

**A NOVEL WAY OF MEASURING ANKLE STABILITY AFTER  
FUNCTIONAL ACTIVITY**

by

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fulfillment of the requirements for the degree of Master of Science in  
Exercise Science

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FUNCTIONAL ACTIVITY**

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## ABSTRACT

**Context:** Ankle sprains make up 85% of injuries to the foot and ankle and up to 70% of cases may develop ankle instability (AI). Functional and mechanical insufficiencies contribute to AI. Taping and bracing have become common practices, to prevent initial and recurrent ankle sprains. They are intended to restrict excessive ankle joint motion; however, their effectiveness *during* sport activity is inconclusive. **Objective:** To compare differences in laxity at the ankle in taped and braced conditions, in individuals with and without ankle instability, before and after exercise. **Design:** Pre-test post-test design with control group. **Setting:** Human Performance Laboratory. **Participants:** Twenty-four participants (20.6±1.6yrs, 173.6±8.3cm, 72.8±12.2kg) were placed into one of three groups; ankle instability, previous sprain with no instability, or no previous sprain. **Intervention(s):** Ankle laxity was assessed on each subject to test the effect of an ankle taping and bracing from pre- to post- exercise. A 20-minute exercise protocol was performed utilizing each of the external prophylactic support (EPS) conditions (tape, brace, control/none). **Main Outcome Measure(s):** Ankle laxity (anterior displacement and inversion-eversion rotation) was measured using an ankle arthrometer under three conditions and in three groups. A repeated measures ANOVA was utilized to analyze differences between the groups and within EPS type and pre-post exercise. **Results:** Taping and bracing both restricted anterior displacement, inversion and eversion rotation at pre and post exercise ( $p<.05$ ). Tape provided greater restriction post exercise in inversion and eversion rotation ( $p<.05$ ). The ankle instability group had a significantly greater anterior displacement post exercise after removal of the brace. **Conclusions:** Ankle taping provides more mechanical restriction at the ankle, compared to the bracing. However, both provided a significant amount of restriction after 20 minutes of exercise when compared to measurements without taping or bracing. It appears that EPS may be effective in providing mechanical support to individuals involved in short-term exercise bouts. **Key Words:** taping, bracing, arthrometer, ankle instability

# CHAPTER 1

## INTRODUCTION

Ankle sprains are the most common injury in athletics.<sup>1,2</sup> With increasing severity, ankle sprains can become quite debilitating, keeping athletes out of activity for several weeks. Signs and symptoms of ankle sprains include pain, swelling, weakness, and the sensations of instability.<sup>3,4</sup> Following an initial ankle sprain, as many as seventy percent of subjects may develop some degree of chronic ankle instability (CAI), while others may have no residual symptoms.<sup>5-8</sup> Symptoms of CAI include repeated sensations of their ankle “giving-way”, the feeling of instability, ligamentous laxity, general weakness and pain.<sup>9,10</sup> CAI can be secondary to mechanical instability, functional instability, or the combination of both.<sup>5,10,11</sup> Mechanical instability is a result of physiological changes at the talocrural and subtalar joints and manifests as increased joint laxity.<sup>4,8,12,13</sup> Alternately, functional instability is caused by alterations in neuromuscular control, muscular weakness or impairments in proprioception.<sup>6,10,14,15</sup> While these two components may exist independently from each other, current treatment options address chronic ankle instability as a single problem, leading to insufficiencies in current prevention and treatment options.<sup>10,11,16-20</sup>

In an attempt to prevent recurrent ankle sprains in athletes, the application of external prophylactic support (EPS), such as taping and bracing, is a common practice.<sup>13,17,19,21,22</sup> Ankle taping and bracing are primarily intended to restrict excessive subtalar joint motion. Current research into the efficacy of taping and bracing in restricting joint motion has been indeterminate as discrepancies exist in taping technique, brace design, and assessment of ankle joint motion. Previous research has



looked into the efficacy of different taping techniques, including the tension, type of tape, and application of strips; as well as differences between lace-up and semi-rigid braces.<sup>22-25</sup> In these conditions, joint kinematics have commonly been investigated using goniometric range-of-motion measurements in the frontal and sagittal planes, both before and after various exercise protocols.<sup>22, 23</sup> Research has suggested that taping is effective in limiting frontal plane motion; however, this restriction is significantly less following exercise.<sup>22, 25</sup>

Although our understanding of physiological ankle motions following the application of taping and bracing is clear, few investigations have been performed examining the effect of accessory ankle motion.<sup>13</sup> Accessory motion of the ankle has been traditionally measured using clinical tests or stress radiographs.<sup>26, 27</sup> Recently, ankle arthrometers have been developed to quantifiably and portably measure ankle ligamentous laxity through anterior translations and inversion and eversion rotations.<sup>28, 29</sup> Through extensive testing these devices have been shown to be valid and reliable.<sup>29-31</sup> Kovaleski et al.<sup>29</sup> used the arthrometer to determine if it was capable of recognizing injury to a ligament. After ligaments were transected in cadaveric ankles, there was a significant increase in laxity of the ankles.<sup>29</sup> One recent study by Hubbard et al. used an ankle arthrometer before and after the application of prophylactic taping and found that despite an increase in laxity after exercise, the tape still provides restriction to the ankle.<sup>13</sup> These findings with the arthrometer run contrary to goniometric measurements suggesting a lack of effectiveness of tape following exercise. No studies utilizing arthrometric measurement systems have been reported investigating the comparative role of taping and bracing in restricting ankle laxity following exercise.

Therefore, the purpose of this study is to examine the effectiveness of taping and bracing on restricting ankle motion, in individuals with and without ankle instability, utilizing contemporary ankle arthrometry. Our study involves a unique dynamic exercise component as well as a rarely studied, one-time lateral ankle sprain group. We hypothesized that based on previous research, unstable ankles would have increased laxity compared to healthy and previously sprained ankles; and this increased laxity will be corrected with the application of EPS. Additionally, we hypothesized that laxity would increase from pre- to post-exercise both with and without the application of EPS.

## CHAPTER 2

### METHODS

#### 2.1 Participants

We tested 24 participants (9 female and 15 male), between the ages of 18 and 25 in this study (age =  $20.6 \pm 1.6$  yrs, height =  $173.6 \pm 8.3$  cm, mass =  $72.8 \pm 12.2$  kg). Both ankles (48) on all participants were used for analysis. All participants were free from injury at the time of the study and not undergoing any formal rehabilitation. In addition, they had no previous history of fracture or surgery to the lower leg. All subjects were tested bilaterally. Subjects were stratified into 3 groups based on their history of ankle injury and scores on the Cumberland Ankle Instability Tool<sup>32</sup> (CAIT): ankle instability (AI), lateral ankle sprain (LAS), and control (CON). Those ankles assigned to the AI group had a unilateral CAIT score less than 24. Ankles assigned to the LAS group were those that suffered a previous lateral ankle sprain, but did not have instability as measured by a CAIT score of 28 or greater. Ankles assigned to the control group had no previous history of ankle sprain and a CAIT score of 28 or higher. Subjects whose ankles scored between 25 and 27 were excluded. Group assignments for ankle and gender are presented in Table 1.

<u>Group</u>	<u>Number (n=48)</u>
<b>Ankle Instability</b>	<b><u>18</u></b>
Males	11
Females	7
Left	9
Right	9
<b>Lateral Ankle Sprain</b>	<b><u>7</u></b>
Males	6
Females	1
Left	3
Right	4
<b>Control (Healthy)</b>	<b><u>23</u></b>
Males	13
Females	10
Left	12
Right	11

**Table 1. Group assignments for ankle and gender.**

Before beginning the study all subjects signed the consent form, approved by the University of Delaware Human Subjects Review Board (HS 09-593). Demographic data (age, height, mass, gender) were collected prior to the start of the first session. All subjects completed the Physical Activity Readiness Questionnaire (PAR-Q) which was used to rule out any health conditions that would demonstrate a risk for participating in

the study. Any “yes” responses, excluded the subject from participating in the study. In addition, all subjects completed the CAIT to determine ankle instability status, and the International Physical Activity Questionnaire (IPAQ) to gauge their activity levels. The exercise protocol used in this study is rigorous, so it was important that subjects had some level of fitness in order to complete the activity safely.

## 2.2 Ankle Arthrometer

Ankle stability was measured using a portable instrumented ankle arthrometer, (Blue Bay Research Inc., Milton, FL) (Figure 1). The arthrometer is made up of a foot plate, dorsal and heel clamps, a tibial pad, a 6 degree of freedom (3 rotations, 3 translations) spatial kinematic linkage, and load cells attached to a handle. The heel and dorsal clamps secured the foot to the arthrometer footplate, while the tibial pad was secured to the lower leg. During anterior translations (ANT), the ankle was loaded with 130 N of anterior force, while during inversion-eversion rotations (IE) 4.2 N-m of inversion and eversion torque was applied to the ankle.<sup>29</sup>



**Figure 1. The ankle arthrometer used in this study.**

The analog signal from the ankle arthrometer was converted to a digital signal with a data acquisition card (USB 6212 multifunction DAQ, National Instruments, Austin, TX) within the arthrometer and the signal was analyzed using custom LabVIEW software (National Instruments, Austin, TX) allowing real-time monitoring of position and force data. Anterior displacement was reported in millimeters, while inversion-eversion rotation was reported in degrees. The foot was maintained in a neutral flexion angle throughout testing. 3 ANT trials were performed first, followed by 3 IE trials. Based on the protocols of previous studies, and the recommendations of the manufacturer, ANT displacement was measured first and followed by inversion-eversion (I-E) rotation.<sup>29</sup> Posterior displacement was not of interest, as this measurement is rarely assessed in a clinical setting.

### **2.3 Test Procedures**

Subjects in all groups completed 3 sessions of testing. These 3 sessions were randomized using a 3x3 Latin Square. The sessions included (1) a taped condition, (2) a braced condition, and (3) no tape or brace (No- EPS) condition. There was 7 days between test sessions to eliminate any residual soreness that could have affected physical performance. All sessions followed the same order of testing, except for EPS application. During each session, baseline ankle arthrometer measurements were taken on both ankles using the procedures described above. At the conclusion, subjects were then randomly assigned to either the taped, braced, or control conditions. Following this assignment process and the application of either tape, brace, or No-EPS, an additional set of arthrometer measurements were taken on both ankles.

## 2.4 Taping Procedure

All subjects were taped using standard taping techniques performed by the principal investigator (HAM). Adhesive spray, heel and lace pads, and pre-wrap were applied with each ankle taping. Basic taping procedures including two sets of heels locks and a figure-8 were applied to the ankle.<sup>33</sup>

## 2.5 Bracing Procedures

All subjects wore ASO EVO (Medical Specialties, Inc., Charlotte, NC) ankle braces (Figure 2). Brace size was determined by the foot size. The brace was applied according to manufacturer's instructions, except that each subject secured the brace directly over the skin and not the sock. This was done to prevent discrepancies of sock thickness in our subjects. We did this to prevent discrepancies of sock thickness in our subjects. The heel lock straps were applied first medially, then laterally.



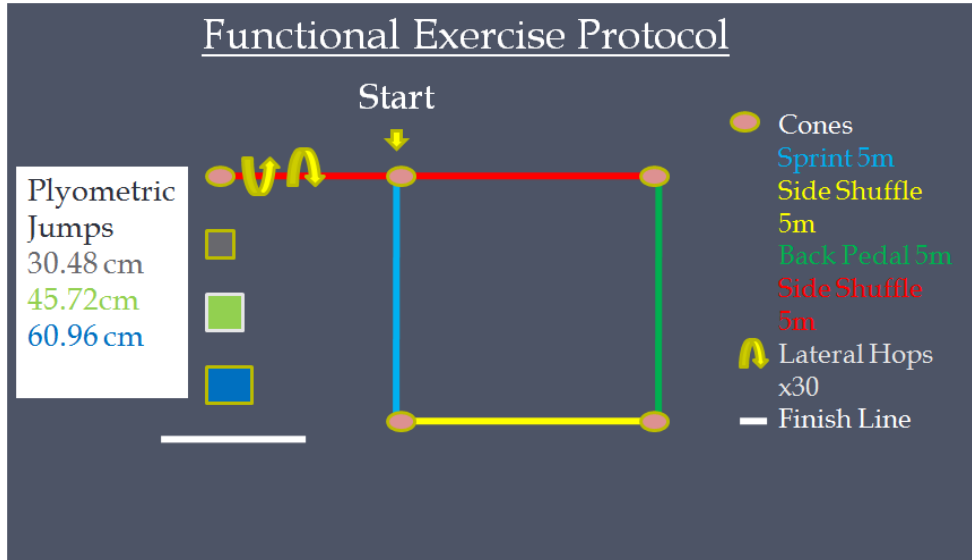
**Figure 2. The ASO EVO brace used in the study. The picture on the left shows the outlining of the reinforced sides of the brace.**

## 2.6 Functional Exercise Protocol

Subjects were provided a 5 - minute warm-up on a stationary bike followed by a short series of stretching exercises for the lower extremity. Immediately following this, subjects performed 20 repetitions of the functional exercise protocol (FEP) (Figure 3); a variation of the functional fatigue protocol described by Douex et al.<sup>34, 35</sup> The FEP begins with a 5m sprint to a cone, followed by a 5m side shuffle, a 5m backpedal, and finishes with a 5m side shuffle back to the starting cone. The subject then moves around the last cone and performs 30 lateral hops back and forth over a line marked on the floor. The course ends with subjects performing 3 consecutive box jumps onto boxes at heights of 30.5cm, 46cm, and 61cm. Subjects were encouraged to perform at a level of 80% of their maximal effort. If the course was completed in less than one minute, the subject was asked to walk around the course for the remainder of the minute, as an active recovery. A total of 20 repetitions were performed such that the total amount of exercise time was 20 minutes. Following each repetition, the subjects provided a rating of perceived exertion (RPE) based on the Borg scale (Figure 4).<sup>36</sup> The RPE was important and helped to ensure that the subjects were maintaining the same level of exertion from session to session. It was expected that all subjects would require 20 minutes to complete the 20 repetitions of the FEP. Subjects failing to complete the 20 repetitions were excluded from the study. Immediately upon concluding the FEP, ankle arthrometry measurements were taken on both ankles as previously described. In addition, arthrometry measurements were taken following the removal of either the taping or bracing conditions. Therefore, a total of 12 arthrometer measurements were obtained for each ANT and IE motions; 3 trials each at pre-EPS, pre-exercise, post-



exercise and post-EPS. In the no-EPS condition, only pre- and post-exercise measurements were obtained.



**Figure 3. The functional exercise protocol used in this study.**

Rating of Perceived Exertion (RPE)	
6	No exertion at all
7	Extremely light
8	Very light
9	Light
10	
11	
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

**Figure 4. The Borg scale for rating of perceived exertion.**

## 2.7 Data Reduction

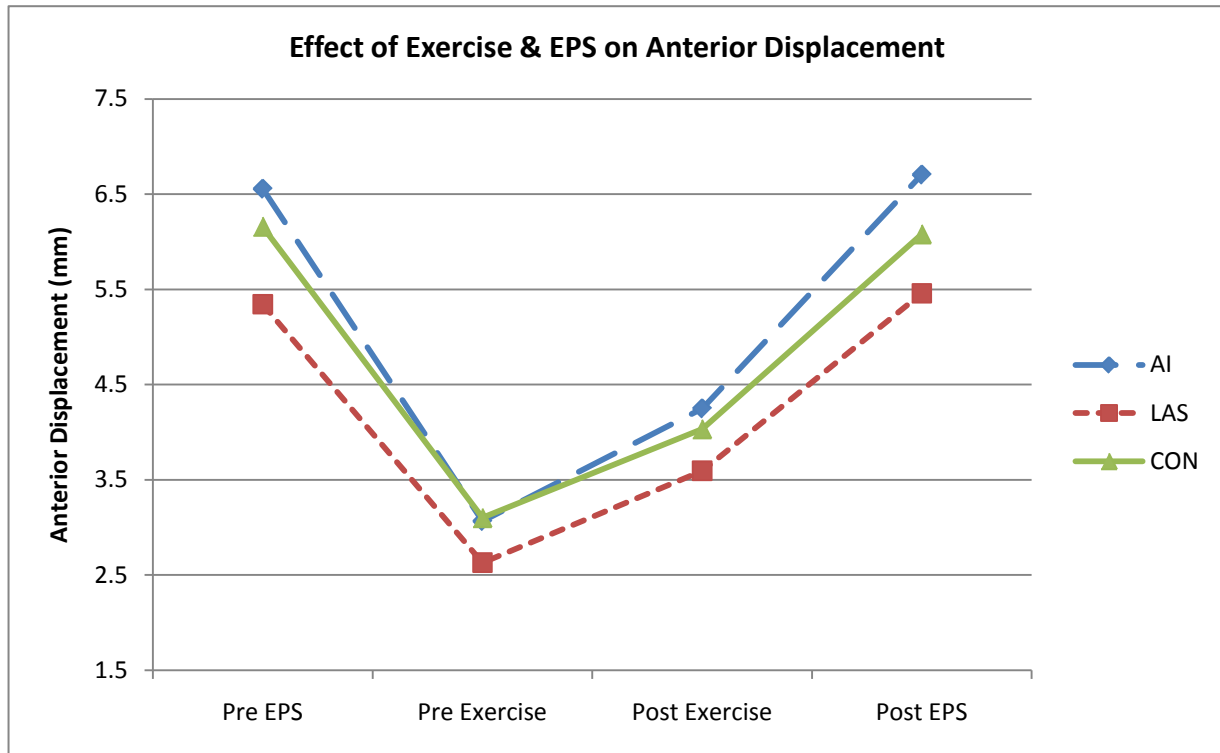
Arthrometric measurements served as the dependent measures in this study. They included peak anterior displacement (mm), peak inversion rotation (deg); and peak eversion rotation (deg).<sup>30</sup> Independent variables included group (AI, LAS, CON), condition (Tape, Brace, No-EPS), and time (pre-post exercise, pre-post EPS). Data were analyzed using Statistical Product and Service Solutions (SPSS) 17.0 (Chicago, IL) software. A pre-test/post-test design was used to evaluate changes in the arthrometry measurements from pre to post FEP under all 3 conditions. Specifically, the data were analyzed using a factorial repeated measures ANOVA with 1 between subject factor (group: 3 levels) and 2 within subject factors (EPS: 3 levels: time: 4 levels). Tukey's post-hoc test and pairwise comparisons were utilized to examine differences of interest. An alpha level was set *a priori* at  $p < 0.05$  to determine statistical significance.

## CHAPTER 3

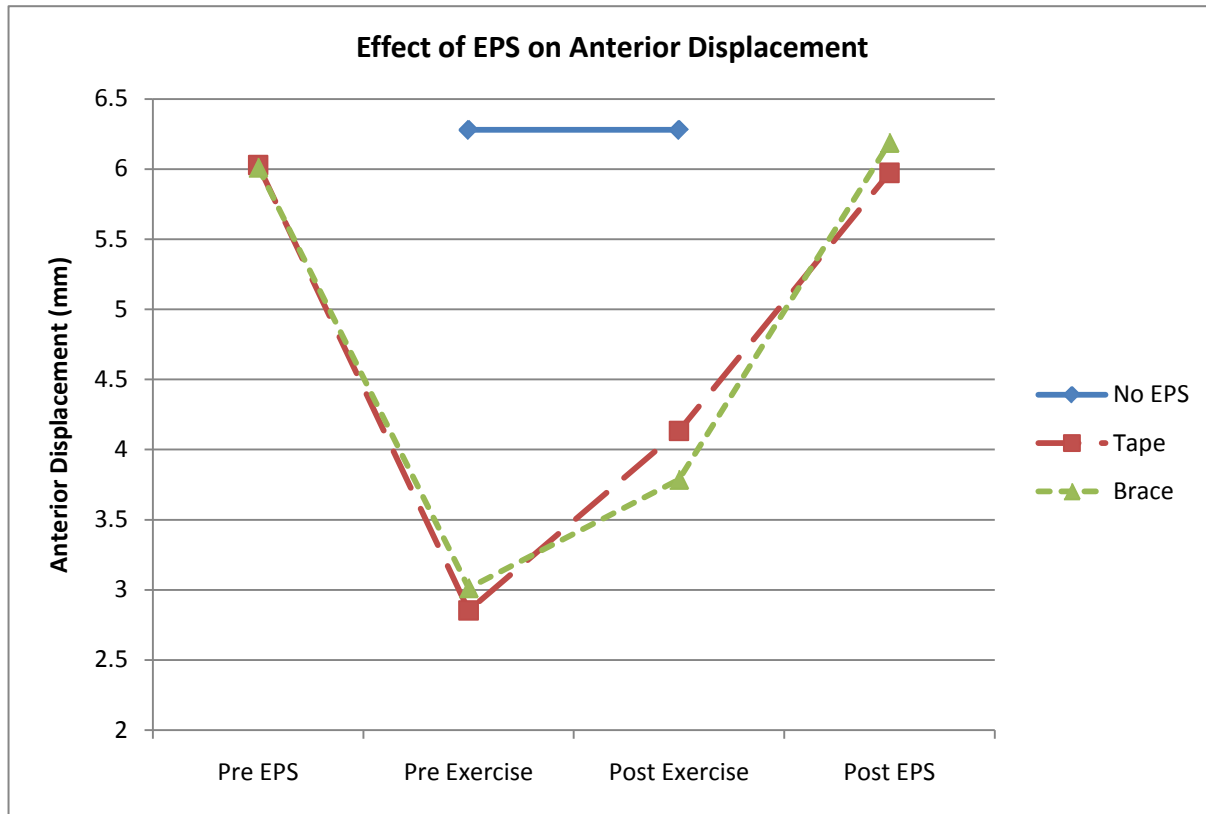
### RESULTS

#### 3.1 Anterior Displacement

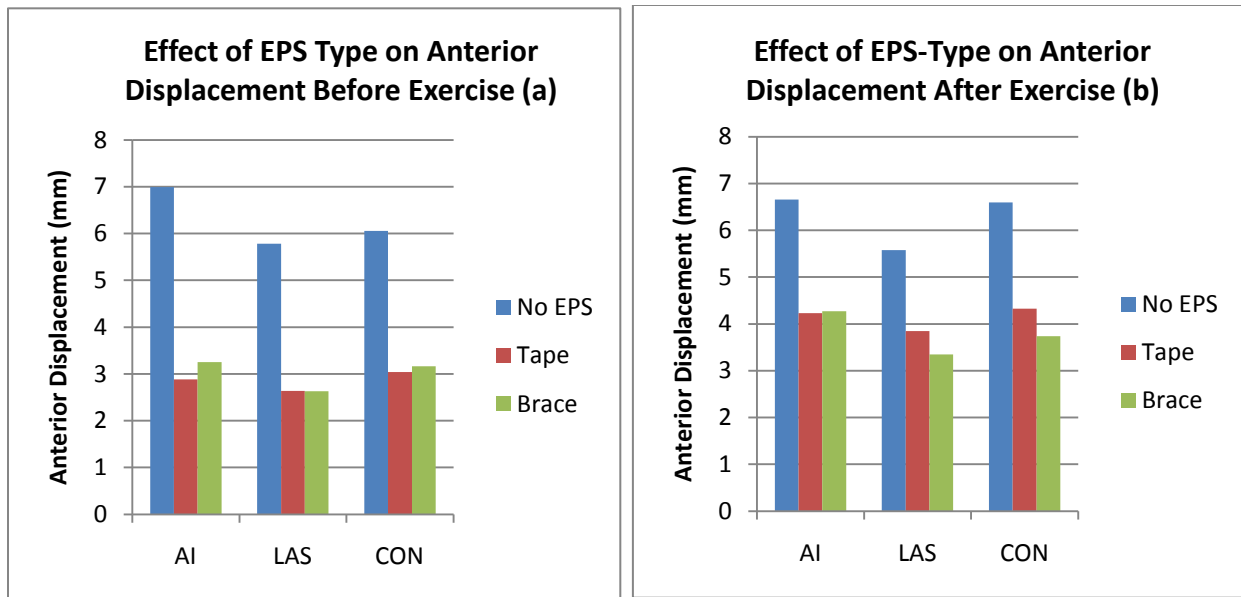
A significant 3-way interaction for group, time, and EPS was observed for measures of anterior displacement ( $F=2.028$ ,  $p=.018$ ); however, Tukey's HSD post-hoc test revealed no differences between groups. Pairwise comparisons revealed that the application of EPS significantly decreased anterior displacement over the No-EPS condition, at both pre- and post-exercise, in all groups ( $p<.001$ ) (Figure 5). In both taped and braced conditions, laxity increased significantly from pre- to post-exercise ( $p<.01$ ) with the exception of a trend ( $p=.065$ ) observed in the braced condition in the LAS group (Figure 6). With no EPS, the CON group had a significant increase in laxity post-exercise ( $p=.01$ ), while the AI group had a significant decrease in laxity post-exercise ( $p=.05$ ). Following removal of the brace, the AI group had a significant increase in anterior displacement compared to the CON group ( $p=.024$ ) and the LAS group ( $p=.039$ ), as compared to the taped condition ( $p=.045$ ) (Figure 7).



**Figure 5. The effect of exercise and EPS on anterior displacement. The application of the tape and brace significantly reduced laxity pre and post-exercise in all groups.**



**Figure 6. The effect of EPS on anterior displacement. A difference between the tape and brace at post-exercise is observed, however, there is no significant difference. The application of tape and brace significantly reduces laxity in anterior displacement pre and post-exercise.**

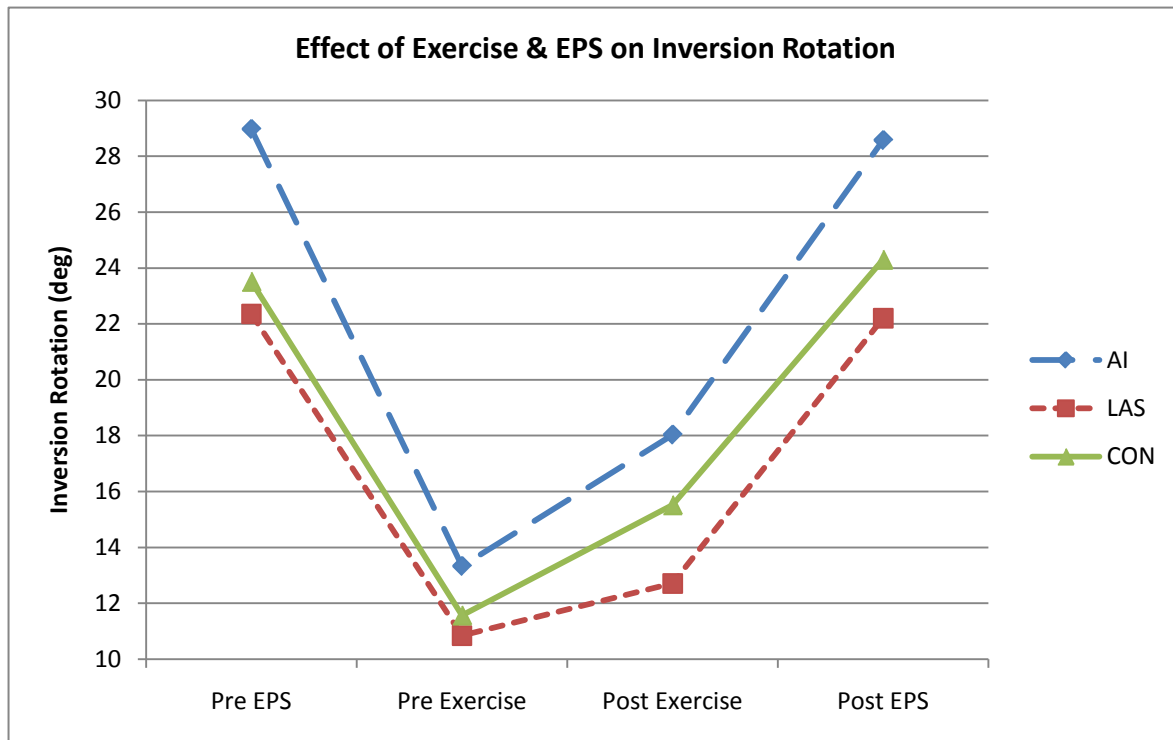


**Figure 7. The effect of EPS type on anterior displacement before (a) and after (b) exercise. Significant differences between the tape and brace groups are observed in relation to the control condition. In addition, ankle group across the three conditions shows that in the AI group, the brace appears to be slightly more restrictive from pre to post-exercise.**

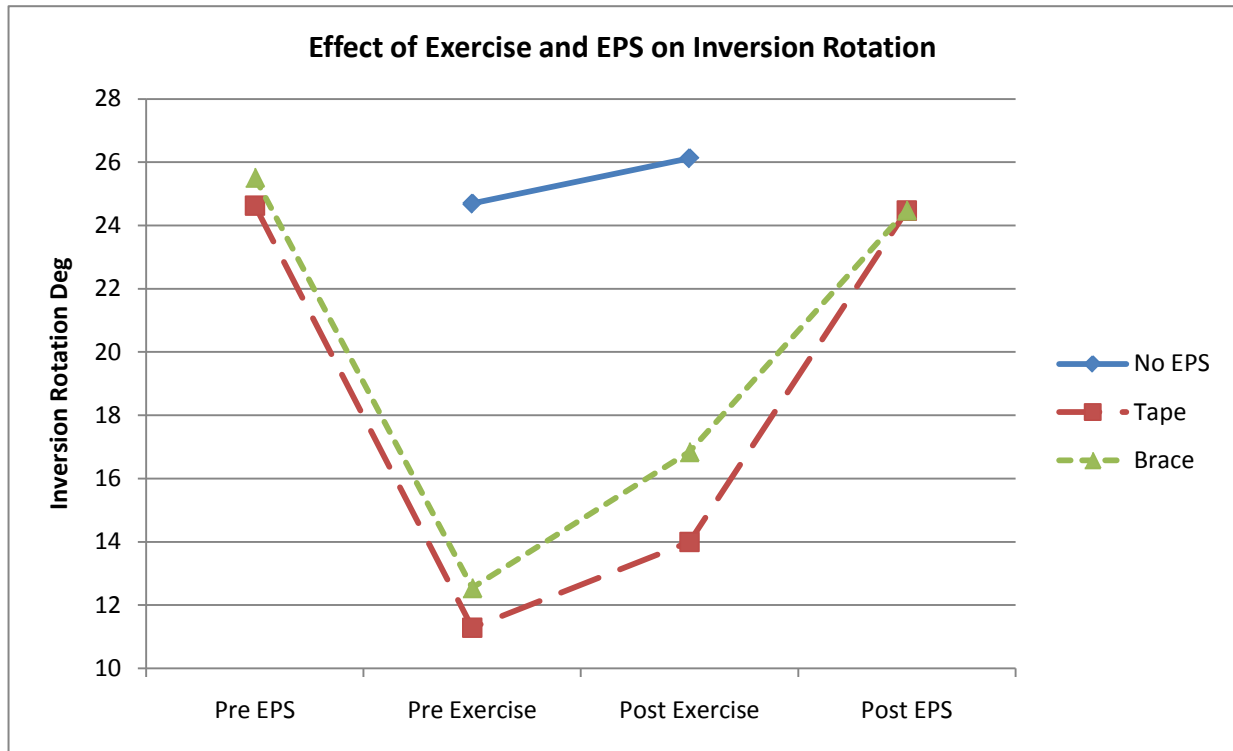
### 3.2 Inversion Rotation

Inversion measurements revealed no significant group by time by EPS interaction ( $F=.547$ ,  $p=.882$ ). No significant interactions were observed for EPS by group ( $F=.523$ ,  $p=.719$ ), or time by group ( $F=1.42$ ,  $p=.212$ ) (Figure 8); however a significant interaction was observed between EPS and time ( $F=56.06$ ,  $p<.001$ ). Pairwise comparisons revealed that there was a significant decrease in inversion rotation in the tape and brace groups compared to the No-EPS group, both pre- and post-exercise ( $p<.001$ ) (Figure 9). Tape was significantly more restrictive than the brace following exercise ( $p=.004$ ). Taping and bracing both demonstrated increases in

inversion laxity post-exercise ( $p=.001$ ), as did the No-EPS condition ( $p=.05$ ). There was no change in laxity following the removal of the tape ( $p>.05$ ), however there was a trend towards an increase in laxity, observed after the removal of the brace ( $p=.12$ ) (Figure 10).

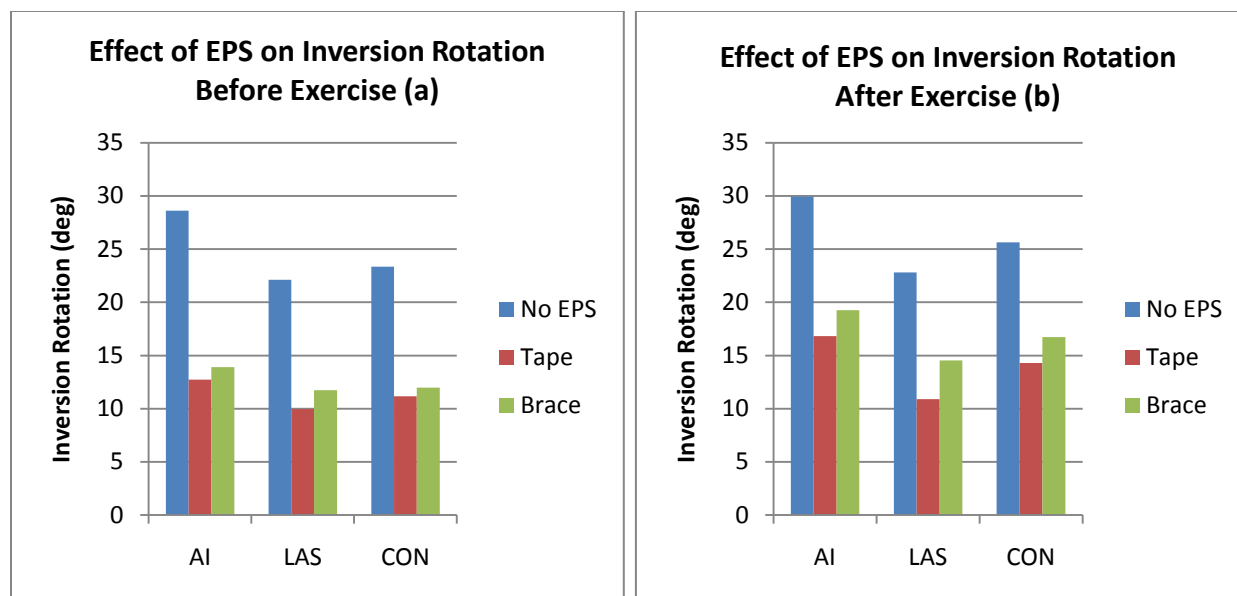


**Figure 8. The effect of exercise and EPS on inversion rotation. In all three groups, a significant decrease in laxity is observed at pre and post-exercise.**



**Figure 9. The effect of exercise and EPS on inversion rotation. Tape is significantly more restrictive than the brace at post-exercise. Both do provide a significant decrease in laxity at post-exercise.**



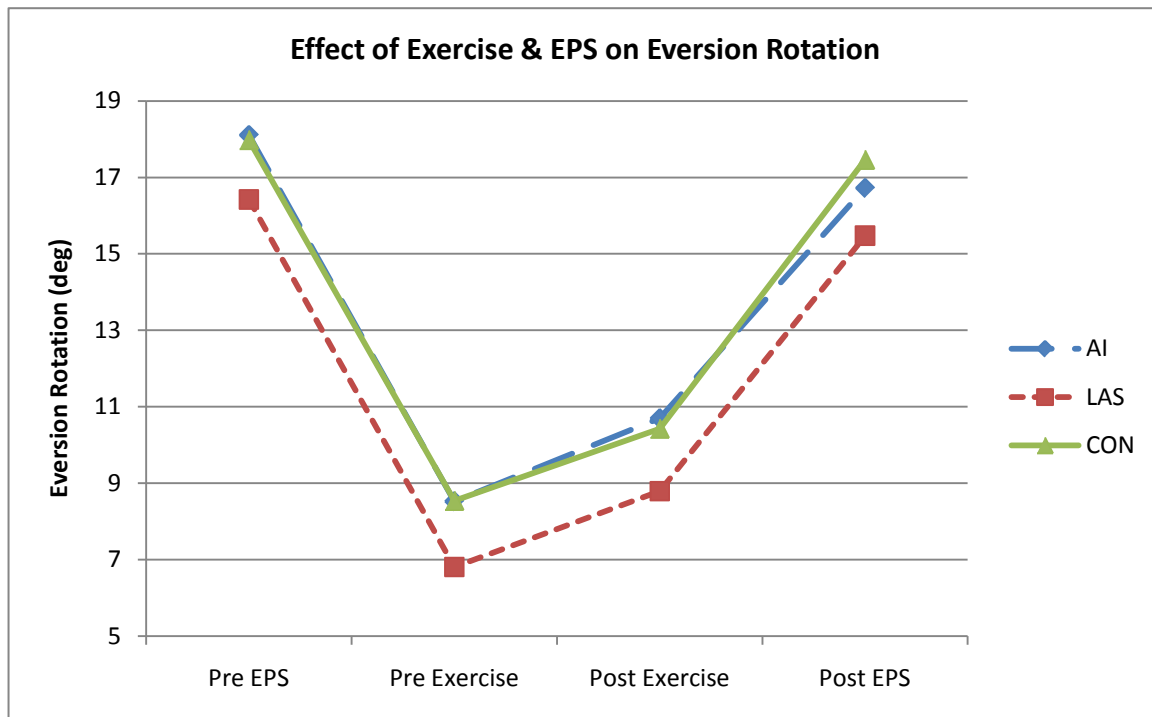


**Figure 10. Effect of EPS on inversion rotation before (a) and after (b) exercise.**

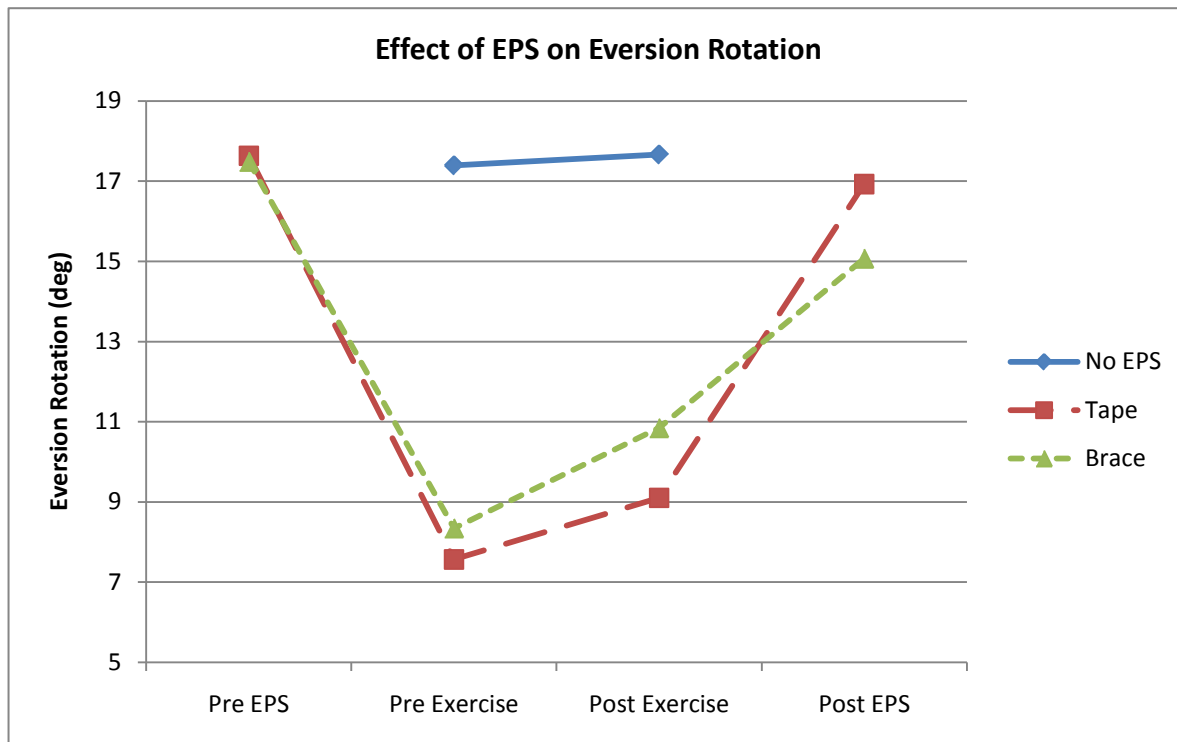
**Tape was more restrictive than the brace pre and post-exercise.**

### 3.3 Eversion Rotation

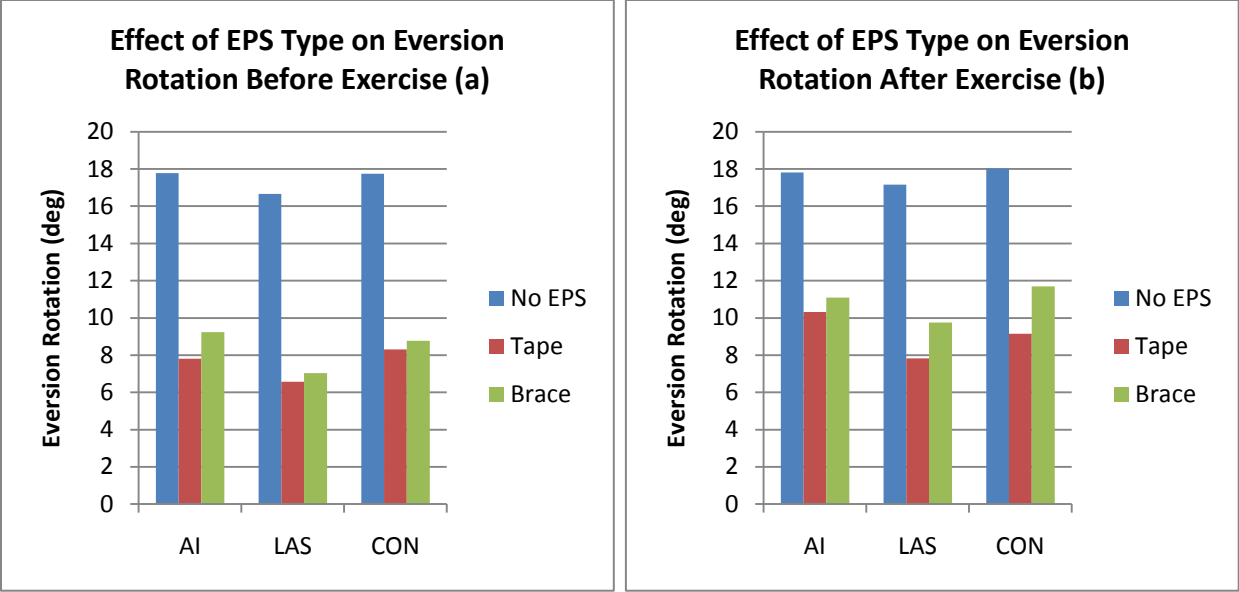
For eversion rotation there was a significant interaction between EPS and time ( $F= 53.110$ ,  $p<.001$ ); but no significant interactions were observed between EPS and group ( $F=.305$ ,  $p=.874$ ), or time and group ( $F=.277$ ,  $p=.947$ ) (Figure 11). There was a significant decrease in eversion rotation pre- and post-exercise in the tape and brace conditions, as compared to the No-EPS condition ( $p<.001$ ) (Figure 12). Eversion rotation significantly increased after exercise in both tape and brace conditions ( $p<.001$ ). Tape was significantly more restrictive than the brace after exercise ( $p=.009$ ). There were no changes in eversion rotation, following the removal of the brace in all 3 conditions ( $p>.05$ ) (Figure 13).



**Figure 11. The effect of exercise and EPS on eversion rotation. In all three groups, a significant decrease in laxity is observed both pre and post-exercise.**



**Figure 12. The effect of EPS on eversion rotation. Tape is significantly more restrictive than the brace post-exercise.**



**Figure 13. The effect of EPS type on eversion rotation before (a) and after (b) exercise. Tape is more restrictive both pre and post-exercise.**

## CHAPTER 4

### DISCUSSION

In this study, we utilized a novel method for measuring ankle laxity under a taped, braced and No-EPS condition, before and after a functional exercise protocol to quantify any differences in ankle restriction from pre- to post-activity. To date, methods used to investigate whether taping or bracing is more effective have varied in results, likely due to the many ways that ankle laxity or range-of-motion has been measured, the type of functional activity required, and the variety of ankle braces and taping techniques used. In this study, ankle laxity was examined using an ankle arthrometer, which has been shown to be reliable in providing peak measures of laxity in anterior displacement and inversion-eversion rotation.<sup>30, 37</sup> Three different ankle stability groups were used in order to identify any differences in unstable versus healthy ankles, as well as how subjects with a history of ligament sprain but no sensations of instability respond to the application of EPS.<sup>20</sup> Our novel FEP used a multi-directional course intended to stress the ankle in a variety of directions, similar to that which an athletic population would experience during practice or competition.

The results of this study showed that there was no difference between the AI, LAS, and CON groups at baseline for anterior displacement, inversion and eversion rotation. It was hypothesized that the AI group would have more laxity than the LAS and CON groups; however, there was no evidence of mechanical instability in the AI group compared to the LAS and CON groups at baseline. Perhaps it is likely that the AI group was comprised mostly of ankles where functional and not mechanical was the cause of their ankle instability. A similar study by Gribble et. al. looked at the effects of

ankle bracing on mechanical restraint in individuals with and without ankle instability utilizing an arthrometer like the one in our study.<sup>41</sup> They too did not find a significant difference between groups. Delahunt et al.<sup>11</sup> define mechanical instability as motion beyond normal physiological range measured with ankle arthrometry or stress radiography, and that this may be present *independent* of functional instability.<sup>8, 10, 11</sup> Previous arthrometry studies investigating ankle instability have used subjects that have both mechanical and functional instability; however, these investigations do not allow us to understand the role of mechanical laxity and EPS on subjects with only functional instability.<sup>12, 13, 27</sup> Our study did not recognize a difference in arthrometry measurements between the CON and AI groups.

Our study results also suggest that there was an effect of EPS on ankle joint laxity. The tape and brace significantly decreased anterior displacement and inversion and eversion rotation, both pre- and post-exercise compared to having No- EPS applied. This is consistent with previous research regarding the role of taping on ankle laxity; however, no comparisons have been made for anterior laxity between taping and bracing.<sup>13</sup> Previous studies on sagittal plane motion reported that tape provides greater dorsiflexion restriction versus the lace-up brace.<sup>22, 25</sup> While no differences between taping and bracing were observed for ANT displacement, the IE measurements demonstrated that the tape provides significantly more restriction over the brace following exercise. Cordova et al.<sup>22, 25</sup> contradicts these findings by reporting no difference between tape and lace-up brace pre- and post-exercise for inversion laxity, however, the brace provided more eversion restriction post-exercise. Differences in exercise protocols may account for the differences between these studies and ours. To

our knowledge, no previous studies have utilized an FEP. Additionally, arthrometer measurements are very different than goniometric measurements as joint laxity is being assessed as opposed to gross range-of-motion.<sup>18, 23</sup> Gribble et. al. reported a significant effect of bracing on both the control and ankle instability groups for I-E and A/P, however, larger restraint in I-E rotation.<sup>41</sup>

Using motion analysis, Delahunt et al.<sup>18</sup> examined the effect of ankle taping in individuals with ankle instability before and after performing 3 single-leg drop landings and found that there was a significant difference in plantar flexion at 50 ms before landing and at initial contact, from pre-tape to post-tape and tape-post-exercise. The exercise protocol used in this study included hopping, ladder, and cutting drills that persisted for 25 minutes. However, there was no significant difference with tape from pre- to post-exercise, indicating that the reductions in plantar flexion kinematics were maintained throughout exercise.<sup>18</sup> Although, variables were different in this study, it contradicts our findings, which may be because of the difference in intensity and time of the exercise. Methods for measurement differed in this study, as they used a force plate and motion detection to determine the amount of plantar flexion prior to and at landing. The kinematics involved in the drop landing differ from those involved in ankle arthrometry measurement.

Purcell et al.<sup>23</sup> examined the differences in range-of-motion before and after 30 minutes of exercise using two different types of tape (self-adherent and traditional white cloth).<sup>11</sup> Range-of-motion was measured using an electrogoniometer. Both types of tape significantly reduced inversion and eversion range-of-motion before exercise, but after exercise only the self-adherent tape maintained the decrease in range-of-motion.

In dorsiflexion and plantar flexion, both tapes significantly decreased motion before and after exercise.<sup>23</sup> In our study, we used a different technique for measuring the effectiveness of the tape; however, the exercise protocol incorporated similar motions. We used the white cloth tape in this study and it significantly reduced inversion-eversion rotation both pre- and post-exercise. All motions were significantly reduced by the application of tape, even post-exercise. After the removal of the tape, there was an additional increase in anterior displacement, and inversion and eversion rotation. This increase signifies the importance of the tape and that it still provides restrictive properties after 20 minutes of exercise. The tape maintained a certain degree of restrictiveness throughout the exercise.

Hubbard et al.<sup>13</sup> examined the effect of ankle taping on laxity in healthy, uninjured subjects and those with unilateral chronic ankle instability using arthrometry measurements. Ankle laxity was measured two times during testing, first before the application of tape, and then after 15 minutes of exercise with the tape still in place. Their exercise protocol included 20 minutes of jogging, followed by sprints, zigzag running, and running while changing directions, for an overall total of 30 minutes. Following exercise, they reported more anterior displacement and inversion rotation in the unstable ankle compared to the healthy ankle.<sup>13</sup> Tape application decreased inversion and eversion rotation in the unstable ankles.<sup>13</sup> Comparably, our study did not find any significant differences in anterior displacement between the unstable and healthy ankles, but there was a slightly greater, but non-significant difference with inversion rotation in the unstable ankles compared to the healthy ankles. The Hubbard et al.<sup>13</sup> report differed from our study with regard to the definitions of “ankle instability,”



the inclusion of the LAS group, the number of measurements taken, and the comparative use of taping and bracing. In addition, following the removal of the brace, there was more anterior displacement in the AI group compared to the LAS and CON groups. Previous research has not investigated ankle laxity following the removal of an EPS.<sup>13, 37</sup> This finding may indicate that there may be more accessory motion allowed at the talocrural joint with application of a brace, versus the custom-fit of tape. This may support previous findings that positional alterations of the talus may contribute to changes in laxity and function.<sup>38</sup> The brace is placed on the ankle in a neutral position, while the stirrups of the tape pull the talus in an everted position.

#### **4.1 Limitations**

We acknowledge the low percentage of ankles in the LAS group (7 ankles or 15% of those tested). This may be the reason why the sprainer group appears to have less laxity than the healthy group. Subjects were not asked how recent or how severe the ankle sprain(s) was/were, so they were included as long as they were not currently injured or undergoing rehabilitation. Another limitation to this study is the pace at which the FEP was performed could have been different amongst the subjects based on their exertion level. All subjects were told to go at 80% of maximal intensity, and to maintain the same pace for all 20 trials on all three test occasions. Some subjects may interpret 80% faster or slower than others. We attempted to control for this using RPE scores, to gauge subject perceived level of exertion. Finally, the application of the ankle braces varied slightly from the instructions which said to place them over the top of socks, however, in order to control for consistency between subjects, the braces were placed

directly on the skin. None of our subjects reported any discomfort or abnormalities as a result of this change.

## **4.2 Clinical Significance**

This study was useful in identifying that both tape and bracing provide some degree of restriction of ankle motion before and after exercise. Although, there was an increase in motion after 20 minutes of simulated/controlled exercise, there was still a significant amount of restriction when compared to baseline measures. Tape provided more restriction in inversion and eversion post-exercise, as compared to the brace. There was no difference seen between the tape and brace in anterior displacement, except following the removal of the brace. When preventing ankle sprains, it is important to consider that while tape may provide more overall mechanical restriction, bracing effectively provides mechanical restriction when compared to no brace/ tape and may be more cost effective and time-efficient when used over the course of a season.<sup>40</sup> Prophylactic support is important to use in the prevention of ankle sprains, not only in those with mechanical instability but in those with functional instability too. Additionally, taping and bracing have been shown to provide proprioceptive benefits and psychological security following an ankle sprain.

## **4.3 Future Studies**

Interestingly, our study showed that the AI group significantly increased in anterior displacement laxity after the removal of the brace. There are no studies that have looked at ankle instability subjects pre- and post-competition to see if there are any significant differences in individuals with ankle instability. Since the ankle arthrometer is portable and easy to use, it would be an efficient tool to use in measuring

laxity at the ankle in subjects before and after participation in athletics. It is possible that characteristics of mechanical laxity become more evident in those classified with functional instability post-exercise. The ligaments are warm, potentially more elastic and have had ample opportunity to display larger stretch at the ankle joint. A future beneficial study would be to use the ankle arthrometer and measure athletes with ankle instability before and after practice and competition to see if there is a significant increase in laxity, displaying mechanical instability. In addition, using the tape and brace to compare results would be clinically significant.

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**APPENDIX A**  
**INFORMED CONSENT**



## **University of Delaware Human Subjects Informed Consent Form**

Research Study: A Novel Way of Measuring Ankle Stability after Functional Activity

Investigators: Heather E. Abbott and Thomas Kaminski, PhD (Health, Nutrition, and Exercise Sciences)

### **INTRODUCTION**

You are invited to take part in a research project to gain information about the effect of ankle taping and bracing in individuals with and without ankle instability (“giving-way” feelings). This research study will answer questions about the effectiveness of ankle taping and bracing in preventing ankle sprains. Your qualification is based on your age falling between 18 and 25 years. Your participation is voluntary and you are in no way obligated to take part in this testing.

### **PURPOSE**

The purpose of this research is to examine the looseness of your ankle before and after exercise while wearing either tape or a brace. This is important in trying to prevent injury from an ankle sprain.

### **PROCEDURES**

You are one of 48 subjects being chosen to participate in this study. Your participation will involve 4 testing sessions, which include questionnaires, measurement of ankle looseness using a specialized device strapped to your foot, and completion of an exercise protocol. You will wear running shoes and shorts during the testing. The first session will be approximately 60 minutes in length, while the remaining 3 sessions will require 90 minutes each. Testing will occur over 4 consecutive weeks, with one week between each session.

- (A) Test Session I - III you will complete three questionnaires (general health, weekly activity, and ankle health). Based on your answers on the questionnaires, you will be assigned to one of 3 groups (never sprained, one sprain without ankle instability (“giving-way” feelings), or ankle instability). During each of these sessions you will be randomly selected for the ankle tape, ankle brace, or no tape/brace intervention. There will be one week between sessions. Before application of the treatment condition, ankle looseness will be measured using a device that is strapped to your foot and tests motion in an up/down and rotary manner. Depending on random assignment, both ankles will either be taped or braced using standard procedures. The control condition involves neither taping nor bracing. You will be provided with a 5-minute warm-up period of lower body stretching activities. You will then be asked to complete the functional exercise protocol which consists of you performing a series of sprinting, hopping, shuffling and jumping tasks using maximal effort. Rest periods will be provided during the

20 minute exercise. At the conclusion, another set of ankle looseness measures will be taken, then either the tape or brace is removed; and one final ankle looseness measurement will be taken. You will then be provided with a 5-minute cool-down period of lower body stretching activities.

#### CONDITIONS OF SUBJECT PARTICIPATION

All of the data will be kept confidential. Your information will be assigned a code number. The list connecting your name to the code number will be kept in a locked file. When the study is completed and the data have been analyzed, that list will be destroyed, but the coded data will be kept indefinitely. Your name will not be used in conjunction with this study. In the event of physical injury during participation, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost. You will be removed from the study if you experience any injury that interferes with the results or prevents you from completing it. There are no consequences for withdrawing from the study and you can do so at any time.

#### RISKS AND BENEFITS

As with any vigorous exercise procedure, there are minor risks for cardiac or respiratory injury, as well as leg cramps and dehydration. You may also develop muscle soreness in the lower body 24 - 48 hours following testing. There is a slight risk to you of suffering bone, muscle, or joint injuries during the exercise protocol. In the event of an acute injury, you will receive immediate first aid. Follow-up care will be at your own expense.

#### FINANCIAL CONSIDERATIONS

There will be no compensation for participating in this study. There will be no cost to you, the subject, for participating in the study. Transportation is provided on campus to the testing site and all materials will be provided by the researcher.

#### CONTACTS

Heather Abbott (302) 242-5288 or [habbott@udel.edu](mailto:habbott@udel.edu) & Dr. Thomas W. Kaminski (302) 831-6402 or [kaminski@udel.edu](mailto:kaminski@udel.edu) Questions regarding the research study can be directed to the above email addresses.

For questions of concerns about the rights to the individuals who agree to participate in the study:

Human Subjects Review Board, University of Delaware (302) 831-2136

#### ASSURANCE

Participation in this study is completely voluntary. Refusal or choosing to discontinue participation in this study is the right of the individual, with no loss of benefits to which the subject is otherwise entitled.

#### CONSENT SIGNATURES

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Subject Consent Signature

Date

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Principal Investigator Signature

Date

Signed consent forms will be retained by the researcher for three years after completion of the research.

**APPENDIX B**  
**FORMS AND QUESTIONNAIRES**

# PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. <b>Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?</b>
<input type="checkbox"/>	<input type="checkbox"/>	2. <b>Do you feel pain in your chest when you do physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	3. <b>In the past month, have you had chest pain when you were not doing physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	4. <b>Do you lose your balance because of dizziness or do you ever lose consciousness?</b>
<input type="checkbox"/>	<input type="checkbox"/>	5. <b>Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?</b>
<input type="checkbox"/>	<input type="checkbox"/>	6. <b>Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?</b>
<input type="checkbox"/>	<input type="checkbox"/>	7. <b>Do you know of <u>any other reason</u> why you should not do physical activity?</b>

If  
you  
answered

## YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

## NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

### DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

**PLEASE NOTE:** If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

**Informed Use of the PAR-Q:** The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

**No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.**

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME \_\_\_\_\_

SIGNATURE \_\_\_\_\_

DATE \_\_\_\_\_

SIGNATURE OF PARENT \_\_\_\_\_  
or GUARDIAN (for participants under the age of majority)

WITNESS \_\_\_\_\_

**Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.**

## Cumberland Ankle Instability Tool (CAIT)

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

	LEFT	RIGHT
1. I have pain in my ankle		
Never	<input type="checkbox"/>	<input type="checkbox"/>
During Sport	<input type="checkbox"/>	<input type="checkbox"/>
Running on uneven surfaces	<input type="checkbox"/>	<input type="checkbox"/>
Running on level surfaces	<input type="checkbox"/>	<input type="checkbox"/>
Walking on uneven surfaces	<input type="checkbox"/>	<input type="checkbox"/>
2. My ankle feels UNSTABLE		
Never	<input type="checkbox"/>	<input type="checkbox"/>
Sometimes during sport	<input type="checkbox"/>	<input type="checkbox"/>
Frequently during sport	<input type="checkbox"/>	<input type="checkbox"/>
Sometimes during daily activity	<input type="checkbox"/>	<input type="checkbox"/>
Frequently during daily activity	<input type="checkbox"/>	<input type="checkbox"/>
3. When I make SHARP turns my ankle feels UNSTABLE		
Never	<input type="checkbox"/>	<input type="checkbox"/>
Sometimes when running	<input type="checkbox"/>	<input type="checkbox"/>
Often when running	<input type="checkbox"/>	<input type="checkbox"/>
When walking	<input type="checkbox"/>	<input type="checkbox"/>
4. When going down the stairs, my ankle feels UNSTABLE		
Never	<input type="checkbox"/>	<input type="checkbox"/>
If I go fast	<input type="checkbox"/>	<input type="checkbox"/>
Occasionally	<input type="checkbox"/>	<input type="checkbox"/>
Always	<input type="checkbox"/>	<input type="checkbox"/>
5. My ankle feels UNSTABLE when standing on ONE leg		
Never	<input type="checkbox"/>	<input type="checkbox"/>
On the ball of my foot	<input type="checkbox"/>	<input type="checkbox"/>
With my foot flat	<input type="checkbox"/>	<input type="checkbox"/>
6. My ankle feels UNSTABLE when		
Never	<input type="checkbox"/>	<input type="checkbox"/>
I hop from side to side	<input type="checkbox"/>	<input type="checkbox"/>
I hop on the spot	<input type="checkbox"/>	<input type="checkbox"/>
When I jump	<input type="checkbox"/>	<input type="checkbox"/>

	LEFT	RIGHT
7. My ankle feels UNSTABLE when		
Never	<input type="checkbox"/>	<input type="checkbox"/>
I run on uneven surfaces	<input type="checkbox"/>	<input type="checkbox"/>
I jog on uneven surfaces	<input type="checkbox"/>	<input type="checkbox"/>
I walk on uneven surfaces	<input type="checkbox"/>	<input type="checkbox"/>
I walk on a flat surface	<input type="checkbox"/>	<input type="checkbox"/>
8. TYPICALLY when I start to roll over (or 'twist') on my ankle I can stop it		
Immediately	<input type="checkbox"/>	<input type="checkbox"/>
Often	<input type="checkbox"/>	<input type="checkbox"/>
Sometimes	<input type="checkbox"/>	<input type="checkbox"/>
Never	<input type="checkbox"/>	<input type="checkbox"/>
I have never rolled over my ankle	<input type="checkbox"/>	<input type="checkbox"/>
9. Following a TYPICAL incident of my ankle rolling over, my ankle returns to 'normal'		
Almost immediately	<input type="checkbox"/>	<input type="checkbox"/>
Less than one day	<input type="checkbox"/>	<input type="checkbox"/>
1-2 days	<input type="checkbox"/>	<input type="checkbox"/>
More than 2 days	<input type="checkbox"/>	<input type="checkbox"/>
I have never rolled over on my ankle	<input type="checkbox"/>	<input type="checkbox"/>

## International Physical Activity Questionnaire (IPAQ)

Below are questions about individual's physical activity levels.

Please read the descriptions and answer the questions even if you do not consider yourself to be an active person. Consider all activities, those you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

### **Hard physical activity:**

Think about all the **vigorous** activities which take hard physical effort that you did in the **last 7 days**. Vigorous activities make you breath harder than normal and may include heavy lifting, aerobic, or fast bicycling. Think only about those physical activities that you did for at least 10 minutes at a time.

1. During the last 7 days, on how many days did you do vigorous physical activity?

\_\_\_\_\_days/week    \_\_\_\_\_don't know/not sure

2. How much total time did you usually spend doing vigorous physical activity on one of those days?

\_\_\_\_\_hours/day    \_\_\_\_\_minutes/day    \_\_\_\_\_don't know/not sure

3. If your pattern of activity varies from day to day, how much total time did you spend over the last 7 days doing vigorous physical activity?

\_\_\_\_\_hours/week    \_\_\_\_\_minutes/week    \_\_\_\_\_don't know/not sure

### **Moderate physical activity:**

Think about the activities which take **moderate** physical effort that you did in the **last 7 days**. Moderate physical activity makes you breath somewhat harder than normal and may include carrying light loads, bicycling at a regular pace, or doubles tennis. Do not include walking. Again, think about only those physical activities that you did for at least 10 minutes.

4. During the last 7 days, on how many days did you do moderate physical activity?

\_\_\_\_\_days/week    \_\_\_\_\_don't know/not sure

5. How much total time did you usually spend doing moderate physical activity on one of those days?

\_\_\_\_\_hours/day    \_\_\_\_\_minutes/day    \_\_\_\_\_don't know/not sure



6. If your pattern of activity varies from day to day or includes multiple tasks, how much total time did you spend over the last 7 days doing moderate physical activity?

\_\_\_\_\_hours/week    \_\_\_\_\_minutes/week    \_\_\_\_\_don't know/not sure

**Walking:**

Now think about the time you spend walking in the last 7 days. This includes at work and at home, walking to travel from place to place, and any other walking you might do solely for recreation, sport, exercise or leisure.

7. During the last 7 days on how many days did you walk for at least 10 minutes at a time?

\_\_\_\_\_days/week    \_\_\_\_\_don't know/not sure

8. How much total time did you usually spend walking on one of those days?

\_\_\_\_\_hours/days    \_\_\_\_\_minutes/day    \_\_\_\_\_don't know/not sure

9. If your pattern of activity varies from day to day or includes multiple tasks, how much total time did you spend walking over the last 7 days?

\_\_\_\_\_hours/week    \_\_\_\_\_minutes/week    \_\_\_\_\_don't know/not sure

**Sitting:**

Finally think about the time you spent sitting on weekdays during the last 7 days. Include time spent at work, at home, while doing course work, and during leisure time. This may include time spent sitting at a desk, visiting with friends, reading, sitting or lying down to watch television.

10. During the last 7 days how much total time did you usually spend sitting on a weekday?

\_\_\_\_\_hours/weekday    \_\_\_\_\_minutes/weekday    \_\_\_\_\_don't know

Baseline Data    Date:\_\_\_\_\_

Age:\_\_\_\_\_    Sex:\_\_\_\_\_    Ht:\_\_\_\_\_    Wt:\_\_\_\_\_

*Chronic disease/ complaints Circle:*

Diabetes    Hypertension    High Cholesterol    Heart Disease    Obesity

Migraine headaches    Anxiety

Family/personal history of cancer yes/no | Type \_\_\_\_\_

Daily activities:

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**APPENDIX C**  
**SPECIFIC AIMS**

## Specific Aims

Ankle sprains are the most commonly seen injury in athletics. With increasing severity, ankle sprains can become quite debilitating keeping athletes out of activity for several weeks. Symptoms of ankle sprains include pain, swelling, weakness, and the feeling of instability. Some individuals may experience an ankle sprain and never have another ankle injury, these ankles make up a group called the lateral ankle sprain group (LAS). However, the majority of individuals who experience an ankle sprain will sprain their ankle again. The recurrence rate for ankle sprains can be as high as 70%.<sup>13-15</sup> Individuals who report repeated episodes of their ankle “giving-way”, general weakness and pain following injury are said to have chronic ankle instability (CAI). Chronic ankle instability can be due to mechanical and/or functional ankle instability. Mechanical instability is a result of physiological changes at the talocrural and subtalar joints and portrays more joint laxity. Taping and bracing have been used in an attempt to correct mechanical insufficiencies; however, surgical intervention is often required. Conversely, functional instability is caused by altered neuromuscular control, muscular weakness or impaired proprioception. Functional ankle instability can be treated with a rehabilitation program that targets these areas and helps return an athlete to full functional ability having restored any deficits incurred following the ankle sprain.

In an attempt to try and prevent recurrent ankle sprains in athletes, taping and bracing are a common practice. Ankle taping and bracing are intended to restrict excessive subtalar joint motion. Discrepancies in taping technique, brace design, and assessment of ankle joint motion have brought into question the effectiveness for preventing ankle sprains.

Ankle arthrometers are novel devices developed to measure ankle laxity; most commonly anterior posterior displacement and inversion eversion rotation. Through extensive testing these devices have been shown to be valid and reliable.<sup>11,12,19</sup>

The objective of this study is to examine the effectiveness of taping and bracing in individuals with and without ankle instability, utilizing contemporary ankle arthrometry.

**Specific Aim 1: To determine the effectiveness of taping and bracing on ankle joint laxity as measured by the ankle arthrometer.**

**Hypothesis 1.1: Anterior displacement will be greater in the braced condition when compared to the taped condition post-exercise; however, we do not anticipate a difference pre-exercise.**

Cordova et al. compared several studies that tested taped and braced ankles and reported that the taped ankle provided more restriction in anterior displacement over the lace-up brace.<sup>2</sup>

**Hypothesis 1.2: There will be no differences in inversion rotation in the taped and braced condition, pre and post-exercise.**

Cordova et al. compared taped and braced ankles and found that there was no difference in inversion restriction from pre to post exercise.<sup>2</sup>

**Hypothesis 1.3: Eversion rotation will be greater in the taped condition when compared to the braced post-exercise; however, we do not anticipate a difference pre-exercise.**

Cordova et al. reports that in a comparison between taped and braced ankles, the lace-up brace provided more restrictive properties in eversion. They theorized that the application of tape puts an emphasis on restricting inversion by pulling the calcaneus laterally while the application of the lace-up brace provides less restriction on inversion and its main purpose is limitation throughout the full range of inversion-eversion rotation.<sup>2</sup>

**Specific Aim 2: To determine if differences in ankle laxity exist between subjects identified with ankle instability (AI), a single lateral ankle sprain, but no ankle instability (LAS), and a control group who have never sprained an ankle (CON).**

**Hypothesis 2.1: Pre-exercise, the subjects in the AI group will have a greater anterior displacement when compared to LAS and CON groups.**

Hubbard and Cordova found that subjects with unilateral functional instability had a greater anterior displacement over their healthy ankle.<sup>14</sup>

**Hypothesis 2.2: Ant displacement will increase in all groups pre to post-exercise; however the AI group will demonstrate the greatest difference.**

Hertel et al. found that anterior displacement was greater in subjects with instability in both stress radiographic images and with a positive sign for the manual anterior drawer test.<sup>8</sup>

**Hypothesis 2.3: IE rotation will increase in all groups pre to post-exercise; however the AI group will demonstrate the greatest difference.**

Hertel et al. found a strong relationship between stress radiographic images exhibiting increased talar tilt and a positive sign for the manual talar tilt test in ankles with instability.<sup>8</sup>

**Specific Aim 3: To examine the effectiveness of ankle taping and bracing in subjects with ankle instability, pre to post-exercise.**

**Hypothesis 3.1: There will be a difference between the taped and braced ankles in the A displacement of the AI subjects from pre to post-exercise.**

Hubbard and Cordova found ankles with instability had more anterior displacement both pre and post-exercise before and after a taped condition.<sup>16</sup> In conjunction with the findings of Cordova et al. where tape is more restrictive than a lace-up brace, instable ankles should be more restricting in AP displacement in the taped condition.<sup>2</sup>

**Hypothesis 3.2: There will not be a difference between the taped and braced ankles in the IE rotation of the AI subjects from pre to post-exercise.**

Hubbard and Cordova found that the application of tape to instable ankles restricted inversion and eversion motion from pre to post-exercise.<sup>16</sup>

**APPENDIX D**  
**BACKGROUND AND SIGNIFICANCE**



## **Background and Significance**

Approximately 1 million ankle sprains occur each year. About 85% of injuries incurred at the ankle are lateral ankle sprains.<sup>3,4</sup> They are the most commonly seen injury in the athletic population due to the dynamic movements required to participate. Sports that require athletes to make excessive cutting motions, jumping or landing can have larger incidence rates for ankle sprains.<sup>4,6</sup> The common mechanism for a medial ankle sprain is dorsiflexion and external rotation of the ankle, and for a lateral ankle sprain, the common mechanism is plantar flexion and internal rotation. Lateral ankle sprains occur much more frequently than medial ankle sprains due to the biomechanics of the foot and ankle.<sup>8,12</sup> The most frequently injured ligament in the lateral ankle is the anterior talofibular ligament, followed by the calcaneofibular and the posterior talofibular ligaments.<sup>8</sup> Injury produces a combination of symptoms including, pain, swelling, discoloration, and decreased function that can vary in severity. Symptoms can persist in 55% to 72% of patients from 6 weeks to 18 months.<sup>7,16</sup>

## **Chronic Ankle Instability**

Repetitive occurrence of ankle sprains that limits regular function is termed chronic ankle instability.<sup>9,12,13</sup> The most common symptom is a feeling of the ankle “giving-way”. About 70% people who have sprained their ankle will sprain their ankle again.<sup>9,12,13</sup> Individuals with chronic ankle instability have functional ankle instability and mechanical ankle instability.<sup>5,7,9,12,13,19,21</sup>

## **Functional Ankle Instability**

Functional instability occurs in approximately 40% of individuals who experience an ankle sprain.<sup>2</sup> Functional ankle instability is classified as motion beyond voluntary control, but not past the physiological range-of-motion. However, studies have shown that this feeling of instability may not actually be a result of ligament laxity but loss of proprioception or weakness of the peroneal muscles.<sup>9,12,13,16,25</sup> Possible causes of functional ankle instability are proprioceptive deficits, impaired neuromuscular control, strength deficits and impaired postural control.<sup>12</sup> Assessment of functional ankle instability is based on the individual's symptoms of pain and swelling and their reported episodes of instability and recurrent sprains.<sup>20</sup> Functional instability can be treated with ankle rehabilitation, concentrating on strengthening the ankle musculature, improving neuromuscular control and proprioception.<sup>16,25</sup> Even with rehabilitation, it can take several weeks to months in order to achieve favorable results. Patients often have poor compliance continuing rehabilitation once their symptoms have resolved. Buchanan et al. looked at functional insufficiencies in functionally unstable ankles compared to healthy ankles and determined that symptoms varied throughout the FAI group and were more severe in those who self-reported more instability.<sup>2</sup>

## **Mechanical Ankle Instability**

Another factor of chronic ankle instability is mechanical instability. Mechanical instability is characterized by anatomic changes which lead to excessive physiological motion of the talocrural and subtalar joints,<sup>16,18</sup> resulting from increased laxity and damage of the injured ligaments that support the joint. Other anatomical changes at the ankle such as altered arthrokinematics, synovial or degenerative damage can result in

joint laxity that predisposes an individual to further injury. Mechanical laxity can be assessed through stress radiography, the most common examination technique, despite some evidence concerning the reliability of such methods.<sup>8,16</sup> Other forms of assessment include physical examination, and instrumented arthrometry. Hubbard et al. tested 51 subjects with unilateral ankle instability using stress radiography with a portable fluoroscope and with instrumented arthrometry. Both instrumented arthrometry and stress radiography recognized an increase in anterior displacement in the unstable ankles.<sup>16</sup>

### **Clinical Implications**

Hertel discusses the pathomechanics of chronic ankle instability and how mechanical and functional insufficiencies can occur in parallel to each other.<sup>25</sup> Delahunt et al. (2010) recently further re-defined chronic ankle instability and its components since there is such a wide variation of definitions for the term. The main point of the study is to show that in individuals with chronic ankle instability, the person exhibits signs and symptoms of both mechanical and functional instability. Clinically, it is important to accurately assess the mechanical and functional insufficiencies of an individual's ankle instability in order to correctly and efficiently attempt to prevent recurrent injury. Specific functional insufficiencies can be targeted through rehabilitation while mechanical insufficiencies have been treated with taping and bracing, but the most effective intervention appears to be surgery.<sup>12,16,25</sup>

Hubbard et al. tested 30 subjects with unilateral chronic ankle instability on different insufficiencies associated with both functional and mechanical ankle instability.<sup>9</sup> Both mechanical and functional insufficiencies were found in the subjects.

Of the 13 dependent variables assessed, four (anterior and inversion laxity, plantar flexion and dorsiflexion torque) significantly predicted 80% of the chronically unstable ankles and 73.3% of the healthy ankles. Anterior and inversion laxity were assessed using the ankle arthrometer and found to be significantly different in the chronically unstable ankles, compared to the healthy ankles. Also peak torque for plantar flexion and dorsiflexion were significantly lower in the chronically unstable ankles.<sup>9</sup> Thus, they suggest that for those with mechanical instability, anterior and inversion laxity is helpful in classifying them, while those with functional instability can best be categorized based on their plantar flexion and dorsiflexion peak torque measures. Thus, these two insufficiencies were recognized for both mechanical and functional instability respectively. This study strengthens the argument that clinicians should utilize taping and bracing in those with mechanical instability and employ strengthening exercises in those with functional instability. It is not known what effect taping and bracing have in those with functional instability. In those with significant mechanical deficits, the injured ankle may not return to the same functional level as their healthy ankle without surgery. Most individuals with mechanical laxity do not seek surgery unless severe damage is present. In addition to rehabilitation, these individuals will wear prophylactic devices during activity in an effort to prevent recurrent injury.

### **Taping and Bracing**

Ankle sprains account for a large number of athletic injuries, therefore clinicians have utilized ankle taping and bracing extensively in hopes of preventing recurrence. The topic of ankle taping and bracing has been studied quite extensively over the last

30 years.<sup>3,4,6,11,22</sup> The primary objective of ankle taping and bracing is to limit excessive ankle motion in order to prevent positions of vulnerability to ankle sprains. In conjunction to using taping and bracing as preventative measures, rehabilitation exercises are used to help restore the functional insufficiencies causing the instability.

## **Taping**

Ankle taping has become a common practice for preventing initial and recurrent ankle sprains. Due to the existing variations, studies have looked at different types of taping.<sup>11,22</sup> Variations in taping include the use of pre-wrap versus taping directly to the skin, difference in tension of the strips between testers, the number of heel locks and Figure-8's used, and adding an additional subtalar sling.<sup>22</sup> Measuring the range-of-motion at the ankle pre and post- taping has been performed using manual techniques, goniometry, questionnaires, stress radiography, and arthrometry.<sup>3</sup> Manual techniques such as the anterior drawer test and the talar tilt test are purely subjective. Goniometry is performed passively by the examiner, however, it does not compare to the amount of force that occurs during an ankle sprain. Questionnaires are subjective and interpreting and comparing ratings between subjects is difficult without a quantitative measure. Stress radiography is the most commonly used method of measuring ankle laxity, however, it is expensive and there are no direct quantitative measurements provided; a specialist must determine displacement based on lines made from specific landmarks on the images.<sup>16</sup> Ankle joint arthrometry has been shown to be a reliable tool. It stabilizes the lower and provides a quantitative measure that can be used for comparison. When testing the restrictive properties of ankle tape, studies have also factored in the change in restraint from pre to post-exercise.<sup>1,3,22</sup> Functional testing

varies in each study; some use a combination of straight-line runs, zigzag runs, and figure-8s,<sup>11,22</sup> others have used a treadmill, and others have used daily practice with a sports team as their intervention.<sup>3,4,21</sup> There is no commonly used exercise protocol or testing time designated for testing different methods of taping, which may have led to the differences in results concerning the effectiveness of taping.

## **Bracing**

There is a wide variety of braces available, including lace-up and semi-rigid, offering different restrictive properties.<sup>3,6</sup> Semi-rigid braces have been shown to be the most restrictive of the braces, however they are not commonly used while participating in functional activities (Figure 1).<sup>3,4,6</sup> Lace-up braces are used more often in preventing recurrent injury in those who have previously sprained their ankle or are still experiencing symptoms of instability. Lastly, there are braces which incorporate properties of both semi rigid and lace-up braces (Figure 2). Methods for measuring ankle range-of-motion while wearing braces is performed the same as described for taping.



**Figure 1.** The aircast is an example of a semi rigid brace which is used to help prevent inversion/eversion sprains.



**Figure 2.** The Donjoy velocity is used to prevent abnormal inversion, eversion rotation while still permitting unrestricted dorsi and plantar flexion.

### **Clinical Implications**

Although studies have examined taping and bracing individually and compared them to each other, the results are inconclusive as to whether one is better than the other at restricting the ankle joint.<sup>1,2,3,4,6,11,14,21,22</sup> Hume and Gerrard examined studies that used taping and bracing of the ankle to prevent ankle sprains and found that both taping and bracing restrict range-of-motion, but the restriction was reduced after exercise.<sup>21</sup> The degree of restriction varied depending on the type of brace or tape application, the degree of injury, and the type of exercise. Overall, bracing was shown to be more effective than taping and was more cost-effective in the long-term. Bracing can be applied more easily and readily when compared to taping. Taping was shown to be ineffective after 20 minutes of exercise unless reapplied, however, did appear to have a proprioceptive effect.<sup>21</sup> Cordova and colleagues report that tape loses its restrictive properties after 10 minutes of exercise.<sup>3,4</sup> Tropp compared ankle rehabilitation to ankle bracing and found that ankle bracing does reduce the incidence of ankle sprains in soccer players.<sup>17</sup> Cordova and colleagues report that ankle taping and

bracing lose restrictive properties after exercise in all motions, however, there is still enough restriction that prevents the ankle joint from being freely mobile.<sup>3</sup> Cordova et al. also found that there were no significant differences between the tape and lace-up brace in restricting inversion.<sup>3</sup> Most of the studies in this meta-analysis utilized an electrogoniometer or goniometer to measure ankle range of motion. There are new, more efficient and reliable methods for measuring true ankle laxity, such as the ankle arthrometer. Wilkerson tested 23 healthy individuals without a history of a severe ankle sprain or recurrent ankle sprains.<sup>22</sup> Using the ankle arthrometer, ankle laxity was measured 3 times; prior to the application of tape, after 15 minutes of exercise, and after the taped was removed. The 15 minute exercise session included 10 minutes of jogging, ten 10 m sprints, and three repetitions of a zigzag running pattern that required 10 direction changes within a 10 m x 5 m marked area. Arthrometric measurements were not taken after the application of tape, prior to the start of exercise. The standard taping procedure was randomly assigned to an ankle, and the modified taping with the subtalar sling was applied to the other. Therefore, the dominant leg did not have the same taping procedure throughout all the subjects. All tapings were applied directly to the shaved skin. The results showed that the modified taping provided greater restriction in both anteroposterior displacement and inversion-eversion rotation, post-exercise.<sup>22</sup> Hubbard et al. tested 20 subjects with unilateral chronic ankle instability and 20 healthy subjects under a taped condition, before and after exercise, to examine differences in mechanical laxity at the ankle. They reported that mechanical laxity in the chronically unstable ankles decreased after the tape application, further supporting the benefits of tape in order to prevent recurrent ankle sprains.<sup>1</sup> Delahunt et al. further



examined the idea that individuals with ankle instability who have increased inversion of the rearfoot or increased plantar flexion of the ankle joint during contact with the ground are more susceptible to injury of the lateral ligament complex.<sup>14</sup> Eleven subjects participated in the study where the effects of an ankle taping on ankle movement in the frontal and sagittal planes were analyzed. The subjects jump from a platform onto a force plate under 3 conditions (no tape, taped, and post-exercise taped). The study found that taping did reduce motion in plantar flexion before and at initial contact with the ground, before and after 25 minutes of exercise.<sup>14</sup> Due to the variation in taping methods and brace types, it is difficult to conclude the benefits of either on preventing ankle sprains. However, both provide proprioceptive benefits.<sup>3,4,21</sup>

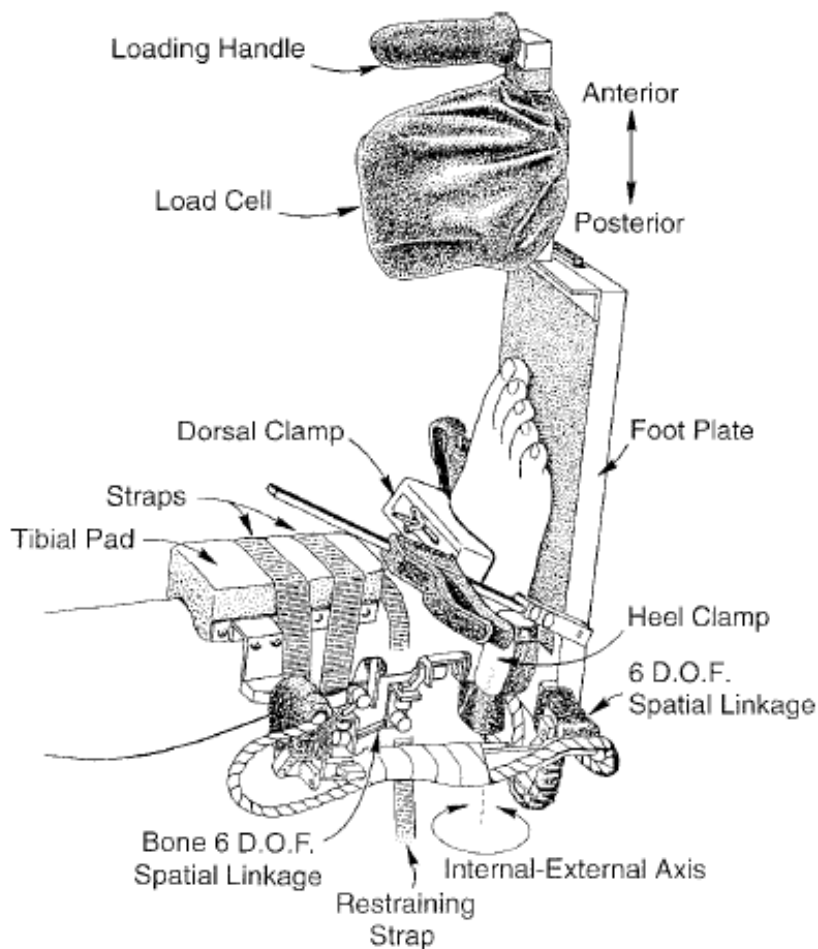
## **Arthrometry**

Arthrometry is the instrumented measurement of joint motion.<sup>29</sup> For years, knee arthrometry has been used to assess adverse motion at the knee joint.<sup>30</sup> Success with knee arthrometry has led to the development of ankle arthrometry. Ankle arthrometry is a fairly new and novel way of measuring ankle stability. The ankle arthrometer (Blue Bay Research, Inc., Milton, FL) and the Lig Master (Sports Tech, Inc., Charlottesville, VA) are two devices that measure joint laxity in order to assess ligament injury.

### **Ankle Arthrometer**

The ankle arthrometer is a portable device that consists of a footplate, a dorsal pad, a tibial pad, and 2 clamps (1 dorsal, 1 heel) to hold the lower leg and ankle in place (Figure 3). There is a load handle on the footplate, used to provide the load to the device. A six-degrees-of-freedom spatial kinematic linkage connects the tibial pad to

the footplate to measure the motion between the two. This device measures anteroposterior displacement and inversion-eversion rotation. The arthrometer is connected to a computer, containing a LabVIEW (National Instruments, Austin, TX) program designed to convert the data from analog to digital. The anteroposterior displacement is presented in millimeters and the inversion-eversion rotation is presented in degrees of range of motion. The ankle is loaded with 125 Newtons (N) of anterior displacement and 4 Newton-meters (N-m) of inversion-eversion rotation.<sup>1,12,16,23</sup>



**Figure 3.** Ankle Arthrometer<sup>20</sup>

## LigMaster

The LigMaster incorporates the Telos GA – II/E stress device (Figure 5). Using electronic sensors it measures joint laxity and calculates the percentage of damage to the ligament or the amount of laxity of the ligament, by comparing the measurements from the opposite side. The LigMaster can be used on the shoulder, elbow, knee and ankle joint.



**Figure 4.**LigMaster

## Reliability

Studies have examined the reliability of the ankle arthrometer and found it to be highly reliable in measuring ankle stability.<sup>12,19,24,31</sup> Kovaleski et al. used 6 cadaveric ankles to assess the efficiency of the ankle arthrometer to measure a difference in ankle laxity from an intact ankle to one where the ATFL has been excised and additionally the CFL. For intratester reliability, the coefficient for anteroposterior displacement was .97 and for inversion-eversion it was .82. For intertester reliability between 2 testers, the coefficient for anteroposterior displacement was .91 and for inversion-eversion rotation

it was .80. Cutting the ATFL and the ATFL + CFL produced a significant increase in the anteroposterior displacement and inversion-eversion rotation. When the ATFL was cut, anteroposterior displacement increased by 2.51mm and inversion-eversion rotation increased by 1.25 degrees, compared to the intact ankle. When the ATFL and CFL were cut, anteroposterior displacement increased by 5.12mm, and inversion-eversion rotation increased by 2.51 degrees, compared to the intact ankle. This study not only provided further support for the reliability of the ankle arthrometer but it also verified the ability of the ankle arthrometer to recognize a difference at the ankle when there is damage to a ligament. This can be beneficial clinically when looking for the most efficient treatment after an acute ankle sprain.<sup>23</sup> If there is no mechanical laxity present, based on ankle arthrometer measurements, then restoring functional insufficiencies is the main focus of the rehabilitation program. In a later study, Kovalski et al. assessed the reliability of the ankle arthrometer to assess the reliability in 41 subjects with no history of an ankle injury. The procedure required 2 measurements to be taken in the anteroposterior direction at loads of 75N, 100N, and 125N. For inversion-eversion, 2 measurements were also taken at 2 Nm, 3 Nm, and 4 Nm of applied force. The reliability coefficients for anteroposterior displacement ranged between .82- .89 and for inversion-eversion rotation ranged between .86-.97. There were no significant differences between the 2 measurements at each load, in both directions. During this study, Kovalski et al. also compared dominant to non-dominant ankles and found no significant differences between the two.<sup>31</sup> Hubbard et al. performed intratester reliability for anteroposterior displacement and inversion-eversion rotation and the measurements were highly

correlated at .91 and .99, respectively. Ankle arthrometry was able to correctly identify an increased anterior displacement in the FAI group.<sup>16</sup>

### **Conclusion**

The purpose of this study is to examine the effect of functional exercise on taping and bracing in individuals with and without ankle instability, utilizing ankle arthrometry. There are a limited number of studies that compare taping and bracing following a functional exercise protocol that incorporates multi-plane movements and ankle arthrometry. Having a better understanding of the effectiveness of these prophylactic devices following exercise will prove useful in the prevention of ankle sprains.