The Effect of an Ankle Brace on
Time to Stabilization Following a Jump Landing

A Thesis
Presented to
Faculty of
Plymouth State University

In Partial Fulfillment
of the Requirement for the Degree
Master's of Education
in Athletic Training

by
Christopher Paul Viesselman, ATC/L
May 2005
We recommend that the master's thesis prepared under our direction by Christopher Paul Viesselman entitled THE EFFECT OF AN ANKLE BRACE ON TIME TO STABILIZATION FOLLOWING A JUMP LANDING be accepted as fulfilling the research requirement for the degree of Master's of Education in Athletic Training.

Approved by:

Julie N. Bernier, Ed.D, ATC
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I will forever remember your version of the story of Noah. Thank you. To Sarah and Chris, your friendships have meant the world to me. Without you two I would be lost. May our lives be intertwined forever.
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The Effect of an Ankle Brace on
Time to Stabilization Following a Jump Landing
Christopher Paul Viesselman, ATC/L
Plymouth State University
The purpose of this study was to assess time to stabilization (TTS) of braced and unbraced subjects during a single-leg jump landing. Twenty-five healthy subjects (age = 20.4, ± 1.6 yrs; height = 169.9, ± 6.5 cm; weight = 67.8, ± 11.0 kg) performed three successful trials of a single-leg jump landing under both braced and unbraced conditions. The brace was an ASO Ankle Stabilizer (Medical Specialties, Inc., Charlotte, NC). Ground reaction forces (vertical, medial-lateral, and anterior-posterior) were collected during the single-leg jump landings onto a Bertec forceplate FP4060-NC (Bertec Corporation, Columbus, OH). A 2 X 2 (Condition X Direction) factorial ANOVA with repeated measures indicated no significant (F(.05)(1, 24) = 4.26, p = .207) interaction for condition (braced and unbraced) in either of the directions (medial-lateral TTS and anterior-posterior TTS). No significant main effect was found for brace condition (F(.05)(1,24) = 4.26, p = .827), but a significant main effect was found for direction (F(.05)(1,24) = 4.26, p = .000) with medial-lateral TTS faster than the anterior-posterior TTS. A paired t-Test showed no significant (t(.05)(24) = 2.064, p = .829) mean difference in vertical TTS between braced and unbraced conditions. An Intraclass Correlation was used to determine
Effect of an ankle brace trial reliability. Reliability ranged from ICC = .87 to .96. The findings of this study suggested the application of ankle brace on healthy subjects does not effect TTS during a single-leg jump landing. Further research is necessary in the area of injured subjects and ankle brace use during lateral jump tasks.
The Effect of an Ankle Brace on Time to Stabilization

The ankle is the most common site of injury in the human body (Billings, 2004; Garrick & Requa, 1989; Gomez, DeLee, & Farney, 1996; Putukian & Knowles, 1996). Studies that investigated injury rates found 12-36% of injuries to be ankle injuries (Billings, 2004; Garrick & Requa, 1989; Gomez et al., 1996; Putukian & Knowles, 1996).

Ankle braces have been used prophylactically to reduce the incidence of ankle injuries (Rovere, Clarke, Yates, & Burley, 1988; Sitler et al. 1994; Surve, Schwellnus, Noakes, Lombard, 1994). Ankle braces have also been shown to decrease the range of motion of the ankle (Metcalf, Shlabach, Looney, & Renehan, 1997; Siegler, Liu, Sennett, Nobilini, & Dunbar, 1997; Wiley & Nigg, 1996). A restriction of range of motion is thought to have a preventative effect on ankle injury (Verhagen, van der Beck, & van Mechelen, 2001). Ankle braces have also been shown to improve proprioception by increasing tactile stimulation (Karlsson & Andreassone, 1992; Hartsell, 2000; Heit, Lephart, & Rozzi, 1996).

Ankle sprains cause damage to the stabilizing structures of the ankle (Denegar & Miller, 2002). Ankle joint stability relies on bony congruency, tendons, and ligaments to reduce abnormal joint movements. Abnormal
movement in the ankle is referred to as mechanical instability (Tropp, 2002). However, mechanical instability is not considered the sole reason for instability of the ankle (De Simoni et al., 1996; Denegar & Miller, 2002; Tropp, Ekstrand, & Gillquist, 1984). Freeman, Dean, & Hanham (1965) were the first to suggest two types of instability: 1) mechanical, and 2) functional instability. Functional instability was first described by Freeman et al. (1965) as a feeling of the foot to "give way" (p. 678). They used a modified Romberg's test as an objective measure of functional instability and found no relationship between functional and mechanical instability (Freeman et al. 1965). De Simoni et al. (1996) also reported no relationship between anterior talofibular lesion and postural sway.

Mechanoreceptors found in the ankle joint capsule, ligaments, and musculotendinous units are responsible for proprioception (Michelson & Hutchins, 1995). The proprioceptive system along with the visual and vestibular systems are used for postural control (Knoles & Castelein, 1980). Postural control is defined as the ability of a person to maintain an upright stance over a base of support (Nashner, Shupert, Horak & Black, 1989). Mergner, Maurer, and Peterka (2003) suggested postural control was dependant
Effect of an ankle brace

on ankle proprioception to stabilize the body. A decrease in postural control has been linked to an increase in the incidence of ankle injury (Tropp et al., 1984; McGuine, Green, Best, & Leverson, 2000). Ankle injury has also been shown to decrease postural control (Freeman et al., 1965; Hertel, Buckley, & Denegar, 2001; Ross & Guskiewicz, 2003). One suggested measurement of postural control is the time it takes to stabilize after a dynamic movement and is called time to stabilization (TTS).

Time to stabilization may allow for detection of dynamic postural control deficiencies that could go undetected during static stance assessment (Ross & Guskiewicz, 2003). Colby, Hintermeister, Torry, and Steadman (1999) and Wikstrom, Powers, and Tillman (2004) used TTS as a forceplate measure to evaluate the transition of the body from dynamic to static state. A decreased TTS was found in subjects with functional ankle instability as compared to subjects without functional instability (Ross & Guskiewicz, 2003).

Ankle braces have been shown to improve proprioception (Hartsell, 2000; Heit et al., 1996; Karlsson & Andreassone, 1992). Proprioception plays a role in postural control (Knoles & Castelein, 1980). However, the effect of ankle braces on static single leg postural control has been...
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inconclusive (Barkoukis, Sykaras, Costa, & Tsorbatzoudis, 2002; Bennell & Goldie, 1994; Kinzey, Ingersoll, & Knight, 1997; Palmieri, Ingersoll, Cordova, & Kinzey, 2002; Feuerbach & Grabiner, 1993). Static single leg postural control may not challenge the postural control system enough to show a difference. Hopper, McNair, and Elliott (1999) used kinematic and electromyographic data during a single leg jump landing to evaluate the effect of ankle braces on dynamic postural control. No difference was found in the kinematic data, but a reduction in the reaction time of the peroneus longus was recorded.

Baker (2002) investigated the effect of ankle brace application on TTS during a drop landing. The subjects dropped from a height of 40.64 cm. A reduction of the TTS of subjects with the application of an ankle brace was recorded in comparison to subjects without the application of an ankle brace (Baker, 2002). Baker (2002) used the center of pressure to calculate TTS while Goldie, Evans, and Bach (1989) suggested that components of ground reaction force may best predict changes in postural control. An investigation of TTS using ground reaction forces may better represent postural control than center of pressure measurements (Wikstrom et al., 2004).
Further research is needed on the effect of an ankle brace on TTS of ground reaction force data. The purpose of this investigation was to utilize the ground reaction force data to better understand the implications of application of an ankle brace during a functional single-leg jump landing. The authors thought the ankle brace would improve the TTS of the subjects during a single-leg jump landing.

Method

The purpose of this study was to investigate the effect of ankle brace application on TTS during a single-leg jump landing. The hypothesis was that there would be a significant improvement in TTS from the unbraced to the braced condition. The method section was divided into the following: 1) subjects; 2) instrumentation; 3) procedure; and 4) data analysis.

Subjects

Subjects (N = 25) (Age = 20.40, ± 1.5; Weight = 67.79, ± 10.98 kg; Max vertical jump = 25.60, ± 7.63 cm) in the study were healthy volunteer college-age males and females. Healthy was defined as subjects who have not had 1) any diagnosed history of concussion, 2) any lower extremity injury in the last six months, and 3) have never experienced a lower extremity injury requiring the use of crutches. Subjects read and signed an Informed Consent
Effect of an ankle brace and completed the health questionnaire prior to participation.

**Instrumentation**

A Bertec forceplate FP4060-NC (Bertec Corporation, Columbus, OH) was used to record the vertical, anterior-posterior, and medial-lateral ground reaction force (GRF) during a single-leg jump landing. The Bertec forceplate is a non-conductive strain gauge unit that measures 0.6 X 0.4 m and weighs 26 kg. The forceplate was mounted level within a free standing 1.21 X 2.42 m raised wooden platform. The forceplate was interfaced with the MotionMonitor™ system Innovative Sports Training Inc. Software (Innovative Sports Training, Inc., Chicago, IL). The MotionMonitor™ system and forceplate was arranged and calibrated according to the specifications of the manufacturer (Innovative Sports Training, Inc., Chicago, IL). An x, y, z, orthogonal coordinate system was used for ground reaction force data collection. Positive directions of the coordinate system were as follows: horizontal x directed medial; horizontal y directed anterior; and vertical z directed upward. Data was recorded at a sampling rate of 400 Hz at an amplification of 500.

The Vertec© (Vertec, Sports Imports, Inc., Columbus, OH) was used to measure maximum vertical jump. The Vertec©
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was calibrated before each testing session by measuring the height of the bottom vane. The position of the Vertec© was marked on the floor to insure the same testing surface for each subject. A starting point was marked directly below the testing vanes with the use of a string gauge.

The ASO Ankle Stabilizer (Medical Specialties, Inc., Charlotte, NC) was used for the experimental condition. The ASO Ankle Stabilizer is a cloth lace-up brace designed to be pulled on over an athletic sock. The ankle brace has one stabilizing strap on the medial side and one on the lateral side. The straps pull forward across the top of the foot, under the heel, and fasten to the brace. A top stabilizing strap wraps around the top of the ankle covering the side straps and laces to insure neither become loose during use.

Procedures

After approval of the Institutional Review Board, testing was completed at the human performance laboratory of a small university in the northeast. Subjects were tested in one 30 min testing session. Upon arrival the subjects were required to read and sign the informed consent statement (Appendix C) and complete the health questionnaire (Appendix D). The height, weight, and lower leg dominance of the subjects were recorded. Lower leg
dominance in this study was defined through testing as the leg the subject chose to perform a single-leg jump.

Two handed standing reach was measured by having the subjects stand on the start point and raising both hands to the highest vane possible. The standing reach of the subjects was subtracted from the max vertical jump. This difference was multiplied by 70%, which was added to the standing reach to determine the height of the target ball used in testing. The subjects performed 3 trials of a standing vertical jump. The subjects positioned themselves with their feet shoulder width apart with the marked starting point directly between the arches of their feet. The subjects were instructed to pre-load, jump, and touch the highest vane possible with both hands. The subjects were allowed to swing their arms during take off but any adjustment of feet before take off resulted in a retrial. Subjects were asked to complete 3 trials of a maximal vertical jump.

The target ball was a 21.5 cm diameter inflatable ball and served as a visual reference for the subjects to jump and grab when performing the jump landing maneuver. The ball was hung from a rope suspended from the ceiling with a pulley system. The rope was attached to a pulley system to allow ball height to be adjusted. The ball was positioned
to allow the dominant limb of the subject to land in the center of the forceplate.

Subjects completed three successful jump trials in which 5s of forceplate data was recorded. Each trial began with a two footed take-off and ended with a single leg landing. Subjects performed each testing condition in low top athletic footwear, which they provided. They received a 30s recovery between each trial and a 5 min recovery between conditions to reduce the influence of fatigue. The order of condition testing was counter balanced to increase external validity.

Subjects started on a mark 25 cm from the center of the forceplate, performed a two legged jump, grasped a target ball hung at 70% of their max vertical jump height, and completed the landing on their self selected dominant foot. The subjects were instructed to balance themselves on the forceplate as rapidly as they could and then held that position until queued to step down. The guidelines for successful and invalid trials were explained. Invalid trials were defined as: 1) the inability of the subject to maintain foot position after initial contact; 2) the subject not landing with the entire foot on forceplate; 3) the subject touching down with the non-dominant leg; 4) failure of the subject to grasp the target ball; and 5)
excessive body movement (movement of the arms away from the body or kicking of the uninvolved leg, by the subject during landing).

Subjects were tested under the following two conditions: dynamic single-leg jump landing with ankle brace and dynamic single-leg jump landing without ankle brace. The ankle brace was applied by the investigator using the specifications of the manufacturer. A Latin Square table was used to determine testing order. The first 3s after maximum ground reaction force were used for analysis. Three dependent measures were used to assess postural stability: 1) medial-lateral TTS; 2) anterior-posterior TTS; and 3) vertical ground reaction force TTS.

Time to stabilization was used to determine if a difference existed between conditions in the time it took to stabilize following a single limb landing. Sequential estimation was used to calculate TTS for medial-lateral and anterior-posterior ground reaction forces. This is an algorithm that calculates the cumulative average of data points in a series. The series was considered stable when the sequential average reached and remained within 25% of a standard deviation of the overall series mean. The vertical component of the ground reaction force was considered stable when it reached and stayed within 5% of the ground
reaction force of the subjects in static state (Colby et al. 1999; Wikstrom et al. 2004).

**Data Analysis**

The TTS was used as the dependent variable assessing postural control during a dynamic landing. A low TTS was indicative of improved postural control by the subject. A 2 X 2 repeated measures analysis of variance (ANOVA) was calculated to compare the dependent variable of TTS (medial-lateral and anterior-posterior) for condition (braced and unbraced). The 2 X 2 repeated measures analysis of variance uses the within error to explain a difference found. The between groups error is unexplained by the treatment. A Paired t-test compared the mean vertical TTS of the braced condition to the mean vertical TTS of the unbraced condition. An IntraClass Correlation (ICC) was calculated to determine the trial reliability of TTS in the medial-lateral, anterior-posterior, and vertical directions. A one-way repeated measure analysis of variance (ANOVA) was used to calculate the ICC. The significance level was set a priori at $p < 0.05$. SPSS version 10.0 was used for all statistical analysis.
Results

The average TTS measurements were calculated following a single-leg jump landing from 70% of the vertical max. The average TTS measurements were the dependant variables. The TTS was calculated for each subject with and without an ankle brace. The trial reliability of TTS measurements ranged from ICC = .87 to .96. The descriptive statistics for medial-lateral and anterior-posterior TTS of the braced and unbraced condition are presented in Table 1.

The results for the 2 X 2 factorial ANOVA with repeated measures are presented in Table 2. No significant interaction was observed for direction X condition (p = .207) No significant main effect was found for bracing condition (p = .827) but a significant main effect for direction (p = .000) was found with anterior-posterior TTS (1.40 ± .21s) being significantly longer than medial-lateral (.98 ± .34s) TTS. The results for the mean differences of vertical TTS are located in Table 3. No significant mean difference was observed between the braced and unbraced condition of vertical TTS (p = .829).

Discussion

The current study was designed to examine the effectiveness of an ankle brace on TTS during a single-leg jump landing. Brace condition had no affect on any of the
measures of TTS during the single-leg jump landing. These results supported much of the literature on static postural assessment and the effect of ankle braces on balance (Barkoukis et al., 2002; Hopper et al., 1999; Kinzey et al., 1997; Palmieri et al., 2002).

Hartsell (2000) and Heit et al. (1996) both found that the application of ankle braces increased the joint position sense of healthy subjects. The findings of Hartsell (2000) and Heit et al. (1996) suggested the application of an ankle brace provides increased proprioceptive input to allow for increased ability to reproduce active and passive joint position. Because proprioception provides input into the postural control system the findings of Hartsell (2000) and Heit et al. (1996) suggested the ankle brace would affect postural control. The current study did not investigate the effect of the ankle brace on joint position sense but the effect of an ankle brace on a more functional activity, TTS. The research of Hartsell (2000), Heit et al. (1996), and Karlsson and Andreassone (1992) indicates that an ankle brace may affect one aspect of the postural control system; however the application of an ankle brace did not lead to an improved TTS in the current study.
A closer look at the postural control system may help in understanding the lack of significance during the current investigation. The postural control system relies on proprioceptive, visual, and vestibular systems for input into the feedback loop system of the central nervous system. This overall system allows for the body to maintain an upright stance over a base of support. Age and pathological changes in this system impair postural control leading to an increase in sway (Karlsson & Persson, 1997). The subjects in this investigation were healthy; therefore they may not have needed the additional proprioceptive input provided by the ankle brace. If this additional information was disregarded by the postural control system it would explain the lack of significance found. Ross & Guskiewicz (2003) found an improved TTS in healthy subjects compared to subjects with ankle instability. Unhealthy subjects with acute ankle sprains or chronic instability may have been able to use the additional proprioceptive input from the ankle brace which may have resulted in an improved TTS.

Another explanation can be attributed to the work of Barkoukis et al. (2002) who investigated the effect of taping and bracing on balance tasks in the frontal plane. The lack of significance in the Barkoukis et al. (2002)
Effect of an ankle brace study was attributed to the nature of the task involved. Researchers stated that because no sharp lateral movements were used in the balance task the additional support of the brace may not have been needed (Barkoukis et al., 2002). In the current study this would also be true. Even though a single-leg jump landing was used as the functional task, the landing was on a firm and flat surface. The path of the jump landing did have a small horizontal component but this was in the sagittal plane and may not have been enough to adequately stress the postural control system. A jump landing with a horizontal component in the frontal plane may have put the additional lateral stress needed for the subject to effectively use the ankle brace support.

Baker (2002) found a significant difference for medial-lateral center of pressure stabilization time and standard deviation of medial-lateral center of pressure stabilization time between control and braced conditions. No other significant difference was found (Baker, 2002). The subjects took longer to stabilize medial-lateral center of pressure during the braced condition and had a faster stabilization time for the standard deviation of medial-lateral center of pressure. This suggested that subjects took longer to stabilize position, but had less variability of stabilization during the braced condition (Baker, 2002).
These results are inconclusive regarding the prophylactic importance of the ankle brace. Baker (2002) used a controlled height of 40.64 cm for the subjects to land from. This height was found to be higher than the max vertical jump heights (25.60 ± 7.63 cm) of the subjects in the current study. The difference between the landing heights of Baker (2002) and the current study may explain why no significance was found in the current study. By forcing the subjects to compensate for forces high than what they are used to encountering the subjects may have used the additional proprioceptive input from the ankle brace affecting their TTS.

The anterior-posterior TTS was found to be significantly slower than the medial-lateral TTS. The anterior-posterior TTS was higher for both conditions. This can be explained by the increased range of motion of the talocrural joint in the sagittal plane. The talocrural joint has an average range of motion of 70° in the sagittal plane while only allowing for 50° in the frontal plane. This difference in movement could explain for the increased anterior-posterior TTS. The subjects also traveled in an anterior direction during the jump landing. The subject had to compensate for the anterior movement during stabilization which may also explain the difference.
Several factors may have attributed to the lack of significance in the current study. One limitation was the use of healthy subjects. Their TTS was unimpaired and therefore brace condition provided no additional proprioceptive cues. By using a preloaded jump landing, the subjects may have been more likely to use a knee/hip strategy than an ankle strategy to maintain balance. If this were the case, ankle bracing would have little effect on postural control and could explain the lack of significance. Perhaps capturing kinematic data during the jump landing would have provided additional data for improved evaluation of the ankle brace.

Conclusion

The results of the current study suggested that application of an ankle brace does not have an effect on the TTS in healthy subjects wearing the ASO Ankle Stabilizer following a single-leg jump landing. The incorporation of a functional task; however was shown to be a reliable method of evaluating TTS. The results did show that the ankle brace does not negatively affect postural control during a dynamic single-leg jump. There are no reasons not to use an ankle brace to reduce the incidence of ankle injury. Further investigation into single-leg
landing with lateral movement and using subjects with ankle instability may reveal differences in TTS.
References


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Table 1

Descriptive Statistics for Condition by Direction \((N = 25)\)

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<th>Variables</th>
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<tr>
<td>Medial-Lateral TTS</td>
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<td>.386</td>
</tr>
<tr>
<td>Anterior-Posterior TTS</td>
<td>1.363</td>
<td>.191</td>
</tr>
<tr>
<td><strong>Braced</strong></td>
<td></td>
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<tr>
<td>Medial-Lateral TTS</td>
<td>.968</td>
<td>.297</td>
</tr>
<tr>
<td>Anterior-Posterior TTS</td>
<td>1.431</td>
<td>.220</td>
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Medial-Lateral TTS

- **Unbraced**
  - Mean: 1.016
  - \(s\): .386
- **Braced**
  - Mean: .968
  - \(s\): .279

Anterior-Posterior TTS

- **Unbraced**
  - Mean: 1.363
  - \(s\): .191
- **Braced**
  - Mean: 1.431
  - \(s\): .220

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Table 2

2 x 2 Factorial ANOVA with Repeated Measures on TTS for Condition by Direction

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<td>Within Groups</td>
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<td>B - Direction</td>
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Table F (.05)(1, 24) = 4.26
Table 3

Paired t-Test for Vertical TTS Means of Control and Braced Conditions (N = 25)

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<th>Group</th>
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<td>24</td>
<td>.017</td>
<td>.078</td>
<td>.219</td>
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Table t (.05)(24) = ± 2.064
Appendix A

RESEARCH DESIGN

The mechanism by which prophylactic ankle braces prevent injuries is not completely understood. The affect of ankle braces on postural stability during a single leg static stance, as measured on a force plate have been inconclusive (Barkoukis, Sykaras, Costa, & Tsorbatzoudis, 2002; Bennell & Goldie, 1994; Feuerbach & Grabiner, 1993; Kinzey, Ingersoll, & Knight, 1997; Palmieri, Ingersoll, Cordova, & Kinzey, 2002). Feuerback and Grabiner (1993) found ankle braces to increase postural stability while Bennell and Goldie (1994) found decreased postural stability when ankle braces were used. No significant difference was found in the majority of the studies using a force plate to measure static postural stability (Barkoukis et al., 2002; Kinzey et al., 1997; Palmieri et al., 2002). Static stance may not challenge the ankle stability system to the degree necessary to show a significant difference in stability with ankle brace application. Dynamic assessment may be more useful to determine the effects of prophylactic ankle bracing on injury during activity (Ross & Guskiewicz, 2003).
Statement of the Problem

The purpose of this project was to investigate the effect of ankle bracing on time to stabilization in healthy subjects during a single-leg jump landing. Ground reaction force data will be measured using a Bertec forceplate FP4060-NC (Bertec Corporation, Columbus, OH) in medial-lateral, anterior-posterior, and vertical components during a single-leg jump landing.

Definition of Terms

The following definitions are used when interpreting the findings of the current study:

College-aged

Any individual found to be in the age range of 18-30 years.

Healthy

Any individual found to be without diagnosed history of concussion; injury to lower extremity in the last six months; and without any history of lower extremity injury requiring the use of crutches.

Dynamic single-leg landing

Dynamic single-leg landing was defined as a single-leg jump landing requiring a two footed take off and a single leg landing. A ball was placed at 70% of the vertical max
of the subject and they will be asked to grasp the ball
during the jump maneuver.

**Dominant limb**

Dominant limb was defined as the leg used by the
subject during a single leg hop.

**Ground reaction force**

Ground reaction force was the force of the center of
mass applied to the forceplate through the base of support
(Karlsson & Persson, 1997).

**Time to stabilization**

Wikstrom, Powers, and Tillman (2004) defined time to
stabilization as a forceplate measure that is used to
evaluate the transition of the body from a dynamic to
static state.

**Delimitations**

The delimitations of this study included:

1. The use of only healthy subjects.
2. The subjects aged from 18 - 30 years.
3. Ankle braces was applied under manufacturer
   specifications.
4. Only one type of brace, the ASO Ankle Stabilizer
   (Medical Specialties, Inc., Charlotte, NC), was used.
5. Dominant limb was used for jump landing.
6. Subjects were instructed on ideal landing position.

Limitations

The limitations of this study included:

1. The inability to limit external visual input.
2. The perceived exertion of the subject on max vertical jump.
3. The inability of the examiner to control footwear.
4. Subjects were volunteers.
5. Researcher assumed subjects will honestly report injury history.
6. Researcher assumed subjects will give max effort to quickly maintain balance during all trials.
7. Only one brace was evaluated.

Hypotheses

1. No significant mean difference would exist between braced and unbraced condition.
2. No significant mean difference would be found in the anterior-posterior and medial-lateral time to stabilization.
3. No significant interaction would be found between bracing conditions and time to stabilization directions.
4. No significant mean difference would exist in the vertical time to stabilization for the braced and unbraced conditions.
Appendix B

LITERATURE REVIEW

Injury during sports participation is common both in the recreational and the competitive athlete. Research has shown the ankle to have the greatest prevalence of injury (Billings, 2004; Garrick & Requa, 1989; Murtaugh, 2001; Meeuwisse, Sellmer, & Hagel, 2003; Putukian & Knowles, 1996; Schefle, 1993). Studies have shown ankle injuries to account for 12% (Billings, 2004) to 31% (Gomez, DeLee, & Farney, 1996) of the total injuries suffered.

The use of ankle braces has been shown to reduce incidence of ankle injury (Rovere, Clarke, Yates, & Burley, 1994; Sitler et al., 1994; Surve, Schwellnus, Noakes, & Lombard, 1994). Rovere et al. (1994) reported a reduction in ankle injury rate by 50% with the use of prophylactic ankle braces as compared to taping in collegiate football. Sitler et al. (1994) found three times the number of injuries in subjects not wearing ankle braces compared to those with ankle braces. Surve et al. (1994) found five times the number of ankle injuries in soccer players with a history of ankle sprains who did not use ankle braces compared to those who wore ankle braces.

The mechanism by which prophylactic ankle braces prevent injuries is not completely understood. Some
theories suggest ankle braces preventative measure comes from a decrease in abnormal range of motion at the ankle (Metcalf, Schlabach, Looney, & Renehan, 1997; Siegler, Liu, Sennett, Nobilini, & Dunbar, 1997; Wiley & Nigg, 1996) or increased proprioception due to increased tactile stimulation (Hartsell, 2000; Heit, Lehpard, & Rozzi, 1996; Karlsson & Andreassone, 1992). The effect of ankle bracing on postural stability during a single leg static stance, as measured on a forceplate has been inconclusive (Barkoukis, Sykaras, Costa, & Tsorbatzoudis, 2002; Bennell & Goldie, 1994; Feuerbach & Grabiner, 1993; Kinzey, Ingersoll, & Knight, 1997; Palmieri, Ingersoll, Cordova, & Kinzey, 2002). Feuerback and Grabiner (1993) found ankle braces to increase postural stability while Bennell and Goldie (1994) found a decrease in postural stability when ankle braces were used. In the majority of the studies, however, no significant difference in static postural stability was found (Barkoukis et al. 2002; Kinzey et al. 1997; Palmieri et al. 2002). Static stance may not challenge the ankle stability system to the degree necessary to show a significant difference in stability with ankle brace application. Dynamic assessment may be more applicable to determine the effects of prophylactic ankle bracing during activity (Ross and Guskiewicz, 2003).
Time to stabilization, a relatively new technique for measuring dynamic stability on the forceplate, is used during single leg landings. This technique measures the amount of time it takes for the medial-lateral, anterior-posterior, or vertical ground reaction forces to stabilize (Brown, Ross, Mynark, and Guskiewicz, 2004; Colby, Hintermeister, Torry, and Steadman, 1999; Ross & Guskiewicz, 2003; Wikstrom, Powers, & Tillman, 2004). To further investigate the role ankle bracing plays on postural control, this literature review has been divided into five sections. The sections are: 1) ankle injury and incidence; 2) ankle anatomy; 3) ankle injury and its effects on proprioception and neuromuscular control; 4) effectiveness of ankle bracing; 5) assessment techniques.

Ankle Injury and Incidence

"Injuries to the foot and ankle in sports are exceedingly common" (Garrick & Requa, 1989 p. 629). Garrick and Requa (1989) performed a retrospective examination of injury rates from July 1979 to January 1987 in a sports medicine clinic. Information collected during this time period was coded according to characteristics of the patients. This was then used to examine the injury patterns in sports. A total of 12,681 injuries were recorded for 19
sports. Injuries to the foot and ankle accounted for 9.7% of the total injuries. The percentage of ankle injuries recorded varied by sport. Basketball and ice skating had the highest incidence at 21.1% while weight lifting and swimming recorded ankle injuries to make up under 2% of total injuries (Garrick & Requa, 1989). The injuries investigated in this study may not be a true representation of the number of ankle injuries experienced throughout the population. The records investigated were in a sports medicine clinic. This suggests that the injuries would have to be extreme enough to require medical attention. Injuries that do not affect the ability of the person to perform a sports related task may be under reported.

An investigation of high school football found the knee and ankle to be the most common anatomical site of injury (DeLee & Farney, 1992). There were 4399 subjects included in the study. Any event that caused a subject to miss all or part of an exposure period, being treated by a physician, or involving the head were defined as injuries. An exposure period was defined as one practice or game. A total of 2,228 injuries were recorded during the study. Four hundred and forty-five injuries (20% of the total) involved the knee and 401 injuries (18% of the total) involved the ankle (DeLee & Farney, 1992).
Gomez, DeLee, and Farney (1996) investigated the incidence of injury in high school women's basketball which included 890 subjects in the study. Four hundred and thirty-six injuries were reported during the study. They defined an injury as any event that resulted in missing all or part of an exposure period, consultation by a physician, or involving the head. An exposure period consisted of one practice or game. They found the ankle to be at the greatest risk of injury and resulted in 31% of the total injuries recorded (Gomez et al., 1996).

Putukian and Knowles (1996) investigated injury rates during a three day soccer tournament. Injury was defined as time lost from practice or play. Eight hundred and twenty-four individuals participated in the tournament. Seventy-nine players were seen resulting in 38 injuries with time lost. Twenty-seven of these injuries involved the lower extremities with 10 ankle sprains. Ankle sprains accounted for 26.3% of the injuries recorded. The ankle sprain was the highest recorded injury in this study (Putukian & Knowles 1996).

Billings (2004) investigated injuries during the United States Air Force Academy's Basic Cadet Training. Eight hundred and forty-six injuries occurred during the
six week Basic Cadet Training. One thousand one hundred and ninety-eight subjects participated in the study. Injuries were recorded from initial visits of the subjects to the medical clinic. Ninety-eight ankle sprains (12% of the total injuries) were reported. The ankle was the most common injury (Billings, 2004).

Ankle Anatomy

The ankle joint or talocrural joint is a synovial joint comprised of the articulation of the distal ends of the tibia and fibula with the talus (Bannister et al., 1999). The talocrural joint gains stability from the ligamentous structures on the medial and lateral side. The ligaments on the lateral side of the ankle are the anterior talofibular, calcaneofibular, and posterior talofibular ligaments. The medial side is made up of the deltoid ligament (Andrews, Harrelson, & Wilk, 1998).

The anterior talofibular ligament attaches to the anterior edge of the lateral malleolus and inserts in the talus. The calcaneofibular ligament attaches to the anterior aspect of the lateral malleolus and inserts into the calcaneus. The posterior talofibular ligament attaches to the posterior aspect of the malleolus and inserts into the posterior-lateral aspect of the talus (Burks & Morgan, 1994). The deltoid ligament is found on the medial side of
the ankle. It attaches to the medial malleolus and inserts into the talus. The deltoid ligament splits into three sections before its insertion into the talus (Harper, 1987). The motion of this joint is found in the sagittal plane with the average range of motion found from 40 to 50 degrees (Norkin & White, 2003).

The calcaneus lies just inferior to the talus and together form the subtalar joint (Andrews et al., 1998). This joint is stabilized by the interosseous talocalcaneal ligament, medial and lateral talocalcaneal ligaments, and cervical ligament (Bannister et al., 1999). The subtalar joint provides motion in three planes allowing for pronation and supination (Andrews et al., 1998). These associated movements occur in different ways when weight-bearing compared to non-weight-bearing. In weight-bearing the talus becomes a movable structure with movement at the midtarsal, subtalar, and talocrural joints. During non-weight-bearing the calcaneus moves about the talus. The average total range of motion for pronation and supination is 25 degrees (Starkey & Ryan, 2002).

Receptors responsible for joint position sense and motion are found in the joint capsule, ligaments, and musculotendinous unit (Deshpande, Connelly, Culham, Costigan, 2003; Lentell et al., 1995; Michelson & Hutchins,
Freeman and Wyke (1967) classified four types of receptors in the ankles of cats. Type I were found in the superficial layers of all aspects of the joint capsule. Type I are responsible for joint position sense and were found in greater quantity in the posterior capsule. Type II were located deeper in the capsule than Type I and outnumber them. These receptors are responsible for joint motion. Type III were found on the exterior surface of the ligament and near bony attachments and are give information on joint position sense. Type IV were found in the joint capsule, posterior fat pad, and ligaments and are responsible for pain (Freeman & Wyke, 1967). Michelson and Hutchins (1995) studied five pairs of human ankles. They investigated the type and frequency of mechanoreceptors in the ankle ligaments. They observed Type I, Type II, and Type III mechanoreceptors. Type II and Type III mechanoreceptors were found to be the most frequent. These are the receptors thought to provide the most proprioceptive input (Michelson & Hutchins, 1995).

Cutaneous mechanoreceptors responsible for joint position sense are found in small quantities and only respond to extreme angular positions (Grigg, 1994). Although it is clear that they respond to movement, the role they play in proprioception is complicated because
they respond to any stretching of the skin. Grigg (1994) suggested the role of cutaneous mechanoreceptors in proprioception were minor.

Muscle spindles are found in the skeletal muscle surrounding the ankle joint, while Golgi tendon organs are found in tendons at the attachment point of the muscle (Marieb, 1995). Muscle spindles are responsible for information on muscle length and thus signal joint movement. However, slow joint movements do not stimulate the muscle spindles because the muscle is not active. Golgi tendon organs are stimulated when the tendon is placed on a stretch (Grigg, 1994).

Ankle Injury and Its Effect on Proprioception and Neuromuscular Control

The movement of the ankle is a complex system relying on a multitude of structures. Ankle injury causes damage to the stabilizing structures of the ankle (Denegar & Miller, 2002; Freeman, Dean, & Hanham, 1965; Robbins, Waked, & Rappel, 1998). The mechanical disruption of stabilizing structures is not considered to be the sole reason for instability of the ankle (Bernier & Perrin, 1998; Denegar & Miller, 2002; Tropp, Ekstrand, & Gillquist, 1984). DeSimoni et al. (1996) looked for a relationship between mechanical instability using magnetic resonance imaging and a postural
sway analysis after lateral ankle injury. They (DeSimoni et al., 1996) used the horizontal force oscillations acting on the frontal plane to measure postural sway. Thirty subjects were assessed following ankle sprains. The subject suffered from either a partial or full tear of the lateral ligaments of the ankle, as shown by magnetic resonance imaging. Twenty-eight of the thirty subjects were found to have a stable single leg stance. No relationship was found between anterior talofibular lesion and postural sway. This corroborates the Freeman et al. (1965) study that stated functional instability and mechanical instability are two different entities.

Freeman et al. (1965) investigated the affect of three treatment procedures on functional instability of the ankle. Functional instability is a term used by the researcher to designate a response of the subject in which their foot tends to “give way” (p 678). Eighty-five patients with ligamentous injuries in the ankle were selected for treatment. The three treatments were: 1) immobilization of the ankle for three weeks; 2) conventional physiotherapy; and 3) conventional physiotherapy and coordination exercises. A modified Romberg’s test was used to evaluate functional instability of the ankle. The coordination exercises significantly
improved the incidence of functional instability as compared to the other treatment conditions. This study suggested mechanical instability may not be the sole reason for functional instability. Freeman et al. (1965) performed one of the first to show a link between decreased postural control and ankle injury. Postural control was defined by Nashner, Shupert, Horak and Black (1989) as the ability of the body to detect errors in the position of the center of gravity over a base of support during stance.

Tropp et al. (1984) found no difference in the sway amplitude between injured and uninjured subjects. An experimental group of 127 subjects was compared to a reference group of 30 healthy subjects. A standard value of postural sway was suggested from the postural sway found in the healthy population. The sway values of the experimental group were compared to the reference group to show a pathological difference. The experimental group was tracked throughout the subsequent soccer season and injuries were recorded. The subjects with a decreased ability to maintain posture had an incidence of injury at 42%, while the normal group had an 11% incidence of injury (Tropp et al., 1984).

McGuine, Greene, Best, and Levenson (2000) also found that an increase in postural sway increased injury rate.
Two hundred and ten subjects were evaluated and divided evenly into three groups of sway values (low, mid, and high). The velocity of the center of pressure was used as the evaluating measure. An increased velocity as the center of pressure moved away from the stable position was deduced as a decreased ability to maintain posture. The ankle injuries of the subjects were recorded in the season after which sway evaluation was completed. The subjects in the low sway value group had an injury rate of 0.40 injuries per 1,000 exposures. The mid sway value group had an injury rate of 1.63 injuries per 1,000 exposures, and the high sway group had 2.68 injuries per 1,000 exposures (McGuine et al., 2000). The data suggests an increase in sway velocity to be related to an increase in injury.

Hertel, Buckley, and Denegar (2001) investigated postural control after an acute ankle injury. Seventeen subjects were tested three times post injury. The single leg balance test was performed for three trials of five seconds. The variables assessed were length of center of pressure excursion, velocity of excursion, and maximum range of excursion. Initial evaluation of the subjects showed decreased ability to maintain posture. This ability improved throughout the month of testing. Hertel et al.
(2001) suggested a decrease in swelling and a learning effect as possible explanations for the improvement of postural control.

Ankle Braces

Ankle braces are routinely used for prevention and treatment of ankle injuries. Several studies have investigated the effectiveness of ankle bracing on ankle: range of motion; proprioception; postural control; and injury rate (Bahr, Karlsen, Lian, & Ovrebo, 1994; Rovere et al., 1988; Sitler et al., 1994; Surve et al., 1994).

Rovere et al. (1988) investigated the effectiveness of prophylactic ankle taping and bracing during six seasons of collegiate football. Ankle taping was the only means of support during the first year and a half of the study. During the last four and a half years of the study, subjects chose between ankle taping and lace-up ankle braces. Two hundred and thirty-three subjects had their ankles taped during 38,658 exposures. An exposure period was defined as one practice or game. Ankle injury and reinjury were classified as a subject missing at least one exposure period after injury. The taped exposures accounted for 159 ankle injuries and 23 reinjuries. One hundred and twenty-seven subjects wore ankle braces during 13,273 exposures. These exposures accounted for 37 injuries and
one reinjury. Subjects who utilized ankle taping were at 1.5 times the risk of injury compared to subjects with ankle braces (Rovere et al., 1988).

Sitler et al. (1994) investigated the use of prophylactic ankle bracing on ankle injuries in 1,601 subjects during 13,430 exposures over a two year time period. Injuries were defined as the inability of a subject to participate in the subsequent exposure period. The subjects were classified into 1,424 noninjured subjects and 177 previously injured subjects during a clinical evaluation prior to the study. The subjects were then randomly assigned to a braced or unbraced condition. Forty-six injuries occurred during the study. Thirty-five injuries occurred in the unbraced ankle group and 11 injuries occurred in the braced group. The injury rate of the unbraced group was three times greater than the braced group. This was found to be statistically significant. The authors concluded that the ankle brace significantly reduced the frequency of ankle injury (Sitler et al., 1994).

Surve et al. (1994) investigated the Sport-Stirrup, a semirigid ankle brace and its effect on the incidence of ankle injury. Subjects were divided into a group with a previous history of ankle sprains (258 subjects) and a
noninjured group (246 subjects). The two groups of subjects were randomly assigned to a control (unbraced) or braced group. Injuries were defined as an inability of the subject to participate in the next exposure period. An exposure period was defined as one practice or game. No significant difference was found in the injury rate of the uninjured subjects between the control and the braced group. A significant difference was found in the previously injured group. The previously injured unbraced subjects were five times as likely to reinjure ankles as compared to the braced group (Surve et al., 1994).

Ankle braces have been shown to reduce the range of motion in the ankle (Metcalf et al., 1997; Siegler et al., 1997; Wiley & Nigg, 1996). This reduction of range of motion is thought to have a preventative affect on injury (Metcalf et al., 1997; Siegler et al., 1997; Vaes et al., 1998; Verhagen, van der Beck, & van Mechelen, 2001; Wiley & Nigg, 1996). Metcalfe et al. (1997) measured passive ankle plantar flexion, dorsiflexion, inversion, and eversion before, after, and in the middle of an exercise session. Ranges of motion were measured by a certified athletic trainer with the use of a hand held goniometer. Metcalfe et al. (1997) found the Swede-O Universal brace (Swede-O Inc.,
North Branch, MN) to restrict plantar flexion, dorsiflexion, and inversion of the ankle.

Siegler et al. (1997) used the ankle flexibility tester to measure the passive three-dimensional flexibility of four ankle brace systems compared to an unbraced control. The ankle flexibility tester was described as "a six degree-of-freedom instrumented linkage used to provide a direct measure of the mechanical characteristics of the ankle joint complex in the joint coordinate frame" (Siegler et al., p. 300). Siegler et al. (1997) compared two cloth lace-up braces, Ascend (AOA Corporation, Parsippany, NJ) and Swede-O (Swede-O Inc., North Branch, MN) and two semirigid ankle braces, Aircast (Aircast Inc., Summit, NJ) and Active Ankle (Active Ankle Systems, Inc., Louisville, KY). All of the ankle braces used in the study reduced the flexibility of the ankle in inversion, eversion, internal, and external rotation. The Active Ankle brace did not affect dorsiflexion. The other three braces did significantly reduce dorsiflexion, but none of the braces significantly affected plantar flexion (Siegler et al., 1997).

While ankle braces effectively reduce range of motion of the ankle, they may also have a negative effect on performance, but results of studies vary. Wiley and Nigg
(1996) investigated the application of the Malleoloc ankle brace, (Bauerfeind GmbH, Germany) a semirigid ankle brace on range of motion of the ankle. The ExperVision Hi Res 3-D motion analysis system (Motion Analysis Corporation, Santa Rosa, CA) was used to measure active and passive range of motion. Active ankle inversion decreased by 33-44%, eversion 21-24%, plantar flexion 11-16%, and dorsiflexion 0-13%. Passive inversion decreased by 45-50%. No other passive motions were tested (Wiley & Nigg, 1996). They (Wiley & Nigg, 1996) also investigated the application of the Malleoloc ankle brace on vertical jump height and a timed figure eight run. No significant difference was found for either performance test.

Metcalfe et al. (1997) investigated the effect of the Swede-0 ankle brace on performance of a vertical jump and timed agility test. The brace resulted in a reduction of the average vertical jump height by 1.42 cm. The average time of the agility run increased 0.33 seconds with the ankle brace (Metcalfe et al., 1997). This showed a negative effect on performance for the Swede-0 ankle brace. The effect on performance however, is minimal in comparison to a 50% reduction of injury with the use of an ankle brace (Rovere et al., 1988).
Hals, Sitler, and Mattacola (2000) investigated the effect of the Aircast Sport Stirrup ankle brace (Aircast Inc., Summit, NJ) on performance in subjects with ankle instability. Instability was defined as a reduced ability to maintain a single leg stance on the injured ankle over a 10 second time period. Two performance tests were recorded: 1) maximal vertical jump and 2) timed 36.58 meter shuttle run. No significant difference was found in the maximal vertical jump. The ankle brace improved the shuttle run performance time. They concluded that the Aircast Sport Stirrup ankle brace improved performance in subjects with an unstable ankle (Hals et al., 2000).

Several studies have examined the effects of ankle braces on balance with varying results. The results of these studies have varied. Feuerbach and Grabiner (1993) applied the Aircast Air-Stirrup, semirigid ankle brace to uninjured subjects and measured postural sway on the Chattecx Balance System (Chattecx Corporation, Chattanooga, TN). They examined the mean relative loading, sway amplitude, and sway frequency. Mean relative loading was defined as the average location of the center of pressure over the 30 second trial. Sway amplitude was defined as the standard deviation of the sway path around the mean relative loading variable. Sway frequency was
defined as the mean of the frequency of the data before it was converted into sway measurements. The mean relative loading showed a small shift laterally with the application of the ankle brace. This shift however, was not statistically significant. The sway amplitude and sway frequency decreased with the application of the ankle brace. This decrease of sway amplitude and frequency showed an increased ability to maintain balance with the application of the Aircast ankle brace (Feuerbach & Grabiner, 1993).

Bennell and Goldie (1994) however, found the opposite result. They examined the effect of the Swede-O Universal ankle brace (Swede-O Inc, Kansas, OH) on medial-lateral ground reaction force and foot touch downs of the uninvolved leg over a five second trial. Much like Feuerbach and Grabiner (1993) they used the standard deviation of the force data as the definition for their ground reaction force data. However, Bennell and Goldie (1994) found the application of the Swede-O ankle brace to significantly increase the ground reaction force data. They also found a significant increase in foot touch down of the nonsupport leg. Both of these findings led Bennell and Goldie (1994) to conclude that the application of the Swede-O ankle brace negatively effected postural control.
A majority of the studies found ankle bracing had no effect on postural control (Barkoukis et al., 2002; Hopper, McNair, & Elliott, 1999; Kinzey et al., 1997; Palmieri et al., 2002). Kinzey et al. (1997) investigated the average center of pressure position and center of pressure total distance in subjects without a history of ankle injury. Center of pressure is the conversion of ground reaction force data to one point under the base of support that is a direct reflection of the movement of the center of gravity. Kinzey et al. (1997) compared an unbraced control to three braces. The three braces were: 1) Active Ankle Trainer semirigid ankle brace (Active Ankle System, Inc, Louisville, KY); 2) AirCast Sport Stirrup semirigid ankle brace (Aircast, Summit, NJ); and 3) McDavid A-101 cloth lace-up brace (McDavid Knee Guard, Inc, Chicago, IL). They compared a 16 second single leg static stance on normal floor conditions and 10.2 cm thick high-density foam. No statistical significance was found between the control and the braced conditions.

Cordova, Armstrong, Rankin, and Yeasting (1998) investigated the difference between ground reaction forces and electromyographic data of braced and unbraced subjects during inversion stress. A lateral shuffling task was used to replicate inversion stress in 24 subjects. The data from
Peak impact force, maximum loading force and maximum propulsion force were collected about the medial-lateral axis. Electromyographic data from the peroneus longus, tibialis anterior, and medial gastrocnemius were also collected. Data were recorded during five trials of each condition. No significant difference was found for the ground reaction force data. The electromyographic data of the peroneus longus was significantly less in the braced condition compared to the control. The authors (Cordova et al., 1998) attributed this to the absorption of force normally placed on the peroneus longus. This may explain the preventative ability of the ankle brace to reduce the lateral force placed on the ankle. This could not be confirmed by the results of the study (Cordova et al., 1998).

Hopper et al. (1999) stressed the stability system by incorporating a single leg forward jump. The Swede-O cloth lace-up ankle brace was used as their test condition. A 16 mm Photosonics high speed camera fitted with an Angeniex 12-120 mm zoom lens was used to film four adhesive reflective markers placed on the rear foot and leg of subjects. This recorded the rear foot angle during a single leg landing. The electromyographic data of the medial gastrocnemius, tibialis anterior, and peroneus longus
muscles were also recorded. No significant difference was found between the rear foot angles of the braced and unbraced conditions. A significant decrease was found for the muscle activity of the medial gastrocnemius and peroneus longus muscles in the braced condition (Hopper et al., 1999). The markers were fixed to the brace which might not have changed position during the landing. The authors also stated the subjects landed primarily on the forefoot and much of the stability difference may have been compensated for without rear foot movement. The decrease in muscle activity was attributed to the ability of the brace to decrease forces on the ankle during landing (Hopper et al., 1999).

Palmieri et al. (2002) investigated the effect of the McDavid A101 cloth lace-up brace to an unbraced control on normal floor conditions. They used the mean frequency of the center of pressure data over a 20 second time period. The subjects were divided into two groups and were tested every 24 to 32 hrs over a four day period. The braced group was required to wear the ankle brace for eight hrs a day. Both groups were tested each time with and without the ankle brace. No significant difference was found for the mean frequency of either group.
Barkoukis et al. (2002) employed a different assessment of postural control. They used a stability platform (Lafayette Instruments, Sabilometer Model 1620) to measure the left and right deviations of movement. The stability platform was a pivoting platform that recorded the degrees of deviation from horizontal. The Swede-0 cloth lace-up ankle brace, Aircast semirigid ankle brace, and modified Gibney closed basketweave taping technique were applied to one ankle of the test subjects. These three stabilizers were tested against an unbraced control. Thirty second trials were recorded for two footed balance. No significant difference was found for either ankle brace application compared to the control (Barkoukis et al., 2002). They (Barkoukis et al., 2002) concluded that application of a single ankle brace during a two footed test did not change the system of stability enough to show significant difference in balance.

Assessment

The forceplate has been shown to be a valid and reliable measure of balance (Birmingham, 2000; Ekdahl, Jarnio, & Andersson, 1989; Goldie, Evans, & Bach, 1992) and the data has been related to functional instability tests (Ekdahl et al., 1989; Riemann, Guskiewicz & Shields, 1999). The terms postural sway, postural stability, and
stabilometry have all been used to describe static balance (Ekdahl et al., 1989; Goldie et al., 1992; Tropp & Odenrick, 1988).

Ekdahl et al. (1989) investigated stabilometric values for healthy subjects 20-64 years of age on a stable AMTI force platform (Advanced Mechanical Technology Inc., Newton, Massachusetts) and compared them to functional balance tests. One hundred fifty-two subjects were divided into seven age groups (20-29, 30-39, 40-44, 45-49, 50-54, 55-59, and 60-64). Ten healthy subjects aged 26.8 ± 6.5 years were tested four times at one-week intervals to evaluate retest reliability. The four functional tests were: 1) a timed 30 m walk in the hospital corridor; 2) three trials of single-leg balance for 30 seconds; 3) three trials of single-leg balance for 30 seconds blindfolded; 4) a concomitant flexion of one arm and the opposite leg alternating between right and left as fast as possible for 15 seconds. The AMTI force platform measured force components in the medial-lateral and anterior-posterior direction. Mean sway amplitude, mean velocity along the sway path, length of sway path, and area within the sway path were measured during four conditions (standing on two feet, standing on two feet blindfolded, standing on one foot, and standing on one foot blindfolded). Each condition
consisted of three 30 second trials. Test-retest reliability of the force platform measures were regarded as acceptable with a correlation coefficient of at least 0.60 for two-legged standing test and 0.65 for one-leg standing test without blindfolding. Excluding the two foot standing test, both age and sex played a role in sway measurements. Men displayed more sway than women and the amount of sway increased as the age of the subject increased. A relationship was found between all the functional balance tests except the coordination test and force platform measures. The authors concluded force platform data to be valid and reliable but gender and age dependant (Ekdahl et al., 1989).

Goldie et al. (1992) developed a reliable testing procedure to assess postural steadiness in a one-legged stance on the forceplate. Twenty-four subjects between 18 and 40 years of age with no history of neurologic injury, neurologic disease, or leg injury participated. The Kistler six-component force-platform system (Kistler Instruments, Winterthur, Switzerland) measured three orthogonal components of ground reaction force and two horizontal plane coordinates of center of pressure. A five second stance time was used with four trials per condition. The four conditions used were: 1) subject standing on their
dominant leg with eyes open; 2) subject standing on the
dominant leg with eyes closed; 3) subject standing on the
non-dominant leg with eyes open; 4) subject standing on the
non-dominant leg with eyes closed. Touchdowns by the
subjects were utilized in the data as long as the touchdown
occurred on the forceplate. Touchdowns occurring off of the
forceplate were discarded and the trial was repeated. The'retest reliability calculations showed the average ground
reaction force correlations to be higher than the average
center of pressure correlations. Two values of center of
pressure (anterior-posterior on the dominant leg and
medial-lateral on the non-dominant leg) during the eyes
closed condition were not statistically significant. All of
the other ground reaction force measurements were
statistically significant (Goldie et al., 1992).

Forceplate data was found to correlate better to an
ankle strategy in maintaining balance than a knee or hip
strategy (Karlsson & Persson, 1997; Tropp & Odenrick,
1988). Karlsson and Persson (1997) investigated the
relationship between forceplate data and body movement
measured through kinematic analysis. Data were collected
simultaneously between a piezoelectric Kistler forceplate
and PAL video camera. The four conditions assessed were: 1)
non-ankle strategy test (subjects moved body in sagittal
plane using hip and knee movements); 2) normal quiet
standing (subjects standing as still as possible with feet
together); 3) quiet standing with eyes closed; 4) ankle
strategy test (subjects moved body in sagittal plane using
ankle strategies). A low correlation was found between
forceplate data and body movement during the non-ankle
strategy tests. A high correlation was found between
forceplate data and body movement during the ankle strategy
test. The authors concluded that the forceplate data is an
effective way to measure ankle strategy during postural
control (Karlsson & Persson, 1997).

Tropp and Odenrick (1988) investigated the role of
ankle strategy in postural control. Fifteen of the subjects
had functional ankle instability assessed by self reported
recurrent sprains and feelings of giving way. Data were
collected with a Kistler 9281A forceplate and an
optoelectronic movement recording system. Infrared light
emitting diodes (LEDs) were placed on: the right ankle 3 cm
above the talocrual axis, the right anterior superior iliac
spine, and the manubrium sterni. Electromyographic data
were collected from the peroneus longus. Three trials of 60
seconds were recorded from a single-limb stance. The
horizontal position of the center of pressure was highly
correlated to the horizontal position of the ankle LED and
peroneus muscle activity. No relationship between center of pressure and horizontal movement of sternum or hip was found. Tropp and Odenrick (1988) suggested that subjects maintained postural equilibrium through ankle corrections because of the relationship between ankle movement and the frequency of center pressure displacement.

While the methods of Ekdahl et al. (1989); Goldie et al. (1992); Karlsson and Persson (1997); and Tropp and Odenrick (1988) were shown to be valid and reliable, they may not be clinically meaningful. Athletes rarely are injured during static stance activities. Rather, injury occurs during dynamic movements. One such method to measure dynamic stabilization is time to stabilization. Time to stabilization is a measurement of the stabilization of the body during a dynamic landing (Brown et al., 2004; Colby et al., 1999; Ross & Guskiewicz, 2003; and Wikstrom et al., 2004). This assessment technique was developed because of the need for a valid and reliable assessment that could be used on functional movements (Colby et al., 1999). Time to stabilization is a forceplate measurement of the amount of time it takes to stabilize after a jump landing (Ross & Guskiewicz, 2003).

Two techniques have been used to assess time to stabilization (Brown et al., 2004; Colby et al., 1999; Ross...
Colby et al. (1999) and Wikstrom et al. (2004) collected vertical, medial-lateral, and anterior-posterior ground reaction forces over a three second trial. The vertical ground reaction force was considered stable when it reached and stayed within five percent of the body weight of the subject. The stabilization time of the medial-lateral and anterior-posterior ground reaction forces were calculated using sequential estimation. This is an algorithm that calculated the cumulative average of data points. The estimation began with the first point of the raw data. The second point was the average of the first two points of raw data, the third point was the average of the first three points. This continued until the last point which was the mean of the raw data. The series was stable when the sequential average reached and remained within one quarter of a standard deviation of the overall series mean (Colby et al., 1999; Wikstrom et al., 2004).

Colby et al. (1999) measured the difference in time to stabilization between subjects with a surgically reconstructed and stable ACL against subjects with an unstable ACL and healthy subjects. Healthy subjects had no previous knee injuries or pathologies. Instability of the ACL was defined as over three mm of laxity compared
bilaterally by a KT-1000 test. The subjects performed two functional tests. The first test was a one legged step down from a 19 cm high box onto a Bertec forceplate (Bertec Corp, Columbus, Ohio). The second test was a one legged hop equal in length to the subjects leg and over a 7.5 cm barrier onto the forceplate. Twelve of the healthy subjects were tested three times during a week long period to test reliability of the time to stabilization measurement. An Intraclass correlation coefficient was calculated and the measures investigated had a correlation coefficient of 0.8 or higher. The ground reaction forces were reliable for both the step down and hop tests. A significant difference was found between healthy subjects and subjects with an ACL reconstruction.

Wikstrom et al. (2004) investigated time to stabilization, ground reaction force, and joint kinematics before and after a fatigue protocol. Twenty healthy subjects performed a jump landing task equal to 50% of their vertical max. The subjects jumped from a point 70 cm away from the center of the Bertec forceplate (Bertec Corp, Columbus, OH) and landed with the non-dominant leg. The jump landings were recorded by the forceplate and two motion analysis cameras (US JVC Corp, Fairfield, NJ). The cameras recorded ankle flexion, knee flexion, and knee
valgus/varus angles. The jump landing was performed before and after one of two fatigue protocols. The subjects reported for testing two times separated by a week recovery period. Each subject performed one of the two fatigue protocols during each session. No significant difference was found for time to stabilization or joint kinematics between conditions.

Brown et al. (2004) and Ross and Guskiewicz (2003) used the anterior-posterior and medial-lateral ground reaction force to measure time to stabilization. They collected 20 seconds of ground reaction force data after the peak ground reaction force. Two sections of data were scanned to find where the subject was at optimal postural stability. This data came from either the 10-15 second or 15-20 second section of the data. The optimal range is taken from the section with the smaller absolute ground reaction force. The smaller absolute ground reaction force reflects the point when the athlete is at optimal stabilization. A third order polynomial trend line was fitted to the 20 seconds of data. The point in time when the trend line crossed the optimal range of stabilization was recorded as the time to stabilization.

Brown et al. (2004) investigated time to stabilization, joint position sense, and electromyography
to assess functional ankle instability. The Biodex System 3 dynamometer (Biodex Medical Inc, Shirley, NY) measured joint position sense during plantar flexion, dorsiflexion, inversion, and eversion. The Bertec forceplate (Bertec Co, Columbus, OH) measured ground reaction forces. The Konigsberg electromyography system (Pasadena, CA) measured electromyography of the tibialis anterior, peroneals, lateral gastrocnemius, and soleus. Subjects performed each trial at 50% of their maximum vertical jump and landed on one leg. The anterior-posterior time to stabilization was significantly longer and the soleus electromyography amplitude was significantly smaller for functionally unstable subjects in comparison to the control group. No other significant difference was found (Brown et al., 2004). The lower soleus amplitude could be explained by an adjustment of the landing technique of the functionally unstable group to rely on the boney articulations of the ankle for stability (Brown et al., 2004).

Baker (2002) investigated the effects of semirigid and cloth lace-up ankle brace application on seven measures of postural stability. Twenty-five subjects performed repeated drop landings from a height of 40.46 cm testing each condition. The seven measures were: 1) medial-lateral center of pressure sway, 2) anterior-posterior center of
pressure sway, 3) sway area, 4) medial-lateral center of pressure stabilization time, 5) anterior-posterior center of pressure stabilization time, 6) standard deviation of medial-lateral center of pressure stabilization time, and 7) standard deviation of anterior-posterior center of pressure stabilization time. A significant difference was found for medial-lateral center of pressure stabilization time and standard deviation of medial-lateral center of pressure stabilization time between control and braced conditions. No other significant difference was found (Baker, 2002). The subjects took longer to stabilize medial-lateral center of pressure during the braced condition and had a faster stabilization time for the standard deviation of medial-lateral center of pressure. This suggested the subjects took longer to stabilize position, but had less variability of stabilization during the braced condition. These results are inconclusive regarding the prophylactic importance of the ankle brace (Baker, 2002).

Summary

Ankle braces have been shown to reduce the incidence of injury but their role in stabilizing the ankle during a dynamic movement is unclear. If ankle braces decrease time to stabilization, a method for measuring stabilization
during a dynamic movement, their involvement in injury prevention might be better understood.
Appendix C

INFORMED CONSENT

AGREEMENT TO PARTICIPATE IN

EFFECT OF PROPHYLACTIC ANKLE BRACE
ON TIME TO STABILIZATION

CHRISTOPHER VIÉSSELMAN
HEALTH, PHYSICAL EDUCATION, AND RECREATION DEPARTMENT
PLYMOUTH STATE UNIVERSITY
17 HIGH STREET, MSC 22
603-535-2771
CPVIÉSSELMAN@PLYMOUTH.EDU

1. Purpose: The purpose of this research is to investigate the effect of ankle braces on balance.

2. Description: The investigator for this project will be Christopher Viesselman a graduate student in the Master’s in Education athletic training program. Participation in the study will entail a single testing session lasting approximately one hour. During this time your max vertical jump height will be assessed. You will then be asked to perform three successful jump landings with and without an ankle brace.

3. Procedures: Your height, weight, and lower leg dominance will be recorded. Lower leg dominance in this study will be defined through testing as the leg you choose to land on during a single leg jump landing. You will be asked to fill out a health questionnaire to insure safe participation in this research project.

Prior to testing, we will measure your maximal jump height. You will be asked to complete three trials of a maximal vertical jump. Each trial will consist of a two legged jump using a natural arm swing. You will be asked to use both hands to reach up and simultaneously hit the highest point possible on a target called a Vertec. The Vertec is simply a device to measure your jump height.

Before testing begins you will become comfortable with the testing procedures. All trials will be performed in athletic shoes you provide. Each trial will consist of a two legged jump and a single leg landing on the dominant limb, and stabilization period after the landing. The test will consist of a total of six successful jump
trials: three trials while wearing a brace and three without. You will receive 30 seconds between trials and a 5 minute recovery period between each condition.

A successful trial will consist of you jumping and grasping a target ball hanging at 70% of your max vertical jump height and landing on your dominant foot on the forceplate. You should try to regain your balance as rapidly as you can and then hold that position until asked to step down.

Invalid trials will be defined as: 1.) failure to remain on the force plate; 2.) touching down with the non-dominant leg; 3.) failure to grasp the target ball; 4.) excessive movement after landing; 5.) adjustment of foot position on the force plate after landing.

4. **Risks:**

   The task is a simple jump and single leg landing. It is unlikely that injury will occur however, there is always a slight risk that injury may occur. A state licensed and nationally certified athletic trainer will be on site throughout the testing process. Should a physical injury occur first-aid will be administered to you if desired. In the event of a medical emergency EMS will be activated by the investigator. Any medical expenses incurred from an injury in relation to participation in research project will be your responsibility. Please contact faculty advisor (Dr. J. Bernier, 535-2235) in the event of research related injury.

5. **Benefits:**

   We know that the use of ankle braces can prevent ankle injury. This study may help us understand better the mechanisms by which injury is reduced. The information collected from the research experiment will add to the scientific knowledge of the mechanisms of ankle braces.

6. **Alternative Procedures:**

   It has been determined that the procedures are those that offer the minimal amount of risk to the subject, while allowing for the collection of significant and relevant data. This investigation is strictly voluntary and you are not required in any way to participate.

7. **Confidentiality:**

   Information obtained during the experiment will be kept confidential. All records will remain in the Plymouth State University Human Performance Lab in a locked filing cabinet. Information collected from subjects will only be used for statistical or scientific purposes without identifying the participant.

8. **Right to Withdrawal:** Participation in this data collection is strictly voluntary and
you may withdraw your participation at anytime without prejudice, penalty or loss of any care or benefits to which you are otherwise entitled.

9. **Costs and Compensation:** There will be no additional costs to you for your participation in this study. In the event you sustain a major injury, emergency medical services will be notified. However, no compensation for medical care, hospitalization, loss of income, pain, suffering or any other form of compensation will be provided as a result of such injury.

11. **Contact Information:** Provide the appropriate contact information for subjects regarding the research or their rights as a research subject. For questions regarding the research the contact person is the principle investigator (in the event of student research, the major advisor should also be listed). The contact information should include: name, department, mail address, telephone, and email address. For questions regarding rights as a research subject indicate that all questions should be directed to the Chair of Plymouth State University, Institutional Review Board, Dr. Brian Healy at bhealy@plymouth.edu.

I CERTIFY THAT I HAVE READ AND FULLY UNDERSTAND THE ABOVE PROJECT. THAT I HAVE BEEN GIVEN SATISFACTORY ANSWERS TO ALL MY QUESTIONS AND THAT I HAVE BEEN ADVISED THAT I AM FREE TO WITHDRAW MY CONSENT AND TO DISCONTINUE PARTICIPATION IN THE PROJECT OR ACTIVITY AT ANY TIME WITHOUT PREJUDICE. I WILLINGLY CONSENT TO PARTICIPATE.

Signature of Subject _______________________________ Date __________

(If you cannot obtain satisfactory answers to your questions or have comments or complaints about your treatment in this study, contact: Institutional Review Board, Plymouth State University, Dr. Brian Healy, bhealy@plymouth.edu).
Appendix D

HEALTH QUESTIONNAIRE

Plymouth State University
Health, Physical Education & Recreation Department
Health Questionnaire

The information on this form will be kept strictly confidential. It will be used for scientific and statistical purposes only and will not be released without your knowledge and consent. Please complete this form to the best of your knowledge.

Demographic information:

Last Name___________________First___________________MI___
Home Address_________________City___________________State___
Birth Date___________________Age____Gender M/F

Emergency Contact Information:

Name_______________________Phone Number_________________
Relationship_________________

Personal Health History

Have you ever had any of the following:

<table>
<thead>
<tr>
<th></th>
<th>yes</th>
<th>no</th>
<th></th>
<th>yes</th>
<th>no</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allergies</td>
<td></td>
<td></td>
<td>Fainting/Dizziness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td></td>
<td></td>
<td>Heart Disease/Murmur</td>
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<tr>
<td>Chest Pain/Heart Attack</td>
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</tbody>
</table>

Injuries to the Following:

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<thead>
<tr>
<th></th>
<th>Back/Spine</th>
<th></th>
<th>Hip/Pelvis</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Concussion/Scull</td>
<td>Back/Spine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>Hip/Pelvis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle/Lower Leg/Foot</td>
<td>Knee/Thigh</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please explain any of the conditions you checked yes. Include date for last episode or injury.
Is there any other medical reason you should not participate in this research experiment?

The undersigned certifies that all answers to the above questionnaire are true to the best of your knowledge.

Signature of Participant

Date
Appendix E

INSTITUTION REVIEW BOARD APPLICATION

Plymouth State University.

Statement Concerning the Use of Human Participants in Research

Name of Principal Investigator: Christopher Viesselman, ATC/L
Faculty Advisor: Dr Julie Bernier, ext 2235, Speare 208

Department: Health Physical Education and Recreation
Email: cpviesselman@plymouth.edu
Address: PO Box 443, Plymouth, NH 03264
Campus Mailing Address: MSC 22
Campus Phone Number: 535-2771

Federal regulations and college policy require that proposals which involve human participants in research must be reviewed by the IRB. Please respond to the following questions and return this form and 10 copies, when complete, to Brian Healey, Chair of the IRB, MSC 31.

1. Title and brief description of project. Include a time line for when you plan to collect data.

Effect of an ankle brace on time to stabilization.

The purpose of this project is to investigate the effect of ankle bracing on time to stabilization in healthy subjects during a single leg jump landing. Subjects will be obtained through use of notice boards in D & M building and PE Center and by informing students of research during lecture classes. Subjects will be excluded from participation if they have a history of any lower extremity injury in the past six months, have ever had an injury requiring the use of crutches, or have ever had a concussion. A health questionnaire will be given to the subjects as a screening tool for history of injury as well as to insure safe participation.

Approximately 25 subjects will be involved in this research study.

Participation in the study will entail approximately one hour.
Procedure:

The subjects' height, weight, and lower leg dominance will be recorded for demographic purposes. Lower leg dominance in this study will be defined through testing as the leg the subject chooses to land on during a single leg jump landing. The subjects will be asked to fill out a health questionnaire to insure safe participation in this research project.

Prior to testing, the subjects will be asked to complete three trials of a maximal vertical jump. Each trial will consist of a two legged jump utilizing a natural arm swing. They will be asked to use both hands to reach up and simultaneously hit the highest point possible on the measuring device.

The test procedure consists of six successful single leg jump landing trials. Each trial will consist of a two legged jump, single leg (dominant limb) landing on a Bertec forceplate, and a 3-second stabilization period after the landing. The subjects will jump up and grasp a target ball hanging at 70% of their maximum vertical jump height. Seventy percent of vertical max was chosen because of a previous study which found subjects had difficulty landing from 90% of maximum vertical. Before testing begins each subject will become comfortable with the testing procedure. Testing will not begin until the subject states they are comfortable with the jump height and single leg landing. All trials will be performed in athletic shoes provided by the subjects. The two conditions examined will be with the dominant ankle braced and unbraced. The subjects will receive thirty seconds of recovery period between trials and a five minute recovery period between each condition.

A successful trial will consist of the subject jumping and grasping a target ball hanging at 70% of their max vertical jump height and landing on their dominant foot on the forceplate. They will be instructed to balance themselves as rapidly as they can and then hold that position until queued to step down.

Invalid trials will be defined as:
1. Failure to remain on the force plate.
2. Touching down with the non-dominant leg.
3. Failure to grasp the target ball.
4. Excessive body movement after landing.
5. Adjustment of foot position on the force plate after landing.

Timeline:
Subject testing will occur during the last two weeks of February through mid March. Data analysis will be complete by the end of March.

2. Indicate how informed consent is to be obtained. Provide a copy of the informed consent documents you will use in your research. If your research involves a survey, also provide a copy of the survey.

Informed consent will be obtained at the beginning of each testing session. The subject will be given time to ask questions after reading the informed consent the subject will be given time to ask questions regarding participation. During this time, the participant will read and sign the informed consent document.

3. How will confidentiality of participant data be assured as it is collected, and, if it is to be retained, over the length of time that it is to be retained.

All subject information will be kept in a locked filing cabinet in the Plymouth State University Human Performance Lab. Each subject will be given a numerical code and any reference to the subject will be to this coded information. The records of the subject will be retained until publication of the project at which time all records linking subjects to the data will be destroyed.

4. List all foreseeable risks which may be encountered by the subjects and the justification for the project in terms of benefits to be realized which might outweigh the risks, and steps taken to reduce any potential risks.

The information collected from the research experiment will add to the scientific knowledge of the mechanisms of prophylactic ankle braces. We know that the use of ankle braces can prevent ankle injury. This study may help us understand the mechanisms by which ankle braces work.
Every precaution will be made to properly instruct the subject to avoid injury. The force plate is surrounded by a wooden platform leveled to the height of the force plate. This is to insure safety of the subject during the landing. The subjects will be allotted practice trials to familiarize themselves with the testing procedure. This acclimatization period will reduce the occurrence of injury. A health questionnaire will be given before participation. This will help to insure the safety of the subject’s ability to perform the jump landing.

For student projects only:

This research has been reviewed and approved by my instructor, who is: Dr. Julie Bernier

Christopher Viesselman, ATC/L
Graduate Assistant Athletic Trainer
Plymouth State University
BIBLIOGRAPHY


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