also found that those subjects with unstable ankles did not have altered kinematics when compared to subjects with stable ankles. Additionally, EAS did not have an impact on the kinetics of the drop-cut.

The lateral ligaments of the ankle are some of the most injured structures in the body (Garrick, 1977; Kannus & Renstrom, 1991), and repeated ankle sprains can lead to the development of CAI (J Hertel, 2002). EAS and CAI have been found to result in altered kinematics (Cordova, et al., 2005; Delahunt, et al., 2006, 2007; Delahunt, et al., 2009; DiStefano, et al., 2008; Monaghan, et al., 2006) and kinetics (Caulfield & Garrett, 2004; Dayakidis & Boudolos, 2006; Delahunt, et al., 2009; DiStefano, et al., 2008; Nyska, et al., 2003; Sacco Ide, et al., 2006) at the ankle during activity. Several clinical methods, including EAS, have been developed to prevent and treat ankle sprains (Bahr, et al., 1997). As a means to determine the effects of various clinically used EAS conditions, we measured the kinematics of the ankle as well as the kinetics of initial ground contact when performing a drop-cut maneuver in subjects with stable and unstable ankles.

Ankle Kinematics

It has been hypothesized that poor foot positioning before initial contact is largely to blame for repeated ankle sprains, with increased plantar-flexion position at initial contact putting the ankle at greatest risk for injury (Wright, et al., 2000). Secondarily, the frontal plane position of the ankle before initial contact (Eils & Rosenbaum, 2003) must be evaluated. These positions put the ATFL in a taught position, and likely to be injured as body weight is applied (Leonard, 1949; Saunders, 1980). With this in mind, it is important to evaluate the affect that EAS has on sagittal and frontal plane position of the ankle to determine if it will be clinically useful to prevent and/or limit ankle sprains.

Previous studies that examined the effects of ankle braces in stable ankles during drop-jump (DiStefano, et al., 2008) and the effect of tape in unstable ankles while performing a drop-landing (Delahunt, et al., 2009), found that ankle braces significantly limited plantar flexion at initial contact when compared to not wearing a support. These studies concluded that this limitation of plantar flexion explains the decreased incidence of ankle sprains when EAS is worn (Delahunt, et al., 2009; DiStefano, et al., 2008).

The present study does not agree with the findings of either of these studies. The present study found that wearing athletic tape and athletic brace was the same as wearing no support at all in terms of its restriction of plantar flexion angle. Clinically, the findings of the current study cast doubt on the use of EAS to prevent ankle sprains as they did not significantly limit ankle angles in plantar-flexion. This can be further illustrated by examining the effect sizes found in Table 7. The smallest effect size was observed in the unstable-athletic tape condition, d=-0.06. This is the only interaction effect that resulted in a reduction of sagittal plane ankle angle, however its value is clinically meaningless, as it is below the .20 level needed to be considered small. This indicates no clinically significant change will occur in the sagittal plane with the application of EAS.

Clinicians should consider the entire body of evidence which has found EAS to prevent ankle sprains (Garrick & Requa, 1973; Mickel, et al., 2006; Moiler, et al., 2006; Rovere, et al., 1988; Sharpe, et al., 1997; Simon, 1969; Sitler, et al., 1994; Stasinopoulos, 2004; Surve, et al., 1994; Tropp, Askling, et al., 1985), with the explanation being limitation of plantar-flexion (Delahunt, et al., 2009; DiStefano, et al., 2008).

There are several explanations for the lack of agreement with previous studies. The kinematic data was highly variable, as can be seen in the large standard deviations associated with both the sagittal and frontal plane kinematic data. This indicates that movement differed greatly between trials of the same subject and between subjects. Subjects in this study seemed to complete the drop-cut maneuver with several different landing strategies, both landing on the forefoot and the rearfoot. It may be that the speed of the task required the subjects to use both strategies during the testing resulting in the differences in position at initial contact.

Even with the large standard deviations, there were statistically significant results. To put these significant findings in their proper context two aspects need to be considered. First, the 95% confidence interval for the mean differences of the statistically significant results needs to be highlighted, these can be found in Table 10. The lower bounds of both difference of means are close to 0 and would indicate that any potential limitation in ankle angle would not be clinically meaningful. This is difficult to be definitive on as there has been no standard of change for a positive clinical outcome. Put another way, research has not determined how much plantar-flexion needs to be limited so that ankle sprains can be avoided. Clinically, it seems that a difference in plantar-flexion of .62° or 1.48° would not be sufficient to prevent an ankle sprain from occurring.

The effect sizes associated with the significant findings can help to illustrate their lack of clinical meaningfulness. While athletic tape significantly limited plantar-flexion when compared with brace, the effect size of athletic tape was -0.03. This would indicate that any change in sagittal plane position would not be clinically meaningful, as it is well below the .20 level needed to consider even a small clinical significance. Similar conclusions can be made about the AS x EAS interaction effect. While unstable-athletic tape condition landed in significantly less plantar-flexion than the unstable-athletic brace condition, the effect size of the unstable-athletic tape condition was -0.06, again well below the level of .20 to be considered even a small clinical significance. The clinical impact of these findings is that any change in ankle position is not likely to reduce the risk of ankle sprain.

Secondly, while there were significant findings between the athletic tape and athletic brace conditions, neither one was significantly different than no support in sagittal plane ankle angles at initial contact. The significant findings indicate that athletic tape reduces plantar flexion at initial contact better than athletic brace, but clinically this is not meaningful since neither differed than the no support condition.

Another study observed high movement variability during execution of 90° shuffling and 45° v-cut tasks (Dayakidis & Boudolos, 2006). This may indicate that there is an inherent variability in the movements that subjects will chose to accomplish a cutting task. This contrasts with the kinetic data in the present study, which was fairly consistent, as found in a low standard deviation. This is odd since high variability in the choice of method to land from a height and then change directions, as in the present study would intuitively seem to influence the manner in which a subject dissipated forces upon landing.

Specifically, a subject or trial in which the landing occurred on the rearfoot would be expected to generate different ground reaction forces when compared to a forefoot landing due to changes in the available sagittal plane motion at the ankle. Explanations of this finding are not possible due to the absence of data on knee and hip kinematics, which would have allowed the examination of compensatory motion at these joints to keep the ground reaction forces consistent. However, subjects may have adopted changes in knee, hip, and trunk kinematics to offset the changes in foot landing position, which may account for the consistency in ground reaction forces.

Frontal plane motion limitation has been hypothesized as the main function of EAS (Cordova, et al., 2000; Eils & Rosenbaum, 2003). Previous studies have demonstrated that this role may be even more important in those that suffer from CAI, as they have been shown to land in excessive inversion (Monaghan, et al., 2006) and tend to have a lateral shift of bodyweight (Nyska, et al., 2003) during walking. However similar inversion, and body weight shifts have not been found in studies that used higher demand activities (i.e. drop landing) in subjects with CAI (Delahunt, et al., 2009). The present study supports this past finding, that CAI and EAS do not affect frontal plane angles.

Delahunt et al, hypothesized that their choice of test, drop-landing, was not stressful enough to detect any changes in frontal plane motion (Delahunt, et al., 2009). The present study chose what is most likely a more stressful activity, the drop-cut maneuver, but it also did not result in any significant changes to frontal plane angles. A similar conclusion can be made that the choice of activity was simply not stressful enough to elicit any changes in frontal plane angles at initial contact.

However, an alternate hypothesis is possible, in that the task resulted in both forefoot and rearfoot landing strategies. The upper and lower bounds of the 95% confidence intervals of the sagittal plane ankle angles at initial contact can support this. The upper bounds are all positive indicating a landing strategy in plantar-flexion. The lower bounds are all negative, which indicates a landing strategy in dorsiflexion. These data support the theory that subjects chose multiple strategies to land. The plantar-flexion landings would constitute a forefoot strategy, while the dorsi-flexion landings would constitute a rearfoot strategy.

The choice in landing strategy is also likely to change the kinematics of landing in the frontal plane. This would result in smaller frontal plane angles with a forefoot strategy and larger frontal plane angles with a rearfoot strategy. The choice of multiple strategies would explain the large standard deviations of the frontal plane data. This could have been the result of subject preference, but it is also could be a result of the drop-cut maneuver. This task is more demanding and a higher speed task than has been used in past studies, which have used walking and drop-landings. The scant significant findings may be a result of this task selection and the corresponding combination of landing strategies. Based upon this it is hypothesized that frontal plane angles at initial contact are less likely to change if the activity is more stressful than walking and takes place on level ground, regardless of EAS and CAI.

This can be supported by the meta-analysis conducted by Cordova, et al (Cordova, et al., 2000), which demonstrated a consistent finding of limited ROM, when tested in a static environment before and after exercise. Intuitively, a restriction of frontal plane angles is to be expected as a result of EAS use. This should serve to highlight the idea that ROM may be limited in the frontal plane in a static environment where the limits of motion are explored. However, during dynamic testing in on a flat surface, more limited and consistent angles should be expected, especially at higher speeds where the rearfoot motion may be reduced.

The differing choice of strategy may also explain the effect sizes of the frontal plane data. The effect sizes are all positive or zero, indicating that there was no change in frontal plane position, or the addition of EAS caused the subjects to land in more inversion. This is not to be expected as the mechanical restraint of the EAS should prevent this. Landing with an emphasis on the forefoot while cutting in the opposite direction, as required in this task may have lead to subjects preferring to land in a more inverted position.

It had been originally planned to examine the position of the ankle during the stance phase to compare the effects that ankle stability and EAS had on kinematics. Upon examination the kinematic data during the stance phase was not useable due to errors that were most likely the result of motion artifact from the movement of the electromagnetic sensors. This prevented any examination of the kinematics during the stance phase. This will be examined in more detail in the limitations section, however it likely contributed to the scant findings and large standard deviations of the kinematic data. It also may lead to questioning the initial contact data and any conclusions drawn from it.

Clinically, the limitation of ROM and ankle angles during activity is the prime reason for applying EAS. As was previously stated, limiting plantar-flexion is one of the key factors in limiting ankle injuries (Wright, et al., 2000). While this is the goal in stable and unstable subjects, the present research does not guide the clinician as to what type of EAS can best prevent plantar-flexion. It is recommended that the entire body of research be considered which indicates a protective effect of EAS.

Drop-Cut Kinetics

Altered kinetics has been identified as a predisposing factor for injury of the lower extremity, in particular the knee (Chappell, et al., 2005; Chappell, et al., 2002; Decker, et al., 2003; Yu, et al., 2006). Previous studies have found alterations in the timing of vertical ground reaction forces (Caulfield & Garrett, 2004; Dayakidis & Boudolos, 2006) and magnitude of vertical ground reaction forces (Dayakidis & Boudolos, 2006) in those suffering from CAI. The use of EAS has been found to have no effect on magnitude and timing of PVGRF in stable ankles (DiStefano, et al., 2008; Sacco Ide, et al., 2006). The present study was in partial agreement with the past literature, as results showed that EAS has no affect on magnitude and timing of PVGRF, however disagreed with previous literature that CAI was not found to affect magnitude and timing of PVGRF.

An explanation for this is difficult given the limitations of the present study. DiStefano, et al (DiStefano, et al., 2008), explained that increased knee flexion at initial contact and displacement of the knee accounted for the lack of any change in PVGRF. However, kinematic data of the knee was not collected in the present study, so no conclusions regarding it can be made. Future research in kinetics should include data collection of the knee to determine if this is the case. It is likely that the high variability of the movement demonstrated in the present study was not a local phenomenon isolated to the ankle only. While it is speculation, it may have been that the knee, hip, and trunk would demonstrate compensatory movement that resulted in similar ground reaction forces.

Research that has demonstrated alterations in magnitude and timing of PVGRF in subjects with CAI has concluded that this is a neuromuscular response that increases the mechanical stability of the ankle. The authors noted a shifting of the medial-lateral ground reaction force to the vertical ground reaction force, which accounted for the increased magnitude of the PVGRF (Dayakidis & Boudolos, 2006). The present study did not find these alterations in kinetics and therefore cannot support the notion of a neuromuscular response to develop stability. Given that there were no significant findings of altered kinematics at the ankle at initial contact it appears that EAS and CAI have no impact on PVGRF. However, the lack of kinetic data in all three dimensions prevents a comparison to past research to determine if there are alterations in medial-lateral ground reaction forces.

While there were no statistically significant findings in regards to kinetic variables, the effect sizes associated with the data does provide some interesting information. Those with unstable ankles demonstrated a moderate PVGRF effect size with no support (d=.60) and tape (d=.50), as well as a main effect that approached moderate (d=.46). These values raise the concern of developing clinically relevant increases in PVGRF, which may increase the risk for lower extremity injury. The effect sizes of the timing of PVGRF lead to the conclusion that there may be a small decrease in the time to PVGRF, which may increase risk for injury. Given these effect sizes the magnitude and timing of PVGRF should continue to be studied until conclusive evidence is obtained.

Clinicians should cautiously apply EAS to both stable and unstable angles as there may be clinically significant increases in PVGRF and decreases in time to PVGRF. This has been a concern among clinicians and athletes alike that warrants further study. While an explanation was not examined in this study, magnitude and timing of PVGRF are moderated by increased knee, hip, and trunk motion when CAI and/or EAS are present. Clinicians should consider caution in applying EAS to athletes who have pre-existing conditions that might compromise motion at the knee, hip, and trunk as this might result in the inability to compensate for the sagittal plane motion limitation at the ankle.

Limitations & Future Research

There were several methodological and conceptual limitations in this study that must be pointed out. First, all the subjects recruited for this study were recreationally active individuals who demonstrated the ability to complete the testing procedures correctly. However, these subjects demonstrated large variability in movement which may have indicated different landing strategies: rearfoot and forefoot. This may have been the result of the subjects selected for the study, as they could not complete the task in a consistent manner.

The completion of the task was deemed sufficient, as all recorded trials were judged to be successful by the primary investigator. Subjects landed on the force platform correctly and the subject cut at the proper angle. However, there was a lack of any objective evaluation of the execution of the trials (i.e. speed of completion, forcefulness of cut) to determine proper execution. In future research standardized approach velocities and minimum PVGRF may be used to avoid this.

The results of the study indicate that the subjects who took part completed the drop-cut in a manner that was highly variable between subjects and within subjects. Evidence of this is the large standard deviations and wide 95% confidence intervals of the kinematic data. This may have been the result of each individual using a large number of landing and cutting strategies to complete the drop-cut task. An alternate explanation may be that there were errors in the data collection and reduction. As was mentioned earlier, in the original conception for this project, it had been planned to examine the position of the ankle during the stance phase to compare the effects that ankle stability and EAS had on kinematics.

However, upon examination the kinematic data was not useable due to errors that were most likely the result of motion artifact from the movement of the electromagnetic sensors during the stance phase. These data were not included in the statistical analysis for this reason. While the primary author is not aware of any errors in data collection and reduction, the poor quality of the stance phase kinematic data cannot be ignored. This is clearly a limitation of the findings of the present study and casts doubt upon all of the kinematic findings of this study.

The nature of CAI itself limits the results of this study, as it is a self-reported phenomenon (Freeman, et al., 1965). This allows individual interpretation to become a main factor in the separation of groups, which in turn may have allowed the stable and unstable groups to be similar in composition. This may have led the lack of a potent enough difference between the ankle stability groups, which may explain the lack of significant findings.

Past research has demonstrated that there are kinematic differences within the spectrum of CAI. Specifically, it has been found that those with MAI move differently than those with FAI and those labeled as copers (C. N. Brown, Padua, Marshall, & Guskiewicz, 2009). This reinforces the concept that both MAI and FAI are different parts of the spectrum of CAI (J Hertel, 2002), and need to be separated in research. Considering this, it is an error to use a single group labeled as CAI in research as was the case in this study. This again may have resulted in the lack of significant findings as the unstable group may have been composed of mainly FAI subjects who may have moved similarly to the stable group.

Future research should focus on development of objective criteria or testing measures, which can be used to create distinct groups. Such a measure could be the use of an objective ankle measurement tool such as the Cumberland Ankle Instability Tool (Delahunt, et al., 2009; Hiller, Refshauge, Bundy, Herbert, & Kilbreath, 2006; Sawkins, et al., 2007) or the star excursion balance test (J. Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Plisky, Rauh, Kaminski, & Underwood, 2006). The objective tools could be used to ensure groups are composed of those that are experiencing CAI.

Joint stress tests, such as the anterior drawer and talar tilt into inversion could be used to further divide the group into a MAI and FAI groups, as has been done in previous studies (C. N. Brown, et al., 2009). This would be useful in research to ensure groups meet specific criteria, but also clinically useful to have a tool that could screen athletes into risk categories and then target intervention strategies to these groups. However it should be noted that under these criteria the situation of a combined FAI & MAI instability cannot be accounted for. Further research into methods to separate out combined instabilities is needed.

Additionally, it has been suggested that a group of "copers", or subjects that have experienced an ankle sprain and not developed CAI, be included in research (J. Hertel & Kaminski, 2005). This may provide more useful information in regards to the risk factors associated with the development of CAI. These factors could then be used to develop injury prevention programs for after an ankle sprain has occurred.

The manner of application of the EAS may have also lead to a lack of significant findings. The principal investigator may have applied the athletic tape in a manner that did not restrict motion of the ankle or provide enough proprioceptive input to affect the variables of interest. This makes generalizing the results to all athletic taping difficult to do as there are a variety of methods of application. The subjects, under the supervision of the principal investigator, applied the ankle brace and the results may be the result of poor application. In the future employing a method to objectively measure the support provided to the ankle may be useful to ensure that it is sufficient.

The non-significant findings of this project were associated with low statistical power. The sample size was calculated *a priori*, based on previously published research involving kinematic data and with a desired power of .80, it was determined that 8 subjects in each group would be sufficient. The sample size surpassed this with 12 subjects in each group. Upon review of the results a post-hoc power analysis was conducted using the means and standard deviations of the results. These calculations indicated that it would have required well over 200 subjects per group. The sample size in the project was not enough to achieve a sufficient level of power, however the required number of subjects was unrealistic. It is likely that the low power associated with the non-significant results indicates that there were no differences between the groups.

Data collection and conclusions were hindered by the lack of a sensor on the thigh, which would have allowed for the collection of knee kinematic data. This would have allowed for the determination of specific points during the stance phase, (such as the end of the loading phase: point of peak knee flexion during stance), at which point ankle angles could have been determined. Without the sensor it was impossible to determine this point and examine the effects of EAS on kinematics past initial contact. It also would have allowed for examination of the role that the knee plays in the kinematics and kinetics associated with both CAI and EAS. Without this information it could not be determined if PVGRF remained unchanged due to kinematic changes at the knee.

The opportunity to examine ground reaction force in all three planes would have been useful to contrast with previous research that has found differences in planes other than the vertical (Caulfield & Garrett, 2004; Delahunt, et al., 2007; Sacco Ide, et al., 2006). This may be useful to shed light on the kinetic compensations that occur with CAI and EAS as well as investigating the risk of further injuries. Future research of this nature should include kinetic data of all three planes.

Another area that should be expanded in future research is to include other types of EAS. The clinical practice of applying EAS is advancing much faster than research can justify at this point. The purpose of this type of research is to evaluate clinical practice and provide some information for the clinician to use. This would be useful with the wide array of athletic braces, athletic tapes, and styles of application.

Clinical Application

The use of EAS to prevent and treat ankle sprains cannot be recommended based on the kinematic and kinetic variables examined in this study. This is due to the lack of any clinically meaningful findings between no support and either of the support conditions in kinematic variables. Without the demonstrated ability to keep the ankle from landing in an increased plantar flexion position, it is unlikely that ankle sprains will be prevented.

However, previous research which has demonstrated a protective effect from ankle sprains (Garrick & Requa, 1973; Mickel, et al., 2006; Rovere, et al., 1988; Sharpe, et al., 1997; Simon, 1969; Sitler, et al., 1994; Stasinopoulos, 2004; Surve, et al., 1994; Tropp, Askling, et al., 1985), range of motion restriction (Cordova, et al., 2000), and no negative affect on performance (Cordova, et al., 2005) with the use of EAS, must be considered. With this in mind, clinicians should use EAS as a method to combat ankle sprains in a comprehensive manner combined with proper screening, injury prevention methods, rehabilitation, and proper execution of sports skills.

APPENDIX A: TABLES

Table 1: Subject demographic data

	Stable (n=12)		Unstable (n=12)	
	Mean	**SD**	**Mean**	**SD**
Males	4		4	
Females	8		8	
Age (years)	22.58	2.19	21.75	2.17
Height (cm)	170.13	11.04	173.09	11.24
Mass (kg)	70.58	14.82	76.57	18.74

Table 2: Means, standard deviations, and 95% confidence intervals for frontal plane ankle joint angles at initial contact (°).

	No Support				Tape				Brace				AS			
	Mean	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**	
			LB	**UB**			**LB**	**UB**			**LB**	**UB**			**LB**	**UB**
Stable	-7.45	24.13	-20.37	5.47	-5.23	19.78	-16.47	6.02	-6.34	14.13	-14.87	2.19	-6.34	14.13	-14.34	1.66
Unstable	0.86	18.69	-12.06	13.78	-1.28	17.73	-12.52	9.97	0.32	14.37	-8.21	8.85	-0.03	16.56	-9.40	9.34
EAS	-3.30	21.43	-11.87	5.27	-3.25	18.48	-10.64	4.14	-3.01	14.34	-8.75	2.73				

SD: Standard deviation, LB: Lower bound, UB: Upper bound. Inversion angles are negative and eversion angles are positive.

Table 3: Means, standard deviations, and 95% confidence intervals for sagittal plane ankle angles at initial contact (°).

	No Support				Tape				Brace				AS			
	Mean	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**	
			LB	**UB**			**LB**	**UB**			**LB**	**UB**			**LB**	**UB**
Stable	-6.35	22.03	-19.83	7.14	-5.04	20.19	-17.38	7.29	-4.72	20.48	-16.95	7.52	-5.37	20.32	-16.87	6.13
Unstable	-5.04	23.02	-18.52	8.45	-7.78*	21.01	-20.11	4.55	-1.48*	20.38	-13.71	10.76	-4.77	21.04	-16.67	7.13
EAS	-5.69	22.04	-14.51	3.13	-6.41*	20.20	-14.49	1.67	-3.10*	20.05	-11.12	4.92				

SD: Standard deviation, LB: Lower bound, UB: Upper bound. *: Significant at the $P<.05$ level. Plantar-flexion angles are positive and dorsiflexion angles are negative.

Table 4: Means, standard deviations, and 95% confidence intervals for peak vertical ground reaction data (% BW).

	No Support				Tape				Brace				AS			
	Mean	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**	
			LB	**UB**			**LB**	**UB**			**LB**	**UB**			**LB**	**UB**
Stable	221.72	19.36	207.55	235.90	218.55	22.84	202.26	234.84	222.25	19.55	210.78	233.72	220.84	20.12	207.52	234.16
Unstable	233.26	27.33	219.08	247.44	231.39	30.97	215.10	247.67	225.36	18.75	213.89	236.82	230.00	25.66	216.68	243.32
EAS	227.49	23.90	217.47	237.52	224.97	27.41	213.45	236.49	223.80	18.80	215.69	231.91				

SD: Standard deviation, LB: Lower bound, UB: Upper bound

Table 5: Means, standard deviations, and 95% confidence intervals for time to peak vertical ground reaction data (ms).

	No Support				Tape				Brace				AS			
	Mean	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**		**Mean**	**SD**	**95% CI**	
			LB	**UB**			**LB**	**UB**			**LB**	**UB**			**LB**	**UB**
Stable	110.31	23.44	92.27	128.35	116.23	45.19	92.34	140.12	102.41	31.62	85.10	119.72	109.65	34.08	92.76	126.54
Unstable	111.55	35.59	93.51	129.59	104.94	33.81	81.05	128.83	107.15	25.92	89.84	124.46	107.88	31.24	90.99	124.77
EAS	110.93	29.48	98.17	123.69	110.58	39.45	93.69	127.48	104.78	28.38	92.54	117.02				

SD: Standard deviation, LB: Lower bound, UB: Upper bound

Table 6: Frontal plane ankle angles at initial contact effect sizes for ankle stability main effect, external ankle support main effect and ankle stability x external ankle support interaction effect

	No Support	Tape	Brace	AS
Stable	N/A	0.09	0.05	N/A
Unstable	0.34	0.26	0.32	0.45
EAS	N/A	0.00	0.01	

AS: Ankle Stability, EAS: External Ankle Support, N/A: Effect size not applicable for control condition.

Table 7: Sagittal plane ankle angles at initial contact effect sizes for ankle stability main effect, external ankle support main effect and ankle stability x external ankle support interaction effect

	No Support	Tape	Brace	AS
Stable	N/A	0.06	0.07	N/A
Unstable	0.06	-0.06	0.22	0.03
EAS	N/A	-0.03	0.12	

AS: Ankle Stability, EAS: External Ankle Support, N/A: Effect size not applicable for control condition.

Table 8: Peak vertical ground reaction force effect sizes for ankle stability main effect, external ankle support main effect and ankle stability x external ankle support interaction effect

	No Support	Tape	Brace	AS
Stable	N/A	-0.16	0.03	N/A
Unstable	0.60	0.50	0.19	0.46
EAS	N/A	-0.11	-0.15	

AS: Ankle Stability, EAS: External Ankle Support, N/A: Effect size not applicable for control condition.

Table 9: Time to peak ground reaction force effect sizes for ankle stability main effect, external ankle support main effect and ankle stability x external ankle support interaction effect

	No Support	Tape	Brace	AS
Stable	N/A	0.25	-0.34	N/A
Unstable	0.05	-0.23	-0.13	-0.05
EAS	N/A	-0.01	-0.21	

AS: Ankle Stability, EAS: External Ankle Support, N/A: Effect size not applicable for control condition.

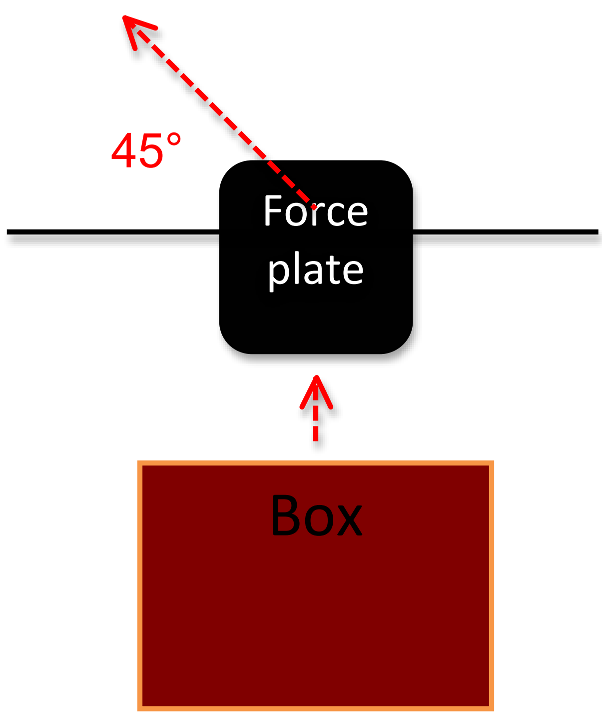
Table 10: 95% Confidence intervals of the difference in means for ankle angles in the sagittal plane at initial contact significant findings.

	95% CI of the Difference	
	LB	**UB**
Athletic Tape - Athletic Brace	-0.62	-6.01
Unstable-Athletic Tape - Unstable Athletic Brace	-1.49	-11.13

LB: Lower bound, UB: Upper bound

APPENDIX B: FIGURES & ILLUSTRATIONS

Figure 1: Diagram of the drop-cut maneuver



The above diagram is an example of the drop-cut maneuver for the right lower extremity. The subject would stand on the box with their left foot, drop onto the force plate with their right foot, and then cut in a 45° angle to the left and land on their left foot.

Figure 2: Tape application

Figure 3: Brace application

APPENDIX C: SUBJECT QUESTIONAIRE

***Subject* #:**____________ Stable Unstable

General

Age__________Yrs Height_________(cm) Mass__________(Kg) Shoe Size______________

Ankle Information

History of ankle sprain with pain and/or limping for more than one day Y N

Affected ankle is less functional (weakness, pain, or instability) since the initial ankle sprain Y N

Sensation or experiencing giving way of the ankle in the last 6 months Y N

Dominant Lower Extremity: L R

Affected Lower Extremity: L R None

Exclusion

History of ankle fracture and/or current participation in formal physical therapy of the lower extremity Y N

History of concussion, balance or vestibular disorders, or history of lower extremity injury during the 3 months prior to enrollment that would prevent you from completing the required tasks Y N

Any medical condition that might compromised by participation in this study Y N

Physical Activity

Sessions of Activity per week:_________________

Time spent per session:_______________________

Type of activity:_____________________________

Counter-balanced EAS Testing Order

1st	No EAS	Tape	Brace
2nd	No EAS	Brace	Tape
3rd	Tape	No EAS	Brace
4th	Tape	Brace	No EAS
5th	Brace	No EAS	Tape
6th	Brace	Tape	No EAS

Trial Notes

1st

2nd

3rd

4th

5th

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