Regular ankle taping is commonly used to prevent ankle sprains, but the effects of its long-term use are not fully understood. This study examined the effects of ankle taping on balance in athletes who regularly tape their ankles versus those who do not. Fourteen collegiate gymnasts’ ability to balance on one foot was tested, with and without tape, under a variety of conditions, using a force plate. In general, the results support the conclusion that ankle taping is detrimental to balancing ability. The results also support the conclusion that the negative effects of ankle taping on balance increase with long-term, regular use. However, long-term ankle tapers may adjust their balancing technique to account for the negative effects of taping. Gymnasts should continue to tape their ankle because the negative effects were found primarily when vision was removed.

**Key Words:** taping, balance, ankle

Corresponding e-mail address: mcgregos@onid.orst.edu
Effects of Long-term Use of Ankle Taping on Balance

by

Stephanie McGregor

A PROJECT

submitted to

Oregon State University

University Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Bioengineering (Honors Scholar)

Presented May 23, 2013
Commencement June 2013
Honors Baccalaureate of Science in Bioengineering project of Stephanie McGregor presented on May 23, 2013.

APPROVED:

___________________________________________________ _____________________
Michael Pavol, Mentor, representing Biological and Population Health Sciences

___________________________________________________ _____________________
Samuel Johnson, Committee Member, representing Biological and Population Health Sciences

___________________________________________________ _____________________
Skip Rochefort, Committee Member, representing Chemical, Biological and Environmental Engineering

___________________________________________________ _____________________
Anthony Wilcox, Co-Chair, School of Biological and Population Health Sciences

___________________________________________________ _____________________
Toni Doolen, Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College, and will become part of the Scholars Archive collection for Bioengineering. My signature below authorizes release of my project to any reader upon request.

___________________________________________________ _____________________
Stephanie McGregor, Author
ACKNOWLEDGEMENTS

First of all, thank you to my mentor, Mike Pavol, for instruction and patience in completing my honors thesis. Through your guidance I have learned a lot about the research process and biomechanics.

Thanks to committee members Sam Johnson for your excellent taping skills and valuable feedback and Skip Rochefort for your continued passion for teaching.

To my teammates, coaches, and all those who support the OSU gymnastics team, thank you for making my past five years at OSU so memorable.

Finally, I am very appreciative of funding received for this project through the HHMI Summer Undergraduate Research Program and the URISC program.
TABLE OF CONTENTS

INTRODUCTION .................................................................................................................. 1
  Purpose and Hypotheses ................................................................................................. 9
MATERIALS AND METHODS................................................................................................. 11
  Participants ..................................................................................................................... 11
  Experimental protocol .................................................................................................. 11
  Data analysis ................................................................................................................ 13
RESULTS ............................................................................................................................ 15
DISCUSSION ....................................................................................................................... 21
  Limitations ..................................................................................................................... 28
  Further Studies .............................................................................................................. 29
  Conclusion ...................................................................................................................... 30
BIBLIOGRAPHY ............................................................................................................... 32
APPENDICES .................................................................................................................... 37
  Appendix A .................................................................................................................... 38
  Appendix B .................................................................................................................... 42
  Appendix C .................................................................................................................... 43
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Effects of ankle taping, as a function of group or surface and direction, on the standard deviation (SD) of center of pressure (COP) position while balancing with eyes closed.</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Effects of ankle taping, as a function of group or surface and direction, on the standard deviation (SD) of center of pressure (COP) position while balancing with eyes closed.</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>Effects of ankle taping, as a function of group or surface and direction, on the standard deviation (SD) of the center of mass (COM) position while balancing with eyes closed.</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>Effects of ankle taping, as a function of vision, on the short-term diffusion coefficient of the stabilogram diffusion function (SDF) while balancing.</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>Effects of group, as a function of surface, on the short-term diffusion coefficient of the stabilogram diffusion function (SDF) while balancing with eyes closed.</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>Effects of ankle taping, as a function of surface, on the critical mean square displacement of the stabilogram diffusion function while balancing with eyes closed.</td>
<td>20</td>
</tr>
</tbody>
</table>
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Informed Consent Form</td>
<td>38</td>
</tr>
<tr>
<td>B. Balance data</td>
<td>42</td>
</tr>
<tr>
<td>C. University Honors College Copyright Release Form</td>
<td>43</td>
</tr>
</tbody>
</table>
DEDICATION

To my parents. Thank you for always supporting and believing in me.
Ankle ligament sprains are the most common injury in collegiate athletes (Hootman et al. 2007). According to the National Collegiate Athletic Association (NCAA) Injury Surveillance System, they represent 15% of all reported injuries and are a problem amongst all levels of collegiate athletes (Hootman et al. 2007). In addition, the rate of ankle ligament sprains has remained constant over 16 years from 1988 – 2004 (Kerkhoffs et al. 2007), despite advances in the field of sports medicine (Kerkhoffs et al. 2007). Many studies have thus been done, examining various aspects of ankle sprains, including mechanisms of injury (Kristianslund et al. 2007), treatment (Kemler et al. 2011), effects on functional performance (Wikstrom et al. 2010), and prevention methods (McKeon & Mattacola 2008). This thesis will address the interaction between ankle sprain prevention and functional performance by focusing on the effects of long-term use of ankle taping on balance.

Balance is a functional motor skill that is of particular importance to athletes. Balance, or postural control, can be defined as the ability to maintain the body’s center of mass (COM) above a base of support with minimal movement or maximal steadiness. It is influenced by a variety of sensory information, including signals from the somatosensory, visual, and vestibular systems (Horak 1987). The central nervous system receives and integrates this sensory information and sends motor commands to the muscles. Static balance is characterized by spontaneous postural sway. The body’s sway
has been described as having a slow and a fast component (rambling and trembling) (Zatsiorsky & Duarte, 2000), similar to a throw-and-catch behavior (Loram & Lakie, 2002) or delayed feedback control (Peterka 2000). Static balance can be affected by many factors within the individual and the environment. Removal of vision by closing one’s eyes places greater demand on somatosensory and vestibular information to maintain postural stability (Ray et al. 2009). The surface also plays a role. Foam provides a compliant surface that requires participants to maintain a static stance while standing on an unstable surface (DiStefano et al. 2009). Both the removal of vision and standing on a compliant surface have been shown to impair balance (Muehlbauer et al. 2012). Clearly the maintenance of balance is a complex system, but methods have been developed to measure balance ability.

The ‘gold standard’ for measuring static balance is considered to be the use of postural sway variables from a force plate (Reimann et al. 1999). One such postural sway variable that is often examined is the movement of the center of pressure (COP). The COP is the application point of the resultant of the ground reaction forces exerted by the foot on the force plate (Le Clair & Riach 1996). Motion of the COP reflects adjustments to the torques being used to control postural sway. Greater and/or faster motion of the COP is taken to indicate poorer postural control (Guskiewicz & Perrin 1996). Force plate data can be used to calculate the center of pressure in the anteroposterior (AP) and mediolateral (ML) directions. The motion of the COP does not, however, correspond directly to the movement of the center of mass (COM) of the individual. The motion of the COM can be estimated using an algorithm based on the ground reaction force data.
(Zatsiorsky & King 1997). The motion of the COM is a better indication of an individual’s ability to maintain balance whereas the motion of the COP better reflects their balancing technique. The relationship between the mean square displacement of the COP over different time intervals, known as the stabilogram diffusion function (SDF), also provides valuable information. The SDF provides information about the diffusion rate of the COP over short and long time intervals, hypothesized to reflect open-loop and closed-loop control strategies, respectively, and the critical transition point between these behaviors (Collins & De Luca 1993). Analyses of the COP, COM and SDF allow balance ability and strategy to be determined and improvements or impairments detected.

Ankle sprains are known to decrease proprioception in the joint and compromise balancing ability, potentially putting athletes at greater risk for re-injury. Forkin et al. (1996) demonstrated this in their examination of kinesthetic deficits in gymnasts. It was found that collegiate-level gymnasts with unilateral, multiple ankle sprains had decreased ankle proprioception and poorer balance during 1–legged stance conditions for the injured compared to uninjured ankle. Fu and Hui-Chan (2005) confirmed this relationship between ankle injury, proprioception, and balance in their findings that ankle repositioning errors and postural sway were greater in basketball players who had suffered multiple ankle sprains compared to those who had no recent history of ankle injury. These findings suggest that enhancing proprioception might improve balance and reduce the risk of re-injury in athletes who have suffered an ankle sprain. Ankle taping may be one means of doing this.
Currently, ankle taping is widely used following an ankle sprain, to allow athletes to return to their sport sooner. Many athletes also continue to use taping long after injury as the primary preventive measure against further sprains (Thacker et al. 1999). Studies have shown taping to reduce the rate of ankle sprains by as much as 50% (Thacker et al. 1999). Garrick and Requa (1973) examined the ankle sprain occurrence in 2,562 college intramural basketball players and found that the group that taped their ankles experienced substantially fewer sprains than the control. A literature review performed by Verhagen et al. (2000) similarly found that the use of tape reduces the incidence, as well as the severity, of ankle sprains. It was further confirmed that external ankle support resulted in a significant reduction in the number of ankle sprains in a recent review of published evidence accumulated from 12,233 participants (Kaplan 2011). It can be seen that the use of ankle tape to prevent ankle sprains is an accepted and helpful practice.

Although the technique of taping has been utilized and promoted for over a century (Gibney 1895), the exact mechanism by which it helps athletes remains unclear (Wilkerson 2002). It is believed that ankle taping provides external mechanical support to lessen excessive motion. By reducing the range of motion and thus limiting abnormal movements, the risk of stretching ankle ligaments is decreased (Firer 1990). However, studies have shown that tape loosens considerably with exercise, significantly lessening these mechanical effects. According to a study completed by Paris et al. (1995), tape provides only minimal range restriction after exercise because plantarflexion range of motion increased significantly after only 15 minutes of treadmill walking. It may be that the benefits of ankle taping are less mechanical and more psychological in nature. In
addition to providing some mechanical support, ankle taping boosts perceptions of confidence, stability, and reassurance (Delahunt et al. 2010). It also decreases anxiety regarding risk of re-injury (Hunt & Short 2006) and therefore plays a psychological role in the success of athletes.

Beyond these effects, it is accepted that taping enhances proprioceptive function of the ankle. The ability to sense the position of one’s ankle joint is important in ensuring the proper positioning of the ankle just prior to ground contact. In one study, strips of athletic tape applied to the ankle joint improved joint position perception in a non-weight-bearing position, which the authors attributed to increased cutaneous sensory feedback (Simoneau et al. 1997). Heit et al. (1996) also found that the application of ankle taping improved joint position sense in the stable ankle. They had participants actively reproduce a passively positioned joint angle, and based on their results, they suggested that the tape provided stimulation of the surrounding ankle tissue so that ankle joint mechanoreceptors were stimulated. Lohrer et al. (1999) calculated a significant increase, with taping, in the proprioceptive amplification ratio at the ankle in individuals with stable ankles. This ratio compares neuromuscular response activity with the mechanical displacement and is normalized to the un-taped condition, with larger values suggesting better proprioception. Further data collected by Robbins et al. (1995) of healthy, young, blindfolded volunteers found ankle taping improves proprioception, as measured by foot position awareness, both before and after exercise. These studies all agree that the use of ankle taping increases an individual’s proprioception at the ankle joint. It may therefore be that ankle taping reduces the incidence or severity of injury by
enhancing proprioception which, in turn, improves balance. This is logical because proprioception is a major component of an individual’s postural control system. It is also consistent with the suggestion that ankle taping is most effective at preventing ankle sprains in previously injured athletes (Verhagen & Bay 2010), in whom deficits in both proprioception and balancing ability have been found, as mentioned earlier (Forkin et al. 1996; Fu & Hui-Chan 2005).

Although the benefits of taping on ankle proprioception have been documented, the effect of taping on balance is equivocal (Hume & Gerrard 1998). A comprehensive literature review completed by Cordova et al. (2002) concluded that the effect of external ankle support on postural control remains unclear. Some studies have shown that taping has no effect on balance while others have demonstrated a decrease in balancing ability with the application of ankle tape. In these studies, various methods were used to quantify balance and the type of ankle examined (healthy versus chronically unstable) also varied.

Among the studies that found no effect of taping on balancing ability was that by Broglio et al. (2009), in which the NeuroCom sensory organization test was used to quantify balance of healthy participants with and without ankle tape under different sensory conditions. Hamer et al. (1992) hypothesized that applying tape to the skin would improve proprioception, allowing for better motor control and thus improving wobble board performance of participants with no history of ankle injuries. The wobble board is an accepted clinical assessment of ankle proprioception and method of balance training. Their results did not support the hypothesis because there was no difference in wobble
board performance with the use of tape compared to no tape. It is possible that the cutaneous receptors adapted to the pressure of the tape so that they were no longer causing an increase in proprioception. Tropp et al. (1984) examined factors affecting stabilometry recordings of single-limb stance for participants with functional ankle instability and found that taping had no effect on postural control. Based on these results, they suggested that the prophylactic effect of ankle taping is not due to an improvement in balance but rather a result of the mechanical restriction of neutral inversion and plantar inversion. Finally, Hopper et al. (2009) found that, in individuals with unilateral chronic ankle instability, Mulligan ankle taping did not impact neuromuscular control during static balance, based on the area of sway of the center of pressure. However, the Mulligan ankle taping technique is not widely utilized amongst collegiate athletes, making these results of limited relevance.

In contrast to these studies that found no effect of ankle taping on balance, the results of Bennell and Goldie (1994) suggested that use of tape adversely effected balance. Participants without ankle instability performing a single-leg balance task with tape showed greater deviations in mediolateral force and their other foot touched the ground more often than when they were un-taped. However, an examination of the methods used in this experiment leads to questions regarding the validity of their results because the force plate trials lasted only five seconds but at least twenty seconds of data collection is necessary for reliable measurements (Le Clair & Riach 1996). Thus, the support for an adverse effect of ankle taping on balance is weaker than that suggesting
ankle taping has no effect. Surprisingly, no study has found balancing ability to be enhanced with ankle taping.

External ankle support methods are thought to work in a similar manner to taping and, therefore, it is relevant to consider studies that have looked at the use of ankle bracing. Kinzey et al. (1997) argued that bracing did not interfere with the integration of sensory data for postural control. They utilized a force plate to quantify the movement of the center of pressure of 24 basketball players and the application of various braces did not significantly change these measures. Feuerbach and Grabiner (1993) analyzed center of pressure data in 15 men with no history of chronic ankle injury and found a decrease in lateral sway with brace application, suggesting that external support did indeed improve postural control by providing important cutaneous feedback. These last results conflict with other studies, contributing to the lack of consensus regarding the effects of ankle taping or bracing on balance.

Previous studies, as outlined above, have all focused on the short-term effects of ankle taping. It has not yet been examined whether those who tape their ankles on a regular basis respond differently to ankle taping when compared to those who do not tape their ankles. It has been shown that the central nervous system adapts and/or habituates to altered sensory input over time (Peterka & Louglin 2004; Honda et al. 2012). Therefore, it is possible that the effects of ankle taping on balance change with long-term use. Furthermore, there is an overall lack of consistency in the methods and results of studies that have been completed regarding taping and balance, and therefore this matter needs to
be further investigated. In particular, nobody has looked at the effects of long-term use of ankle taping on balance in gymnasts. Gymnasts may be a unique population, as they have been shown to have superior joint-position sense in the ankles when compared to non-gymnasts (Aydin et al. 2002). Therefore, they may be better able to use the proprioceptive data that tape provides to control their balance.

Purpose and Hypotheses

Ankle ligament sprains are the most common injury in collegiate athletes (Hootman et al. 2007) and athletes often use ankle taping during rehabilitation following a sprain. Many athletes also continue to tape their ankles as a preventative measure. Taping has been shown to enhance ankle proprioception (Robbins et al. 1995) which, in theory, should improve balance, thereby potentially aiding in injury prevention. Yet most studies have found ankle taping to either have no effect on or to worsen balance (Cordova et al. 2002). A factor that has not been studied, however, is whether the effects of ankle taping on balance change with regular, long-term use.

This study compared the effects of ankle taping on balance between gymnasts who regularly tape their ankles and those who do not tape their ankles. As part of this investigation, different vision and surface conditions were utilized to provide different levels of challenge to the postural control system. The central hypothesis was that, overall, ankle taping would help balance. It was hypothesized that the beneficial effects of tape on balance would be most evident under the eyes-closed-on-foam condition because of the reduced sensory input and increased task difficulty. It was predicted that
tape would improve balance more when the eyes were closed compared to open by forcing participants to rely on proprioception rather than vision. It was also predicted that tape would improve balance more on foam compared to ground because the increased task difficulty would make participants utilize the proprioception benefits of taping. Furthermore, it was hypothesized that taping would be more beneficial to non-tapers than tapers because, with long-term use of taping, the body may become acclimatized to the associated changes in sensory input and ankle stiffness such that the positive effects of taping are less noticeable in the tapers.
MATERIALS AND METHODS

Participants

Fourteen healthy collegiate-level female gymnasts participated in this study. They were deemed eligible to participate in the study only if they had practiced gymnastics in the past 18 months, had not sprained an ankle in the six weeks preceding testing, and did not have an injury or condition that would make it difficult or painful to balance on one foot. Six participants had always taped the same ankle or both ankles (“tapers” group) and eight had never taped either ankle (“non-tapers” group) for gymnastics over the preceding three months. Participant characteristics are presented in Table 1. This study was approved by the Institutional Review Board of Oregon State University and all participants gave their written informed consent prior to participation.

Table 1
Characteristics of the non-taper and taper groups

<table>
<thead>
<tr>
<th></th>
<th>Non-tapers (n = 8)</th>
<th>Tapers (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.5 ± 1.6</td>
<td>19.3 ± 1.2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.6 ± 5.0</td>
<td>158.4 ± 7.7</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>60.8 ± 5.7</td>
<td>54.3 ± 4.8</td>
</tr>
<tr>
<td>Foot length (cm)</td>
<td>23.5 ± 1.1</td>
<td>22.2 ± 0.5</td>
</tr>
<tr>
<td>Forefoot width (cm)</td>
<td>9.0 ± 0.5</td>
<td>8.9 ± 0.4</td>
</tr>
</tbody>
</table>

Values are means ± standard deviation.

Experimental protocol

The participants’ ability to balance on one foot was measured using a force plate (Bertec, Columbus, OH). Participants who taped only one ankle were tested on that foot.
Non-tapers, as well as tapers who taped both ankles, were tested on the foot with the more “normal” ankle, as determined based on self-reported feelings of instability or giving way or a history of reconstructive surgery. If both ankles were similar with regards to these criteria, the foot tested was selected randomly.

Each participant was tested barefooted, with and without ankle taping, under each of four conditions: with eyes open and eyes closed, both with and without a 5 cm-thick block of foam (MuscleDriver USA, Fort Mill, SC) between the foot and force plate. Participants practiced the balancing conditions without tape for 10-30 seconds each prior to the start of data collection. It was determined randomly whether the participant was first tested with or without ankle taping. A Certified Athletic Trainer performed the taping using methods typical to gymnasts. Once taped, participants walked for 5 minutes before testing. A 5-minute period of walking also preceded the testing without ankle taping.

During the testing, participants performed three trials for each condition. They were to try to remain still, with the other foot raised slightly by flexing the hip and knee, legs apart, and hands on the hips, as best they could. As participants balanced, ground reaction force data were collected at 100 Hz with an amplification ratio of 5.0 using a custom LabView program (National Instruments, Austin, TX). A trial continued until the participant touched the other foot to the ground, her eyes opened when supposed to be closed, or 30 s elapsed, whichever occurred first. Trials of less than 15 s were repeated. The order in which the conditions were tested was counterbalanced between participants.
and was the same for the trials with and without ankle taping. Rest was provided between trials.

Data analysis

Ground reaction force data were low-pass filtered using a fourth-order, zero-lag Butterworth filter with a cutoff frequency of 12 Hz. The position of the center of pressure (COP) beneath the foot over the course of each trial was computed from the filtered ground reaction force data. The position of the body center of mass (COM) was also estimated from the filtered force data using the algorithm proposed by Zatsiorsky and King (1997). Finally, the planar stabilogram diffusion function (SDF) was calculated for each trial following the methodology of Collins and De Luca (1993). For trials that lasted less than 30 s, the data from the 2 s before ground contact by the other foot were excluded from the analyses. All calculations were performed using MATLAB (MathWorks, Natick, MA).

Balance measures analyzed were the extent of COP motion as quantified by the standard deviation of COP position, the mean speed of the COP, and the extent of COM motion as quantified by the standard deviation of the COM position. Each of these balance measures was analyzed separately in the anteroposterior (AP) and mediolateral (ML) directions. Values were averaged across the three like trials. Also analyzed were the short-term and long-term diffusion coefficients and the critical time interval and mean square displacement from the ensemble-averaged SDF of the trials for each condition, excluding apparent outlier trials.
Mixed four-factor analyses of variance (ANOVA) were performed on each balance measure to assess the effects of ankle taping (taped vs. no tape) as a function of group (taper vs. non-taper), vision (eyes-open vs. eyes-closed), and surface (solid ground vs. foam). Post-hoc testing was performed using ANOVA, t-tests, or paired t-tests, as appropriate. Effects were considered significant at \( p < .05 \) in the ANOVA and at \( p < .025 \) in the post hoc testing. SPSS version 19 (IBM, Armonk, NY) was used for all statistical analyses.
RESULTS

For all four center of pressure measures investigated, the effects of ankle taping differed between eyes-open and eyes-closed conditions (p < .05 for a taping x vision interaction effect; Appendix B). When the eyes were open, ankle taping had no effect on the extent or speed of COP motion (p > .025). However, ankle taping had a generally negative effect on balancing with the eyes closed. Under eyes-closed conditions, taping was associated with greater COP AP motion, regardless of surface, and greater COP ML motion when on solid ground (Figure 1). These effects of taping did not differ between tapers and non-tapers. The extent of COP motion in the two groups differed only in that

![Figure 1](https://example.com/figure1.png)

**Figure 1**: Effects of ankle taping, as a function of group or surface and direction, on the standard deviation (SD) of center of pressure (COP) position while balancing with eyes closed. AP and ML data have been averaged across surfaces and pooled across groups, respectively. Vertical bars in Figures 1-6 represent the standard deviation about the mean value. * = p < .025 for effect of taping; † = p < .05 for main effect of group.
tapers exhibited lesser COP AP motion than non-tapers, regardless of taping, vision, or surface (Figure 1).

In contrast, effects of ankle taping on the mean speed of COP motion differed between groups (p < 0.025 for the interaction effect with eyes closed). Under eyes-closed conditions, tapers exhibited faster COP AP motion and non-tapers exhibited slower COP ML motion with the ankle taped versus without tape, regardless of surface (Figure 2).

**Figure 2:** Effects of ankle taping, as a function of group and direction, on the mean speed of the center of pressure (COP) while balancing with eyes closed. Data have been averaged across surfaces. * = p < .025 for effect of taping.

The results for the center of mass measures investigated were consistent with the COP results. Again, when the eyes were open, ankle taping had no effect on the extent of COM motion (p > .025). However, a negative effect of ankle taping on balancing was
observed when the eyes were closed. When taped, the standard deviation of the COM AP motion was greater than without tape, regardless of surface (Figure 3). Also, the standard deviation of the COM ML motion was greater with than without tape when on solid ground but not when on foam (Figure 3). The effects of ankle taping on COM motion did not differ between tapers and non-tapers.

Figure 3: Effects of ankle taping, as a function of group or surface and direction, on the standard deviation (SD) of the center of mass (COM) position while balancing with eyes closed. AP and ML data have been averaged across surfaces and pooled across groups, respectively. * = p < .025 for effect of taping.

The investigation of the stabilogram diffusion function measures further confirmed the negative effect of ankle taping. The short-term diffusion coefficient was greater when taped than without tape for both eyes-open and -closed conditions, regardless of surface (Figure 4). The difference was larger under the eyes-closed
condition (p < .025 for the interaction effect). A difference in short-term diffusion coefficient between the taper and non-taper groups was only observed under the eyes-closed-on-foam condition, where non-tapers exhibited a greater short-term diffusion coefficient than tapers (Figure 5).

Figure 4: Effects of ankle taping, as a function of vision, on the short-term diffusion coefficient of the stabilogram diffusion function (SDF) while balancing. Data have been averaged across surfaces and pooled across groups. * = p < .025 for effect of tape.
**Figure 5:** Effects of group, as a function of surface, on the short-term diffusion coefficient of the stabilogram diffusion function (SDF) while balancing with eyes closed. Data have been averaged across taping conditions. * = p < .025 for effect of group.

In general, the critical mean square displacement results corresponded to those for the short-term diffusion coefficient. The critical mean square displacement was greater when taped than without tape on both ground and foam when eyes were closed (Figure 6). Unlike for the short-term diffusion coefficient, for the critical mean square displacement, no differences between the taper and non-taper groups were observed. Both the critical time interval and the long-term diffusion coefficient were not affected by taping and did not differ between groups.
Figure 6: Effects of ankle taping, as a function of surface, on the critical mean square displacement of the stabilogram diffusion function while balancing with eyes closed. Data have been pooled across groups. * = p < .025 for effect of tape.
DISCUSSION

Ankle taping is a widely used preventative treatment for ankle sprains. Previous studies have found that ankle sprains are associated with deficits in proprioception and balance (Fu & Hui-Chan 2005) and that ankle proprioception is improved with the application of tape (Simoneau et al. 1997; Heit et al. 1996), suggesting that ankle taping might improve balance. This is meaningful in that balance is of great importance to athletes. However, studies of the effects of taping on balance have shown mixed results (Hume & Gerrard 1998; Cordova et al. 2002). Furthermore, the effect of the long-term use of taping had not been investigated. Therefore, force plate data were collected to determine effects of ankle taping on the balance of gymnasts who regularly tape their ankles versus those who do not tape their ankles. Originally, it was hypothesized that taping would help balance by enhancing proprioception, particularly in the absence of visual input and/or under more challenging conditions. It was also predicted that the long-term use of tape would result in less improvements to balance because the body becomes acclimatized to the proprioception benefits. However, the results showed that ankle taping had largely negative effects on balance, these occurred almost entirely under eyes-closed conditions, and the long-term use of taping may have allowed tapers to adjust their balancing technique to account for the negative effects. The results can be explained by the interacting effects of the restrictive nature of the tape on ankle motion, resulting alterations in proprioceptive input, the extent of reliance on proprioceptive input, and long-term adaptations to balance control.
Few effects of taping on balance were found with eyes open. In the eyes-open condition, ankle taping had no effect on the extent or speed of COP motion or on the extent of COM motion, regardless of surface or group (non-taper versus taper). The only effect of taping observed in the eyes-open condition was a larger short-term diffusion coefficient of the SDF. The larger short-term diffusion coefficient suggests that taping causes participants to shift their COP more rapidly when making balance corrections. The difference was small and likely of little practical significance, however. Previous studies regarding the effects of taping on balance with eyes open have found mixed results, including hurting balance (Bennell & Goldie 1994) and having no effect on balance (Broglio et al. 2009; Hamer et al. 1992). The present results are consistent with the latter studies. The near-absence of any effects with eyes open suggests that the sensory input coming from the eyes is able to offset any adverse sensorimotor influences of ankle taping. In all, these results suggest that, when sensory input from vision is available to the postural control system, ankle taping has a negligible effect on balance.

However, in the absence of sensory input from vision, several important effects of ankle taping were observed. It was expected that taping would improve balance more when eyes were closed than when open. Previous studies have shown that the amount of postural sway increases when vision is restricted (Edwards 1946; Witkin & Wapner 1950). It was hypothesized that, with the elimination of vision, participants would rely more on the proprioception benefits of taping and thus would not exhibit as large a decrement in balance with eyes closed as occurs without taping. The results from the eyes-closed condition contrast with this hypothesis. Qualitatively, more sway was
observed with eyes closed than with eyes open, as expected. However, balance was negatively affected overall by ankle taping when eyes were closed. Regardless of surface or group, the extent of both COP and COM motion in the AP direction increased with the application of tape under the eyes-closed condition, indicating that balance worsened with taping. Consistent with this, there was an increase in the critical mean square displacement of the SDF with the application of tape under eyes-closed conditions, suggesting that taping caused participants to sway more before correcting their balance when the eyes were closed. Taping also resulted in a larger increase in the short-term diffusion coefficient of the SDF under eyes-closed than eyes-open conditions. This would imply that, when the eyes were closed, taping caused a greater increase in how rapidly participants shifted their COP when making balance corrections. All of these results, as well as others that were dependent on surface or group, indicate that taping had a negative effect on balance when sensory input from vision was absent. The application of tape did not compensate for the elimination of vision. That negative effects of taping were observed mainly with the eyes closed suggests that participants had difficulty integrating into their control of balance changes in somatosensory input that resulted from the presence of taping. This problem may have been compounded by the restrictive nature of the tape on ankle motion, resulting in changes in sensory input such that the body is swaying further than it feels like it is. Other studies have found similar results where taping did not help balance, such as the study by Bennell and Goldie (1994) in which ankle taping increased ground reaction force variability during single-leg balancing with the eyes closed. It thus appears that the removal of vision is a critical factor in determining whether ankle taping has a negative effect on balance.
Balance was tested on two surfaces to determine if the effects of ankle taping depended on the extent to which the postural control system is challenged. It was expected that the benefits of taping on balance would be more evident on foam. Balancing on foam is more difficult than on solid ground (DiStefano et al. 2009) and tape enhances proprioception (Simoneau et al. 1997). It was hypothesized that the increased task difficulty of balancing on foam would cause participants to utilize the beneficial effects of taping on proprioception more, resulting in greater improvements in balance with taping on foam than on ground. The hypothesis was again proven to be incorrect; the results showed ankle taping was no more beneficial to balance when on foam than when on solid ground. In most cases, the effects of ankle taping on balance did not differ between surfaces. As was noted earlier, taping had adverse effects on selected SDF parameters and participants had more difficulty controlling AP sway with eyes closed when taped, regardless of surface. However, the effects of ankle taping on sway in the ML direction when the eyes were closed differed between solid ground and foam. More specifically, increases in the extents of COP and COM motion in the ML direction with taping were found on ground but not on foam. As such, ankle taping had a detrimental effect on ML balance on ground but not on foam under eyes-closed conditions. Again, the reductions in balance ability when on the ground may be explained by the restrictive nature of tape limiting the ability to sense and correct balance. In contrast, the lack of an effect of taping on ML balance while on the foam with eyes closed may be explained by the difficulty participants experienced in balancing under these conditions. It is possible that their balance was already so challenged with eyes closed on the foam that the addition of ankle taping had no further detrimental effect. Ankle movements primarily
control AP balance while movements at the hip joint play a large role in ML balance (Winter et al. 1996; Hof 2007). Hence, restrictions in ankle mobility due to taping might impair the control of balance to lesser extent in the ML direction than in the AP direction when on foam. This may explain why the effect of ankle taping on sway in the ML direction varied as a function of surface whereas the effect on AP sway did not. In all, contrary to the hypothesis, the increase in task difficulty by altering the surface condition had no effect on the effects of ankle taping on balance, except for ML sway with eyes closed, where taping had a negative effect on ground only.

Participants were categorized as tapers or non-tapers based on their taping history in order to determine if there was a difference in the effects of taping on the balance of those who regularly use ankle taping for gymnastics versus those who do gymnastics without tape. It has been shown that the central nervous system (CNS) adapts and/or habituates to altered sensory input over time (Peterka & Loughlin 2004; Honda et al. 2012), including the ability to recalibrate proprioceptive information if it does not match visual input (Henriques & Cressman 2012). Hence, a better understanding of how the body adapts to the long-term use of tape, and its associated changes in proprioceptive information, may help explain how and why taping is beneficial to athletes. It was hypothesized that non-tapers would benefit more from tape than the tapers because they have not habituated to the proprioception benefits of tape. The tapers and non-tapers did respond differently to the application of tape, as expected, but the responses were not completely consistent with the hypothesis. When balancing with eyes closed, the speed of the COP ML motion decreased with taping in the non-tapers but not in the tapers, while
the speed of the COP AP motion increased with taping in the tapers but not in the non-tapers. The result for ML motion, indicative of improved balance in the non-tapers, is consistent with the hypothesis, whereas the result for AP motion, indicative of worsened balance in the tapers, refutes the hypothesis. The differing behaviors in the tapers and non-tapers with regards to the changes in COP AP and ML speed with taping may be explained by the ability of the CNS to adapt to changes in sensory input, such that different sensory integration process are used between groups.

Several variables differed between tapers and non-tapers, independent of whether or not the ankle was taped. Tapers had a smaller short-term diffusion coefficient than non-tapers when balancing on foam with eyes closed. The smaller diffusion coefficient of the tapers indicates that they moved their COP more gradually when making balance adjustments when compared to the non-tapers, suggestive of more finely regulated balance corrections in tapers than non-tapers when faced with the most challenging conditions. The extent of COP AP motion was also less in tapers than non-tapers, regardless of taping, surface, or vision. The reduced COP motion may be related to differences in balance strategy. Interestingly, the extent and speed of COP AP motion in the tapers when taped appeared to have been similar to those of non-tapers without taping. It may thus be that the tapers had somewhat adapted their control of balance over time in such a way as to compensate for the negative effects of the ankle taping. Previous studies have shown adaptations in the control of balance over time to account for changes in sensory input (Vuillerme et al. 2005; Benjuya et al. 2004). Perhaps the long-term use
of tape allows the central nervous system to better adjust in order to overcome balance limitations presented by taping.

These results are important to consider in the context of gymnastics. Visual input is a key component in the body awareness needed for gymnastics, and therefore the sport is performed with the eyes open. In contrast, with one trivial exception, the negative effects of ankle taping on balance were found only under eyes-closed conditions. Therefore, it can be concluded that taping is not detrimental to a gymnast’s balancing ability under conditions typically experienced within the sport. Furthermore, the results show that the long-term use of ankle taping by gymnasts is not a concern with regards to balance because the extent of COP AP motion was less in tapers than non-tapers, regardless of taping, surface, or vision. This is consistent with the widespread long-term use of ankle taping in the sport. Ankle taping has been documented to reduce the risk of injury, especially in athletes with a previous history of ankle injuries (Garrick & Requa 1973; Verhagen & Bay 2010). However, based on the present results, the reduced risk of injury does not appear to be due to improved balance. The reduction of ankle injury as a result of taping may be due to psychological effects, as prior studies found that ankle taping increased athletes’ perceptions of confidence, stability, and reassurance (Delahunt et al. 2010; Hunt & Short 2006). Based on the present study, gymnasts who have experienced ankle injuries should continue to tape their ankles in both the short and long term because the small possibility of a negative effect on balance is outweighed by the reduction in injury rate that has been documented in prior studies by other authors.
(Garrick & Requa 1973; Olmsted et al. 2004). However, the use of tape may have other potentially negative effects on the body that were not investigated in this study.

Limitations

The major limitation to the study was that the taper and non-taper groups were not randomly assigned and could be different in some fundamental way beyond their use of ankle taping. Some of the participants in the taper group had undergone ankle reconstruction surgery (2 out of 6) while none of the non-tapers had (0 of 8). Also, more of the tapers reported feeling that their ankle was unstable (4 of 6 tapers compared to 1 of 8 non-tapers) and that it tended to give way (4 of 6 tapers compared to 2 of 8 non-tapers). It may be that the balancing ability and technique of the participants with reconstructed or unstable ankles differs from those who have not had surgery or feelings of instability. Forcing gymnasts who reported non-surgically reconstructed and stable ankles to tape for 3 months and re-testing them could confirm that the differences found were a result of taping and not ankle injury history. However, this is not a realistic expectation of participants. For the purpose of this study, it was assumed that the difference in ankle injury history amongst participants was not a factor because the prevalence of ankle injuries in the sport of gymnastics is very high (Kirialanis et al. 2002). The study was further limited by the size of the sample. Only 14 participants are a part of these results because it was difficult to find additional participants who met the requirement of being a collegiate-level female gymnast. The reliability of the results would increase if more gymnasts were included in the experiment. The study has since been expanded to a total of 17 gymnasts (9 tapers and 8 non-tapers) and the data are presently being analyzed. If
these same results are found in the larger participant sample, it would be worthwhile to further investigate the topic.

Delimitations of this study included the type of athlete and type of balance studied. Presently, sport-related differences were eliminated as a possible confounding factor in the results by limiting the study to gymnasts. The results of this study may therefore apply only to gymnasts and the effects of ankle taping may be different in other sports. Balance plays a large role in the sport of gymnastics and great demands are placed on these athletes’ postural control systems. It has been speculated that the long-term conditioning gymnasts undergo stimulates their cutaneous nerve receptors or mechanoreceptors to result in an enhanced sense of joint position (Aydin et al. 2002). It is unknown how athletes whose sports place less emphasis on balance would respond to ankle taping. The study was also restricted to static balance to keep the scope of the study reasonable for an undergraduate thesis. Static balance is a component of gymnastics (e.g. remaining stationary on the beam) but the majority of the skills involve dynamic balance. Therefore the results of the study would be more valuable if they also included measures of dynamic balance.

Further Studies

The results of this study show that there are no balance benefits from taping; however, it is proven that taping reduces ankle injury rate in individuals who have a history of ankle injury (Garrick & Requa 1973; Olmsted et al. 2004). Further studies could expand the understanding of how taping is beneficial by interviewing athletes about
their perceptions surrounding ankle taping to better understand the psychological effects. In addition, the present study could be built upon by increasing the sample size and including additional experiments to test dynamic balance. Dynamic balance plays a very important role in gymnastics and better understanding of the effects of ankle taping on dynamic balance would provide valuable information. This line of research could be further expanded to include other athletes, such as soccer, football, and basketball players, to determine if the present results are consistent across a variety of sports.

**Conclusion**

Ankle taping is commonly used by athletes and has been proven to reduce the rate of ankle sprains (Thacker et al. 1999; Garrick & Requa 1973; Verhagen et al. 2000). However, the method by which taping reduces injury is unknown. It has been proposed that ankle taping may aid in injury prevention, in part, through its influence on balance. Proprioception is an important component of balance and taping is known to improve proprioception (Simoneau et al. 1997; Heit et al. 1996). However, in considering the potential effects of ankle taping on proprioception and balance, it must be taken into account that the central nervous system is known to adapt and/or habituate to changes in sensory input (Peterka & Loughlin 2004; Henriques & Cressman 2012). Therefore, the effect of ankle taping on balance was investigated with a particular focus on the long-term use of tape. It was hypothesized that taping would improve balance and that that benefits of taping would be more evident in the non-tapers. The balancing ability on one foot of 14 collegiate-level gymnasts, including six long-term tapers and eight non-tapers,
was determined by measuring parameters related to postural sway, with and without ankle taping, under different vision and surface conditions.

Contrary to the hypothesis, ankle taping largely did not improve balance. In general, the results support the conclusion that ankle taping is detrimental to balancing ability when the eyes are closed. The present results are consistent with those of other studies in finding that ankle taping did not improve balance. The results also suggest that long-term ankle tapers may adjust their balancing technique to account for the negative effects of taping. With one trivial exception, the negative effects of taping were found only when vision was removed, but the sport of gymnastics is performed with the eyes open. Therefore, although negative effects of taping on balance were found, it is recommended that gymnasts with previous ankle injuries continue to tape their ankles to reduce the incidence of further ankle sprains.
BIBLIOGRAPHY


CONSENT FORM

Project Title: The Effect of Long-term Use of Ankle Taping on Balance
Principal Investigator: Michael Pavol
Student Researcher: Stephanie McGregor
Co-Investigators: Elizabeth Doran, Sam Johnson, Jeffrey Doeninger
Sponsor: Oregon State University Research Office
Version Date: 07/29/11

1. WHAT IS THE PURPOSE OF THIS FORM?
This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?
The purpose of this study is to compare the effects of ankle taping on balance, across a variety of conditions, between gymnasts who regularly tape their ankle and those who do not. We believe that the effects of taping on balance may change with long-term use and will differ between conditions that challenge balance to different extents. The study is being conducted for the completion of an Honors College thesis. The results will also be published in professional journals.

Up to 16 individuals may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?
You are being invited to take part in this study because you are a woman; you are at least 18 years old; you are now or once were a collegiate- or national-level gymnast; you have performed gymnastics training within the past 18 months; and you do not have any injuries or conditions that would make participating in this study difficult or painful. In addition, you are being invited to take part because you taped one or both of your ankles every time you practiced gymnastics during the past 3 months, or because you never taped either ankle to practice gymnastics during the past 3 months.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?
If you agree to take part in this research study, you will come to the Biomechanics Laboratory at OSU for testing. The study activities include completing a questionnaire, determining your dominant leg, balancing on one foot under different conditions, both with and without ankle taping, and having body measurements made. Details of these activities are as follows:

Questionnaire: You will record information about your gymnastics participation, health, and ankle taping history on a questionnaire. It is possible that we may ask you to return for testing on a different day or that we may end your participation in the study based on the information you provide. This information will also be used to designate which foot you will balance on.
Study Title: The effect of long-term use of ankle taping on balance
Principal Investigator: Michael Pavel

CONSENT FORM

Dominant leg: We will determine your dominant leg by having you perform 3 tasks that involve stepping or kicking.

Balance testing: For the balance testing, you will wear shorts and will be barefoot. You will perform repeated trials in which you balance on the designated foot while standing on a force platform (a flat, rigid, force-measuring device, mounted flush with the floor). During the trials, you will stand as still as you can, with your other foot slightly above the ground and your hands on your hips. You will perform trials with and without ankle taping under 4 conditions:

1) Eyes open, with your foot directly on the force platform
2) Eyes closed, with your foot directly on the platform
3) Eyes open, with a block of foam (about 2½” thick) between your foot and the platform
4) Eyes closed, with the block of foam between your foot and the platform

You will practice these tasks before any actual balance testing. We will randomly determine whether you are tested first with or without your designated ankle taped. The ankle taping will be done in the laboratory, to your satisfaction, by a Certified Athletic Trainer, using methods typical to gymnastics. In all other respects, the testing with and without ankle taping will be the same: you will walk for 5 minutes and then perform 3 balancing trials for each of the 4 vision-and-surface conditions. In each trial, you will balance for 30 seconds, until you lose your balance, or until you open your eyes when they should be closed, whichever occurs first. We will time you and record the forces between your foot and the ground. Trials of less than 15 seconds will be repeated. You will be allowed to rest between trials. Once the testing for the first ankle taping condition is complete, you will perform the testing for the other taping condition. In all, you will perform a total of 24 balancing trials (not including repeated trials).

Body measurements: We will measure your height, weight, foot length, and forefoot width. Weight will be measured using a scale. Standing height will be measured using a type of wall-mounted ruler. The foot measurements will be made using calipers.

Study duration: The testing will occur in a single session that will last about 1 hour.

Storage of data: The data that we collect from you will be kept for 5 years after the study ends. To preserve your confidentiality, your data will be identified only by an assigned subject code.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?
The possible risks and/or discomforts associated with the being in the study include: some muscle soreness as a result of the balance testing and minor skin irritation from the ankle taping. There is also a risk that we could accidentally disclose information that identifies you. We believe that the possibility of your suffering an injury, such as an ankle sprain, is very low.

Several steps have been taken to lower the risk associated with participating in this study. We will not test you if your answers on the questionnaire suggest that you are at high risk of injury. During the balance testing, you will be allowed to open your eyes or use your other foot to stabilize yourself, if needed, and you will be given as much rest as needed. The ankle taping will be performed by a Certified Athletic Trainer who will use Tuf-skin and pre-wrap to minimize the risk of skin irritation due to the taping. You may also stop the testing at any time for any reason.
6. WHAT HAPPENS IF I AM INJURED?
Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, we need you to tell us. You can do this during your testing session or by contacting Michael Pavol afterwards at (541)737-5928 or by email at mike.pavol@oregonstate.edu

7. WHAT ARE THE BENEFITS OF THIS STUDY?
This study is not designed to benefit you directly.

8. WILL I BE PAID FOR BEING IN THIS STUDY?
You will be compensated for being in this research study. If you complete all of the testing, you will receive a $5 gift card to Yogurt Extreme. However, if you do not complete all of the testing, you will not receive any form of compensation.

9. WHO IS PAYING FOR THIS STUDY?
The Oregon State University Research Office is paying for this research to be done.

10. WHO WILL SEE THE INFORMATION I GIVE?
The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. The Oregon State University Research Office, which is sponsoring this project, may also see the information. Some of these records could contain information that personally identifies you.

If the results of this project are published, your identity will not be made public.

To help ensure confidentiality, we will identify your data only by an assigned subject code and not by your name. Any documents that contain your name will be stored in a filing cabinet, separate from any coded information, in the Biomechanics Laboratory. This laboratory is kept locked when not occupied by the laboratory staff.

11. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?
Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

Participation terminated by investigator: If you cannot meet the criteria for participating in this study, your participation in this study will be ended, without regard to your consent.
12. WHO DO I CONTACT IF I HAVE QUESTIONS?
If you have any questions about this research project, please contact: Michael Pavol, at (541) 737-5928 or by email at mike.pavol@oregonstate.edu

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

13. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?
Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date:

Participant's Name (printed):

(Signature of Participant)  (Date)

(Signature of Person Obtaining Consent)  (Date)
Appendix B

Table B.1
Raw data of balance measures analyzed under all conditions tested.

<table>
<thead>
<tr>
<th></th>
<th>Non-Taper</th>
<th>Taper</th>
<th>Non-Taper</th>
<th>Taper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eyes open, ground</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD COP AP (mm)</td>
<td>8.4 ± 1.2</td>
<td>8.7 ± 2.5</td>
<td>7.2 ± 1.1</td>
<td>7.2 ± 1.4</td>
</tr>
<tr>
<td>SD COP ML (mm)</td>
<td>5.3 ± 0.5</td>
<td>5.3 ± 0.5</td>
<td>5.0 ± 0.7</td>
<td>5.2 ± 0.8</td>
</tr>
<tr>
<td>Mean speed of COP AP (mm/s)</td>
<td>29 ± 5</td>
<td>30 ± 4</td>
<td>28 ± 4</td>
<td>29 ± 4</td>
</tr>
<tr>
<td>Mean speed of COP ML (mm/s)</td>
<td>27 ± 6</td>
<td>26 ± 4</td>
<td>28 ± 6</td>
<td>27 ± 4</td>
</tr>
<tr>
<td>SD COM AP (mm)</td>
<td>7.2 ± 1.1</td>
<td>7.4 ± 2.5</td>
<td>6.2 ± 1.3</td>
<td>6.0 ± 1.7</td>
</tr>
<tr>
<td>SD COM ML (mm)</td>
<td>4.0 ± 0.6</td>
<td>4.1 ± 0.5</td>
<td>3.8 ± 0.6</td>
<td>4.2 ± 0.6</td>
</tr>
<tr>
<td>Short-term diffusion coeff. (mm²/s)</td>
<td>109 ± 46</td>
<td>116 ± 41</td>
<td>90 ± 28</td>
<td>92 ± 22</td>
</tr>
<tr>
<td>Long-term diffusion coeff. (mm²/s)</td>
<td>9 ± 4</td>
<td>10 ± 7</td>
<td>5 ± 2</td>
<td>6 ± 3</td>
</tr>
<tr>
<td>Critical time interval (s)</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.2</td>
<td>0.6 ± 0.3</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>Critical mean square displ. (mm²)</td>
<td>87 ± 23</td>
<td>99 ± 34</td>
<td>96 ± 22</td>
<td>96 ± 32</td>
</tr>
<tr>
<td><strong>Eyes open, foam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD COP AP (mm)</td>
<td>9.7 ± 1.5</td>
<td>10.7 ± 2.0</td>
<td>7.7 ± 0.9</td>
<td>8.5 ± 0.9</td>
</tr>
<tr>
<td>SD COP ML (mm)</td>
<td>5.9 ± 0.7</td>
<td>6.1 ± 0.8</td>
<td>5.3 ± 0.5</td>
<td>5.7 ± 0.7</td>
</tr>
<tr>
<td>Mean speed of COP AP (mm/s)</td>
<td>33 ± 6</td>
<td>34 ± 6</td>
<td>30 ± 5</td>
<td>32 ± 7</td>
</tr>
<tr>
<td>Mean speed of COP ML (mm/s)</td>
<td>29 ± 6</td>
<td>28 ± 6</td>
<td>28 ± 6</td>
<td>28 ± 5</td>
</tr>
<tr>
<td>SD COM AP (mm)</td>
<td>8.3 ± 1.8</td>
<td>8.9 ± 2.2</td>
<td>6.4 ± 1.1</td>
<td>7.2 ± 0.9</td>
</tr>
<tr>
<td>SD COM ML (mm)</td>
<td>5.0 ± 0.5</td>
<td>5.3 ± 0.7</td>
<td>4.5 ± 0.4</td>
<td>4.8 ± 0.6</td>
</tr>
<tr>
<td>Short-term diffusion coeff. (mm²/s)</td>
<td>145 ± 59</td>
<td>168 ± 65</td>
<td>106 ± 36</td>
<td>124 ± 57</td>
</tr>
<tr>
<td>Long-term diffusion coeff. (mm²/s)</td>
<td>11 ± 6</td>
<td>14 ± 10</td>
<td>6 ± 5</td>
<td>6 ± 3</td>
</tr>
<tr>
<td>Critical time interval (s)</td>
<td>0.6 ± 0.3</td>
<td>0.6 ± 0.1</td>
<td>0.7 ± 0.3</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>Critical mean square displ. (mm²)</td>
<td>146 ± 62</td>
<td>172 ± 45</td>
<td>128 ± 22</td>
<td>137 ± 43</td>
</tr>
<tr>
<td><strong>Eyes closed, ground</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD COP AP (mm)</td>
<td>11.4 ± 2.7</td>
<td>13.7 ± 2.7</td>
<td>10.5 ± 1.4</td>
<td>12.0 ± 2.2</td>
</tr>
<tr>
<td>SD COP ML (mm)</td>
<td>8.9 ± 0.6</td>
<td>10.1 ± 0.7</td>
<td>9.0 ± 0.9</td>
<td>9.6 ± 1.1</td>
</tr>
<tr>
<td>Mean speed of COP AP (mm/s)</td>
<td>50 ± 5</td>
<td>55 ± 7</td>
<td>47 ± 8</td>
<td>55 ± 10</td>
</tr>
<tr>
<td>Mean speed of COP ML (mm/s)</td>
<td>47 ± 7</td>
<td>44 ± 4</td>
<td>46 ± 8</td>
<td>49 ± 5</td>
</tr>
<tr>
<td>SD COM AP (mm)</td>
<td>8.3 ± 2.7</td>
<td>10.4 ± 2.2</td>
<td>7.4 ± 1.6</td>
<td>8.9 ± 2.0</td>
</tr>
<tr>
<td>SD COM ML (mm)</td>
<td>6.7 ± 0.6</td>
<td>8.3 ± 0.8</td>
<td>7.1 ± 0.9</td>
<td>7.9 ± 0.9</td>
</tr>
<tr>
<td>Short-term diffusion coeff. (mm²/s)</td>
<td>391 ± 89</td>
<td>459 ± 110</td>
<td>355 ± 115</td>
<td>432 ± 134</td>
</tr>
<tr>
<td>Long-term diffusion coeff. (mm²/s)</td>
<td>4 ± 3</td>
<td>7 ± 6</td>
<td>7 ± 5</td>
<td>5 ± 7</td>
</tr>
<tr>
<td>Critical time interval (s)</td>
<td>0.6 ± 0.3</td>
<td>0.6 ± 0.2</td>
<td>0.5 ± 0.1</td>
<td>0.5 ± 0.0</td>
</tr>
<tr>
<td>Critical mean square displ. (mm²)</td>
<td>394 ± 139</td>
<td>569 ± 220</td>
<td>317 ± 74</td>
<td>428 ± 131</td>
</tr>
<tr>
<td><strong>Eyes closed, foam</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD COP AP (mm)</td>
<td>19.9 ± 1.5</td>
<td>21.3 ± 2.2</td>
<td>16.9 ± 2.7</td>
<td>19.0 ± 2.7</td>
</tr>
<tr>
<td>SD COP ML (mm)</td>
<td>10.2 ± 1.3</td>
<td>9.1 ± 0.7</td>
<td>9.1 ± 0.3</td>
<td>9.1 ± 1.0</td>
</tr>
<tr>
<td>Mean speed of COP AP (mm/s)</td>
<td>75 ± 10</td>
<td>75 ± 11</td>
<td>65 ± 10</td>
<td>73 ± 9</td>
</tr>
<tr>
<td>Mean speed of COP ML (mm/s)</td>
<td>49 ± 7</td>
<td>43 ± 6</td>
<td>46 ± 4</td>
<td>47 ± 7</td>
</tr>
<tr>
<td>SD COM AP (mm)</td>
<td>14.6 ± 1.1</td>
<td>15.8 ± 2.1</td>
<td>12.8 ± 2.5</td>
<td>14.9 ± 2.6</td>
</tr>
<tr>
<td>SD COM ML (mm)</td>
<td>8.6 ± 1.2</td>
<td>7.6 ± 0.8</td>
<td>7.7 ± 0.4</td>
<td>7.8 ± 0.8</td>
</tr>
<tr>
<td>Short-term diffusion coeff. (mm²/s)</td>
<td>829 ± 163</td>
<td>825 ± 175</td>
<td>554 ± 116</td>
<td>673 ± 119</td>
</tr>
<tr>
<td>Long-term diffusion coeff. (mm²/s)</td>
<td>5 ± 9</td>
<td>8 ± 7</td>
<td>6 ± 7</td>
<td>3 ± 5</td>
</tr>
<tr>
<td>Critical time interval (s)</td>
<td>0.6 ± 0.3</td>
<td>0.7 ± 0.2</td>
<td>0.5 ± 0.1</td>
<td>0.7 ± 0.1</td>
</tr>
<tr>
<td>Critical mean square displ. (mm²)</td>
<td>1004 ± 134</td>
<td>1097 ± 254</td>
<td>730 ± 201</td>
<td>899 ± 225</td>
</tr>
</tbody>
</table>

SD = standard deviation; COP = center of pressure; AP = anteroposterior; ML = mediolateral; COM = center of mass; displ. = displacement.
Appendix C

University Honors College Copyright Release Form

We are planning to release this Honors Thesis in one or more electronic forms. I grant the right to publish my thesis entitled “Effects of long-term use of ankle taping on balance” in the Honors College OSU Library’s Digital Repository (D-Space), and its employees the nonexclusive license to archive and make accessible, under conditions specified below.

The right extends to any format in which this publication may appear, including but not limited to print and electronic formats. Electronic formats include but are not limited to various computer platforms, application data formats, and subsets of this publication.

I, as the Author, retain all other rights to my thesis, including the right to republish my thesis all or part in other publications.

I certify that all aspects of my thesis which may be derivate have been properly cited, and I have not plagiarized anyone else’s work. I further certify that I have proper permission to use any cited work which is included in my thesis which exceeds the Fair Use Clause of the United States Copyright Law, such as graphs or photographs borrow from other articles or persons.

Signature: ____________________________________________

Printed Name: Stephanie McGregor

Date: June 5th 2013