AN ABSTRACT OF THE THESIS OF

Ryan A. Jorden for the degree of Master of Science in Human Performance presented on May 5, 2000. Title: Influence of Ankle Orthoses on Ankle Joint Motion and Postural Stability Before and After Exercise.

Redacted for privacy

Abstract Approved: ______________________

Rod A. Harter

Ankle injuries comprise more than 15% of all sports injuries worldwide. The efficacy of the ankle taping for injury prevention has long been under scrutiny as numerous studies have shown that tape rapidly loses its ability to constrain ankle motion with exercise. Consequently, ankle braces (orthoses) are being used with increasing frequency for the prevention and functional management of ankle injuries. However, the motion restraining qualities of ankle orthoses have not been widely evaluated in closed kinetic chain environments under physiologic loads. The primary purpose of this study was to compare the abilities of four ankle orthoses (ankle taping, lace-up brace, semirigid orthosis and hybrid brace) against a control condition (no brace or tape) to control subtalar and talocrural motion during running on a laterally-tilted treadmill at 16.2 km/h before and after exercise. It has been hypothesized that ankle orthoses make a secondary contribution to injury prevention through enhanced proprioception. The secondary purpose of this study was to quantify the effects of the aforementioned ankle orthoses on

postural stability during single-limb stance following a bout of exercise. Fifteen healthy university students (8 men and 7 women) with no history of significant ankle injuries (age, mean ± SD: 22.9 ± 3.9 years) volunteered to participate in this study. Three-dimensional kinematic data were captured with an active infrared digital camera system sampling at 120 Hz. To address the first question, data analyses were performed using 2-way univariate (Ankle Orthoses x Pre/Post-Exercise x Subjects) (5 x 2 x 15) repeated measures analysis of variance (ANOVA) to determine the existence of differences among three closed and four open kinematic chain dependent measures before and after exercise. Maximum inversion angles (MAXINV) were similar for all ankle orthoses, with no orthosis limiting inversion during tilted treadmill running significantly more than another, or compared to the control condition, either before or after exercise ($p > .05$). Pre-exercise MAXINV group means and standard deviations during treadmill running ranged from 6.8 ± 3.4 deg with the Royce Medical Speed Brace to 9.5 ± 4.1 deg in the tape condition; post-exercise MAXINV mean values ranged from 7.6 ± 3.2 deg for the Aircast Sport Stirrup to 9.1 ± 4.6 deg with closed basketweave tape. While not statistically significant ($p = 0.10$), ankle taping provided the least amount of inversion restraint, both before and after the exercise bout. The MAXINV angles measured during treadmill running (8.2 ± 4.0 deg) and open chain inversion AROM measured with a goniometer (34.5 ± 6.2 deg) were not related ($r = -0.0003$). The compressive forces present during closed kinetic chain activity are known to increase joint stability and thus may explain why MAXINV under dynamic varus loads was so much less in magnitude than inversion AROM measured under open kinetic chain conditions. The nonlinear relationship of these two variables supports our contention that reports of the motion controlling properties of ankle orthoses measured in open kinetic chain environments should not be used to infer the response characteristics of these same orthoses under dynamic, physiologic loads. To address the second question, data were analyzed using 3-way univariate (Ankle Orthoses x Pre/Post-Exercise x Eyes Open/Closed x Subjects) (5 x 2 x 2 x 15) repeated measures ANOVAs. Subjects' postural stability was assessed using a Biodex Balance System with eyes open and eyes closed conditions, before and after an exercise bout. The ankle orthoses evaluated did not influence postural stability as measured by mediolateral sway index, anteroposterior sway index, and overall sway index. Removal of visual perception via blindfolding resulted in significant decreases in all three measures of postural stability ($p = .001$). There was poor association among the closed chain postural stability parameters and the open chain AROM measures. These correlations ranged from $r = .04$ to $.17$, indicating minimal relationship between the amount of AROM permitted by the orthoses and postural stability as quantified by this method.

Influence of Ankle Orthoses on Ankle Joint Motion and Postural Stability
Before and After Exercise

by

Ryan A. Jorden

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Ryan A. Jorden, Author

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CONTRIBUTION OF AUTHORS

Dr. Rod A. Harter was involved in the conceptualization and development of the research questions and design, analysis and writing of each manuscript. Dr. Gerald A. Smith assisted in the design and assessment of the methodology for the biomechanical study and manuscript.

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The completion of this Master of Science thesis has been possible

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INFLUENCE OF ANKLE ORTHOSES ON ANKLE JOINT MOTION AND POSTURAL STABILITY BEFORE AND AFTER EXERCISE

CHAPTER 1

INTRODUCTION

1.1 Background and Significance

Ankle injuries are the most commonly sustained lesions in sports, accounting for greater than 15% of all injuries worldwide.[20,33] In men's soccer, Tropp et al.[52] reported an ankle injury incidence rate of 25%, while Garrick[20] observed a 38% ankle injury rate in male basketball players and a 45% injury rate for female players. The most frequently occurring ankle injury is the inversion sprain, which accounts for approximately 85% of all ankle sprains.[11] The frequent occurrence and re-occurrence of ankle sprains has led to extensive research to determine the efficacy of ankle prophylactic devices (orthoses) and the mechanism(s) by which they provide motion control and/or stabilization.

Ankle orthoses are frequently used to support and protect the ligaments of the ankle joint complex, and aid the musculotendinous structures in providing improved stability. Ankle orthoses have been shown to reduce the impulse at the ankle by increasing the stiffness of the joint and extending the time to maximal pathological inversion.[2] In addition to reducing the frequency and severity of ankle injuries, these orthoses may also enhance proprioception and neurological control of the ankle.[6,17,27]

Research studies investigating the protective and proprioceptive benefits of ankle orthoses have been typically performed using passive, low magnitude physiological loads.[22,23,25,54] However, Martin and Harter[36] suggested that ankle orthoses be evaluated under dynamic, closed kinematic chain experimental conditions in order to generalize any injury protection provided to sports situations.

During the past four decades, ankle taping for the purpose of injury prevention has been widely investigated.[1,16,19,20,21,24,26,31,35,37,42,46,54] The majority of these studies used passive loading in open kinetic chain environments to measure the restrictive properties of tape after exercise. Research has shown that after as little as 10 to 20 minutes of vigorous exercise, taping did not retain its pre-exercise level of ankle range of motion (ROM) restraint, and was statistically no different than the control (not taped) ankles.[10,36,43] Despite these findings, ankle taping continues to be a popular method of injury prevention used by certified athletic trainers, coaches, and others.

To identify the contributions that ankle taping and orthoses make to the stabilization and control of the ankle it is necessary to quantify ankle joint motion prior to and after bouts of exercise. There are two important reasons why both pre-exercise and post-exercise assessment is necessary: (a) human tissues are viscoelastic in nature and their material properties differ with the conditions under which they are loaded; and (b) testing prior to, during, and after exercise more closely reflects the reality of the sports settings.

The ability of the body to utilize information from the receptors in our joints, muscles, and tendons is known as proprioception. A component of proprioception associated with the detection and sensation of joint movement and positioning sense in both active and passive settings is known as kinesthesia. These two important concepts must be considered when investigating the contributions of ankle orthoses on postural equilibrium and control.

Research has shown that ankle taping loses its restrictive properties during short durations of exercise, yet epidemiological studies have reported reduced injury rates with taped versus control ankles.[21,46] It has been theorized that the prophylactic benefit associated with ankle taping may be attributed to heightened proprioception. Feuerbach et al.[18] found that ligamentous mechanoreceptors in the ankle had limited contribution to proprioception, whereas the afferent feedback receptors in the muscles, joints and skin adequately controlled joint position sense. These authors concluded that orthotic application increased ankle unilateral postural stability significantly when compared to controls ($p < 0.01$). Measuring postural stability enables the assessment of the contributions to proprioception made by ankle orthoses before and after exercise. The use of closed kinetic chain functional balance testing allows for sport related assessments to be made which would not be possible using open kinetic chain testing.

Numerous ankle orthoses have been compared in laboratory studies in effort to determine the effectiveness of each in preventing pathological talocrural and/or subtalar joint motion. In recent years, the use of lace-up braces and semirigid orthoses has become more widespread for ankle injury prevention, and in many situations have replaced repeated taping because lace-up braces and semirigid orthoses are less expensive, reusable, and self adjustable.[31,46,48] Several laboratory studies have shown that these orthoses, e.g., Swede-O-Universal, Aircast Sport-Stirrup, to be as or more effective than ankle taping in limiting ankle range of motion.[10,23,25]

In the classic laboratory study of ankle inversion using a drop platform, Kimura et al.[28] found that the Aircast semirigid orthosis constrained subtalar inversion by 9.8 degrees more than their non-braced condition ($p < 0.001$). However, this study has limited generalizability of the results because it was performed in a non-sport related activity setting and their testing device lacked a sagittal plane motion component commonly present in many if not most inversion sprains. Kimura et al.[28] recommended that further research was needed to test semirigid orthoses in actual sports situations.

Gross et al.[24] noted that pre-exercise inversion passive ROM during open kinematic chain testing was significantly less with their ankle taping and their semirigid orthosis conditions. These authors suggested that the semirigid orthosis was more effective in preventing ankle inversion injuries because of the ability to restrict inversion ROM following exercise. However, the Gross et al.[24] study also lacked generalizability to actual sports settings.

Several previous studies have investigated the capability of lace-up braces to limit subtalar inversion.[10,23,25] The results of these studies were mixed regarding the benefits of lace-up braces on ankle support when compared to other bracing options. Gross et al.[25] concluded that a lace-up brace (Swede-O-Universal) restricted inversion ROM after 10 minutes of vigorous exercise approximately 5% less than either taping or a semirigid orthosis (Aircast). Greene and Wright[23] concluded that the motion restraint provided by a lace-up brace (Swede-O) after 40 minutes of exercise was 35% less than its original level of support when compared with a semirigid orthosis (Aircast Air-Stirrup), whose degree of ROM restraint decreased an average of 12%.

Semirigid orthoses have been shown to reduce subtalar inversion ROM by up to one-third.[2,25,28] By design, semirigid orthoses are intended to limit inversion and eversion without significantly affecting plantarflexion and dorsiflexion ROM. When compared with a lace-up brace and tape, subjects in a study by Greene and Wright[23] rated a semirigid orthoses (Aircast Sport-Stirrup) lower in terms of comfort. However, in studies involving high school basketball and football players, neither the Aircast Air Stirrup or the Swede-O Universal braces were found to significantly affect athletic performance, e.g., vertical jump, agility run, and sprints.[34,41,53]

Several studies have compared a variety of commercially-available ankle braces with ankle taping to determine if any prophylactic effect can be achieved.[23-25,31] These studies were performed under passive ROM, open kinetic chain, non-physiologic load conditions. The limited generalizability of these studies is attributed to the absence of dynamic and closed-chain activity in their experimental protocols, but present in actual sports situations.

Martin and Harter[36] performed a two-dimensional kinematic analysis of ankle orthoses worn by subjects who walked and ran on a laterally-tilted treadmill, examining dynamic ankle inversion before and after a bout of vigorous exercise. These authors found that a lace-up brace (Swede-O) and semirigid orthosis

(Aircast) provided significantly greater post-exercise restriction of subtalar inversion than did closed basketweave ankle taping, which provided a level of inversion restraint no different than the control (no brace or tape) condition. To date there has been only one three-dimensional kinematic study that compared the motion restraint capacities of ankle orthoses under dynamic, closed chain loading.[47] We contend that laboratory studies of ankle orthoses must be tested under dynamic, closed kinetic chain conditions in order to achieve the external validity necessary to generalize the results to sports settings and be applied for the benefit of physically-active individuals.

1.2 Statement of Purpose

There remains a void in our understanding of how ankle bracing and taping techniques constrain subtalar and talocrural joint motion under dynamic physiologic loads. Since the stresses applied to ankle orthoses in most laboratory testing situations have been under passive, open kinematic chain conditions, there is little direct evidence of how these devices perform under the loads encountered during dynamic locomotor activities such as treadmill running.

The primary purpose of this study (Chapter Two) was to evaluate and compare the abilities of selected ankle orthoses to restrain dynamic, closed kinematic chain subtalar and talocrural motion before and after 20 minutes of exercise. The secondary purpose of this investigation (Chapter Three) was to examine possible contributions of ankle orthoses to proprioception as evaluated by postural stability testing before and after exercise.

Chapter Two consists of a manuscript entitled "Effects of Ankle Orthoses on Subtalar and Talocrural Joint Motion Before and After Exercise" and will be submitted for publication in the *American Journal of Sports Medicine.* The study primarily investigates and compares the abilities of four ankle bracing conditions and a control (nonbraced) condition in restricting subtalar inversion during laterally-tilted treadmill running at 16.2 km/h. Measurements of the restrictive abilities of the ankle orthoses were made in both open and closed kinematic chain formats before and after exercise.

Chapter Three, a manuscript entitled "The Influence of Ankle Orthoses on Postural Stability", will be submitted for publication in the *Archives of Physical Medicine and Rehabilitation.* This study investigated the hypothesis that ankle orthoses may provide an additional proprioceptive benefit beyond constraint of ankle motion, as evidenced by improved postural stability (balance) during unilateral stance. Of secondary interest was the question if whether the observed benefits of wearing ankle orthoses to postural stability, if any, were altered following a bout of exercise.

CHAPTER 2

EFFECTS OF ANKLE ORTHOSES ON SUBTALAR AND TALOCRURAL JOINT MOTION BEFORE AND AFTER EXERCISE

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2.1 Abstract

Ankle injuries are the most commonly sustained lesions in sports, accounting for greater than 15% of all injuries worldwide. Numerous studies have investigated the prophylactic effects of ankle taping and bracing in effort to reduce both the incidence and severity of these injuries. However, the motion restraining qualities of the various ankle orthoses have not been evaluated in a closed kinetic chain environment under normal physiologic loads. The purpose of this study was to compare the effects of four ankle orthoses (ankle taping, lace-up brace, semirigid orthosis and hybrid brace) and a control condition (no brace or tape) in controlling rearfoot (subtalar and talocrural) motion during running at 16.2 km/h on an 8.5 degree laterally-tilted treadmill. Fifteen apparently-healthy university students (8 males and 7 females) who ranged in age from 20 to 34 years (mean age ± SD, 22.9 ± 3.9 years) volunteered to participate in this study. Three-dimensional kinematic data were captured with an active infrared digital camera system sampling at 120 Hz. Data analyses were performed using univariate (Ankle Orthoses x Pre/Post-Exercise x Subjects) (5 x 2 x 15) repeated measures analysis of variance (ANOVA) to determine the existence of differences among three closed and four open kinematic chain dependent measures before and after exercise. The closed kinematic chain dependent variables calculated were: maximum inversion angle (MAXINV), talocrural joint angle at maximum inversion, and maximum inversion angular velocity. Open chain dependent variables measures were: inversion, eversion, plantarflexion, and dorsiflexion active range of motion (AROM).

MAXINV values were similar across all five experimental conditions, with no orthosis significantly limiting inversion during tilted treadmill running more than another, or when compared to the control condition, both before and after exercise ($p > .05$). Pre-exercise MAXINV group means and standard deviations ranged from 6.8 ± 3.4 deg with the Royce Medical Speed Brace® to 9.5 ± 4.1 deg in the tape condition; post-exercise MAXINV mean values ranged from 7.6 ± 3.2 deg for the Aircast Sport Stirrup® to 9.1 ± 4.6 deg with closed basketweave tape. While not statistically significant ($p = 0.10$), ankle taping provided the least amount of inversion restraint of all the orthoses, both before and after the exercise bout. The MAXINV angles measured <u>during</u> treadmill running (8.2 ± 4.0 deg) and open chain inversion AROM measured with a goniometer (34.5 ± 6.2 deg) were not related ($r = -0.0003$). The compressive forces present during closed kinetic chain activity are known to increase joint stability and thus may explain why MAXINV under dynamic varus loads was so much less in magnitude than inversion AROM measured under open kinetic chain conditions. The nonlinear relationship of these two variables supports our contention that reports of the motion controlling properties of ankle orthoses measured in open kinetic chain environments should not be used to infer the response characteristics of these same orthoses under dynamic, physiologic loads.

2.2 Introduction

Ankle injuries are the most commonly sustained lesions in sports, accounting for greater than 15% of all injuries worldwide.[11,19] In men's soccer, Tropp et al.[27] reported an ankle injury incidence rate of 25%, while Garrick[11] observed a 38% ankle injury rate in male basketball players and a 45% injury rate for female players. The most frequently occurring ankle injury is the inversion sprain, which accounts for about 85% of all ankle sprains.[4] The frequent occurrence and re-occurrence of ankle sprains has led to extensive research to determine the efficacy of ankle prophylactic devices (orthoses) and the mechanism(s) by which they provide motion control and/or stabilization.

Ankle orthoses are frequently used to support and protect the ligaments of the ankle joint complex, and aid the musculotendinous structures in providing improved stability. Ankle orthoses have been shown to reduce the impulse at the ankle by increasing the stiffness of the joint and extending the time to maximal pathological inversion.[2]

During the past four decades, ankle taping for the purpose of injury prevention has been widely investigated.[1,9-12,15,17,18,20,22,23,25,28] The majority of these studies used passive loading in open kinetic chain environments to measure the restrictive properties of tape after exercise. Research has shown that after as little as 10 to 20 minutes of vigorous exercise, taping did not retain its pre-exercise level of ankle range of motion (ROM) restraint, and was statistically no different than the control (not taped) ankles. [3,21,24] Despite these findings, ankle taping continues to be a popular method of injury prevention used by certified athletic trainers, coaches, and others.

Many of the previously published studies that investigated ankle orthoses were performed under conditions that did not closely reflect the normal physiologic loads present in daily activities.[13-16,28] These studies used open kinematic and kinetic chain measurement techniques to quantify the restriction of ROM that specific ankle orthoses provided prior to and after an exercise bout.

To date there has been only one three-dimensional kinematic study that compared the real-time motion restraint capacities of ankle orthoses during dynamic, closed chain loading.[26] The purpose of this study was to test the subtalar and talocrural motion restraining capabilities of selected ankle orthoses running at 16.2 km/h on a laterally-tilted treadmill before and after 20 minutes of exercise.

2.3 Methods

Subjects who participated in this study were recruited from the student population at Oregon State University. Fifteen apparently-healthy subjects (8 males and 7 females) who ranged in age from 20 to 34 years (mean ± SD, 22.9 ± 3.9 years) volunteered to participate. Subject demographic data are summarized and presented in Table 2.1.

Table 2.1 Subject Demographic Data

Parameter	Mean	Standard Deviation	Range
Age (years)	22.9	± 3.9	20-34
Height (cm)	172.5	± 7.6	162.5-190.5
Weight (kg)	70.6	± 10.2	61.4-102.3
Fick angle (deg)	7.5	± 3.5	1-13

For inclusion in the study, each subject was required to have no history of ankle sprain greater than grade 1 (mild) as determined through an oral medical history administered by one of us (RAH). Subjects were required to have a negative anterior drawer sign in their right ankle, defined by Cox et al.[6] as no greater than 2 mm difference in anterior talar displacement in neutral position in comparison with their contralateral ankle. Leg dominance was determined by asking the subjects which foot they would kick a soccer ball with; 14 of 15 preferred to kick a soccer ball with their right foot. Subjects were also required to be heel-toe runners in order to observe subtalar inversion during the early stance phase of gait during treadmill running. Prior to participation in this study we obtained informed consent from each subject in accordance with institutional guidelines regarding the protection of human subjects.

During the screening session prior to the start of the study, subjects were given unlimited practice time to familiarize themselves with running at 16.2 km/h on a laterally-tilted treadmill. The 8.5 degree lateral tilt of the treadmill was intended to simulate the conditions and dynamic forces placed on the subtalar and talocrural joints during running on a paved cambered road. The treadmill was tilted so that the right ankle of each subject was always the "downhill" ankle, subjected to increased varus forces (inversion) during the stance phase of gait. Subjects were also given unlimited practice to familiarize themselves with both stationary cycling and slide boarding.

In order to complete the study, subjects were required to participate in five experimental sessions over a maximum period of 14 days. Experimental sessions were not held on consecutive days to control for the possibility of fatigue due to participation in the study. Each session consisted of having one of the four ankle orthoses or the control (non-braced) condition applied to both ankles of the subject. The order of testing (the five experimental conditions) was counterbalanced to control for learning and/or practice effects.

We used standard athletic tape (3.8 cm width Zonas porous, Johnson and Johnson, New Brunswick, NJ) for all closed basketweave taping procedures. All ankle taping was performed by a certified athletic trainer not otherwise associated with the study. Spray adherent, heel and lace pads, and underwrap were used in conjunction with the taping. The ankle taping technique used was a combination of the Gibney basketweave and figure-8 heel locks, modified from Rarick.[24] For consistency, both ankles were taped for the testing session.

For the lace-up bracing condition, a new pair of Swede-O-Universal® Ankle Lok braces with plastic inserts (Swede-O-Universal, North Branch, MN) were worn over athletic socks that were supplied to the subjects by the investigators. Once each brace was properly fitted and applied, it was not adjusted for the duration of the experimental session.

Each subject also wore a new pair of Sport-Stirrup® ankle braces (Aircast, Inc., Summit, NJ) during the study. These semirigid orthoses were applied over the subjects' socks and worn on both ankles during the testing session. An identical procedure was followed for the testing session that involved the hybrid Speed Brace® (Royce Medical Products, Camarillo, CA), an orthosis that combines the features of a lace-up brace, semi-rigid lateral stabilizers, and Velcro™ heel-lock straps.

Throughout the duration of the study, the same one of us (RAJ) fitted and applied the commercially-available orthoses to the subjects' ankles. Another one of us (RAH) performed all open kinematic chain active range of motion (AROM) measurements of plantarflexion, dorsiflexion, inversion and eversion using a standard goniometer. This protocol established the active subtalar and talocrural joint ranges of motion for each of the experimental conditions prior to and following the treadmill running and exercise bout.

After the subject's ankle AROM was measured, four 10 mm diameter spherical reflective markers were placed on the posterior aspect of the lower leg of each subject as recommended for rearfoot motion analysis of human gait[5] by the same one of us (RAJ). This marking scheme permitted creation of separate leg and ankle segments and allowed for measurement of the absolute values of segment and joint angles, as well as the identification of any deviations from normal standing position.[8] We created a template of the marker placements for each subject to insure repeatability of marker placement within and across each of the five testing sessions. A fifth reflective marker was placed on the dorsum of the forefoot at the interspace between the second and third toes for use in calculation of plantar and dorsiflexion angles. Marker placement and subsequent kinematic analyses were performed on the right leg only in all testing conditions. A kinematic recording of static stance was taken during each testing session before the treadmill running to establish a reference position for calculation of sagittal plane angle measurements during running.

Three shuttered active infrared digital cameras (MacReflex, Qualisys, Glastonbury, CT) were utilized to record the running trials on the laterally-tilted treadmill (Max-1, Marquette Electronics, Milwaukee, WI). This camera and video processing system allowed for the three-dimensional (3-D) kinematic data associated with the right lower extremity to be captured digitally and automatically analyzed as the treadmill running was taking place. The framing rate of the digital cameras was set at 120 fields per second (120 Hz) with a selected shutter rate of 1/250 sec. Subjects ran on the treadmill for approximately 10 seconds at 16.2 km/h (6:00 per mile), sufficient time to obtain 3-D kinematic records of a minimum of 10 footfalls (trials) of the right foot. All treadmill running was performed while the subject was wearing the assigned experimental condition, but without shoes so as not to obscure rearfoot motion.

Subjects then performed 20 minutes of vigorous exercise alternating between five minute segments of stationary cycling and slide boarding, always beginning with biking. Subjects rode a stationary bicycle (Model 868, Monark Exercise AB, Vansbro, Sweden) at a self-selected pace between 70 and 90 rpm with a constant resistance of 1.5 N. Slide boarding was performed using a 213 cm x 58 cm slide board (Fitter International, Calgary, Canada). The slide board exercise bout was paced using a metronome with a LED display at a rate of 40 slides (cycles) per minute.

Once the 20 minute exercise bout was finished, subjects completed a second treadmill session, during which they again completed a minimum of 10 footfalls of the right foot. The postexercise treadmill running was followed by open kinematic chain ankle AROM measurements. At the conclusion of the session subjects completed a 100-mm visual analog scale (VAS) that asked them to rate the (a) comfort, (b) stability, (c) confidence they had in the device to prevent injury, and (d) an overall evaluation of the ankle orthosis they had just worn during the testing session. The VAS scores were calculated by assigning one point per millimeter on a zero to 100 scale (see Appendix D).

There were two separate measurement components in the study. The dependent variables of greatest interest were the closed kinematic chain, 3-D measurements of maximum inversion angle (MAXINV), the talocrural joint angle at maximum inversion (TCA@MAXINV), and the maximum inversion angular velocity achieved between foot contact and the occurrence of maximum inversion (MAXAV). Of secondary interest were the open kinematic chain AROM measurements of plantarflexion, dorsiflexion, inversion, and eversion.

Ten trial averages of the pre-exercise and postexercise stance phases during running on the laterally-tilted treadmill were calculated for each of the three 3-D kinematic variables for each of the five experimental conditions. These parameters were used to quantify subtalar joint motion in the frontal plane and talocrural motion in the sagittal plane. The maximum ankle inversion angle (MAXINV) and the talocrural joint angle at maximum inversion (TCA@MAXINV) achieved during each stance phase were used to compare the motion restraining effects of the ankle orthoses. The MAXAV results were used to determine the stiffness provided to the ankle by each bracing or control condition. The MAXINV values were calculated using computer programs that were specifically written for this study by one of us (RAJ). Calculations utilized the 3-D kinematic coordinate data from the reflective markers and were adjusted for each subject's Fick angle (turn-out angle of the foot in normal stance).

Data analyses were performed using univariate (Ankle Orthoses x Pre/Post-Exercise x Subjects) (5 x 2 x 15) repeated measures analysis of variance (ANOVA) to determine the existence of differences among three closed and four open kinematic chain dependent measures before and after exercise. Differences were accepted as significant at the alpha level of 0.05. In the presence of significant main effects, post hoc analyses were performed using Fisher LSD pairwise comparisons. Counterbalancing of the order of ankle orthosis exposure was employed to control for fatigue and possible learning effects. All statistical analyses were performed using SPSS 10.0 software (SPSS, Inc, Chicago, IL).

2.4 Results

2.4.1 Closed Kinematic Chain Variables

Maximum inversion angles (MAXINV) during treadmill running at 16.2 km/h were not significantly different ($F = 2.0$, $p = .10$) among the five ankle orthoses or affected by the exercise bout ($F < 1.0$, $p = .93$). The pre-exercise 10-trial averages for MAXINV ranged from a most restrictive low of 6.8 ± 3.4 deg with the Royce brace to a least restrictive high of 9.5 ± 4.1 deg with closed basketweave taping (Figure 2.1).

Significant differences among ankle orthoses ($F = 5.1$, $p = .001$) were observed for the talocrural angle at maximum inversion (TCA@MAXINV). Fisher post-hoc analyses collapsed across exercise revealed significant differences in TCA@MAXINV for the Swede-O brace compared to each of the other four experimental conditions ($p < .05$). Maximum inversion occurred during treadmill running at 4.3° of dorsiflexion in the pre-exercise measurement and at 4.8° of dorsiflexion following the exercise bout with the Swede-O brace (Table 2.2), compared with dorsiflexion angles of 6.9° or greater in the control, tape and Aircast conditions.

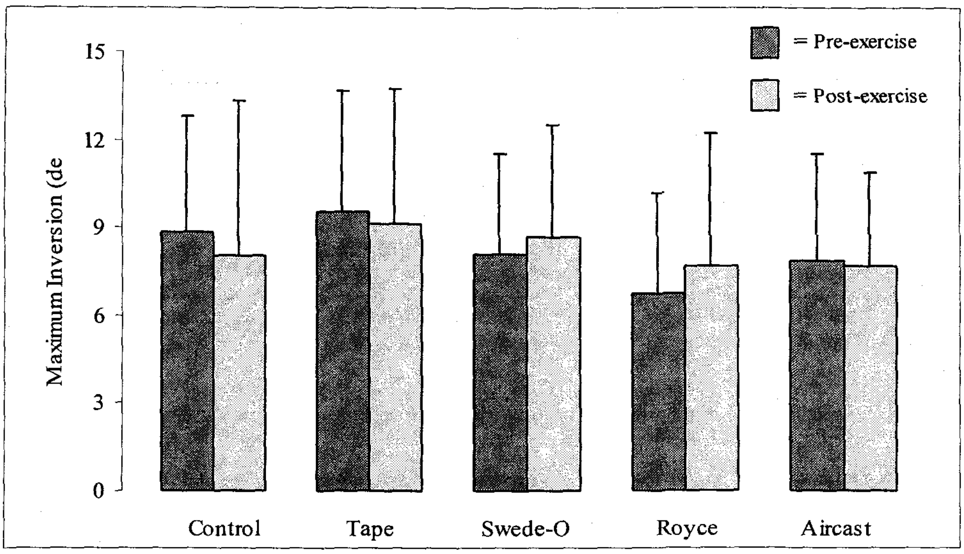

Figure 2.1 Maximum inversion angles from treadmill running. Group means ± SD across subjects, pre-exercise and postexercise; $p = 0.10$.

Maximum inversion angular velocity from foot contact to maximum subtalar inversion (MAXAV) was significantly different among the ankle orthoses ($F = 3.3$, $p = .02$). The ankle taping (84.9 ± 50.5 deg/sec) and Swede-O (86.1 ± 51.3 deg/sec) conditions permitted significantly greater maximum angular velocities ($p = .02$ and .03 respectively) than did the control condition (56.8 ± 43.2 deg/sec). Post-hoc analysis collapsed across exercise also revealed that Aircast MAXAV (59.8 ± 32.0 deg/sec) was significantly less than taping (Table 2.2).

Table 2.2. Three-dimensional closed kinematic chain variables (mean ± SD). (TCA@MAXINV = talocrural angle (dorsiflexion) at maximum inversion angle, MAXAV = maximum inversion angular velocity. Symbols(#, *) indicate Fisher LSD post-hoc analysis collapsed across exercise, $p < .05$).

	TCA@MAXINV (degrees)		MAXAV (deg/sec)	
Condition	Pre-Exercise	Post-Exercise	Pre-Exercise	Post-Exercise
Control	7.2 ± 3.7 #	7.3 ± 3.5 #	63.3 ± 36.6 *	56.8 ± 43.2 *
Tape	7.5 ± 3.6 #	6.9 ± 2.9 #	80.3 ± 35.8 *	84.9 ± 50.5 *
Swede-O	4.3 ± 3.4 #	4.8 ± 4.2 #	74.9 ± 31.0 *	86.1 ± 51.3 *
Royce	5.7 ± 2.8 #	6.4 ± 3.6 #	70.3 ± 27.3	69.7 ± 22.0
Aircast	7.0 ± 4.0 #	7.1 ± 3.7 #	59.8 ± 36.1 *	59.8 ± 32.0 *

2.4.2 Open Kinematic Chain Variables

Inversion AROM measurements were significantly different among the ankle orthoses ($F = 8.7$, $p = .001$) and between exercise conditions ($F = 7.5$, $p = .016$) (Figure 2.2). Post-hoc analyses with Fisher LSD pairwise comparisons collapsed across exercise revealed significant differences between the control condition (39.2 ± 6.5 deg) and tape (29.6 ± 6.7 deg) ($p = .0001$), control and Swede-O (31.0 ± 6.3 deg) ($p = .0001$), control and Royce (35 ± 5.4 deg) ($p = .04$), and control and Aircast (32.0 ± 5.9 deg) ($p = .004$). A significant ankle orthosis x exercise interaction was observed ($F = 4.0$, $p = .007$) (Figure 2.3).

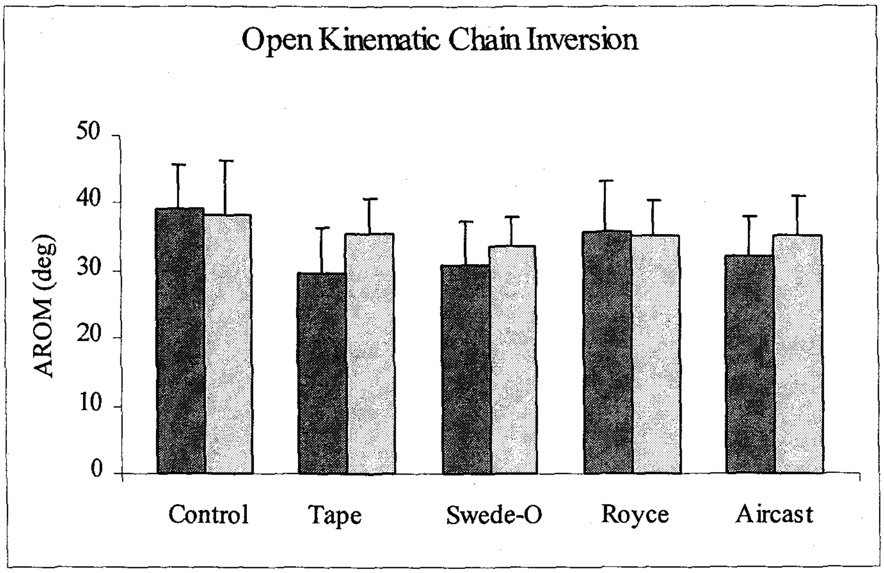

Figure 2.2 Active range of motion inversion means ± SD, ($p = .001$). Pre/Post Exercise.

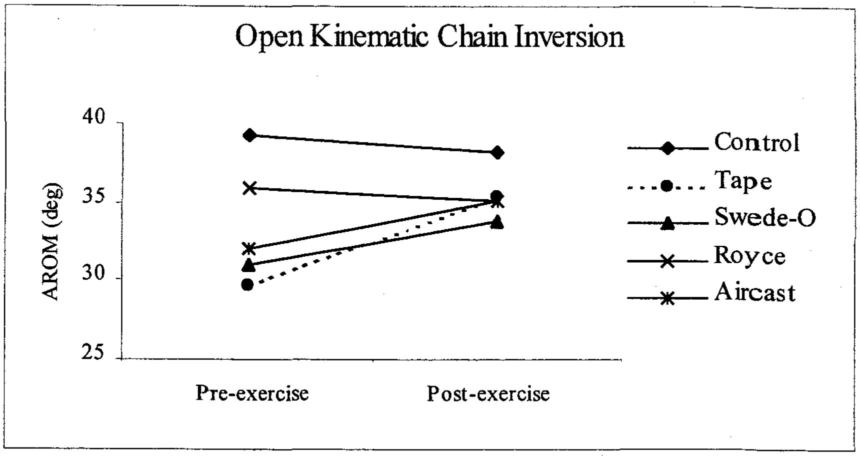

Figure 2.3 Active range of motion inversion interactions, p = .007.

Eversion AROM was significantly different among the ankle orthoses (F = 10.3, p < .001) measurements (Figure 2.4); pairwise post-hoc comparisons

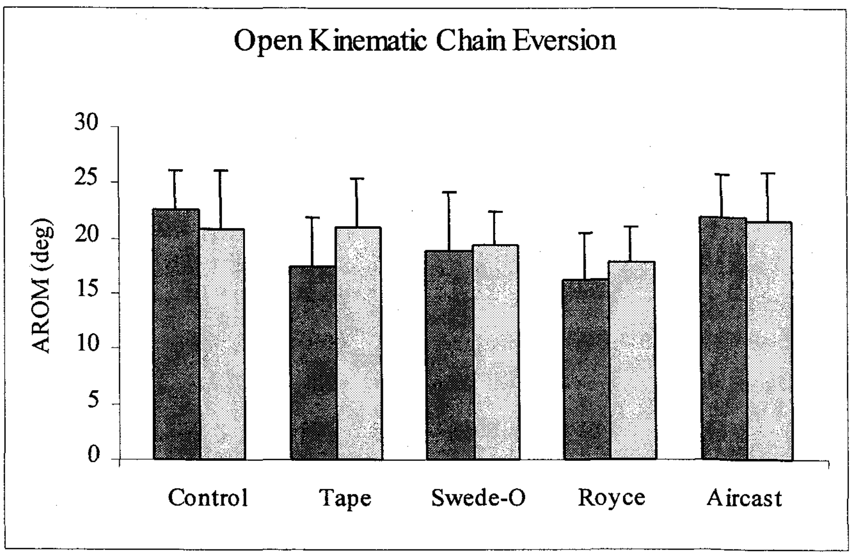

Figure 2.4 Active range of motion eversion means ± SD. Pre/Post Exercise open kinematic chain (p = < .001).

collapsed across exercise indicated significant differences between the control (22.5 ± 3.6 deg) and tape (17.5 ± 4.4 deg) ($p = .01$), control and Swede-O (18.9 ± 5.3 deg) ($p = .007$) and the control and Royce conditions (16.3 ± 4.1 deg) ($p = .0002$). There was a significant ankle orthosis x exercise interaction effect ($F = 4.2$, $p = .005$) (Figure 2.5).

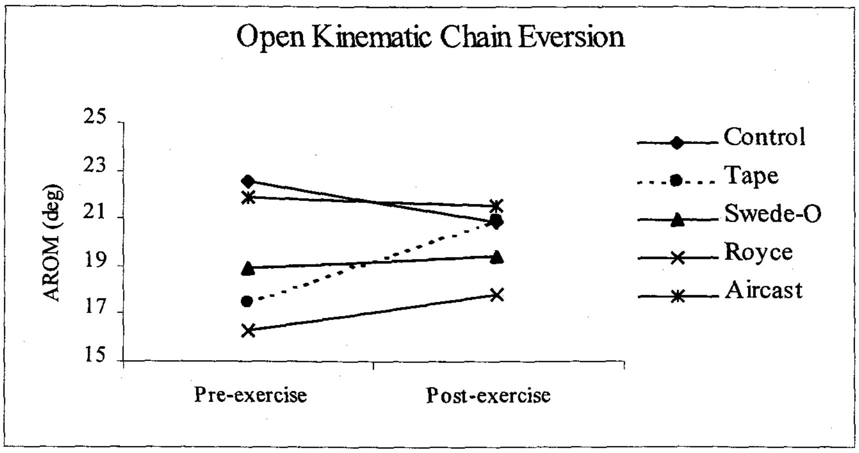

Figure 2.5 Active range of motion eversion interactions, $p = .005$.

Ankle plantarflexion AROM measurements were significantly different ($p < .001$) among the ankle orthoses. Post-hoc analysis for simple main effects collapsed across exercise indicated significant differences between the control (57.3 ± 10.3 deg) and tape (46.6 ± 10.0 deg) ($p = .0001$), control and Swede-O (47.7 ± 12.4 deg) ($p = .001$), and control and Royce (45.7 ± 10.8 deg) ($p = .0001$). In each case the plantarflexion AROM in the control condition was greater than that permitted by the ankle orthosis (Figure 2.6). There was also a significant ankle orthosis x exercise interaction present (F = 5.488, p = .001) (Figure 2.7).

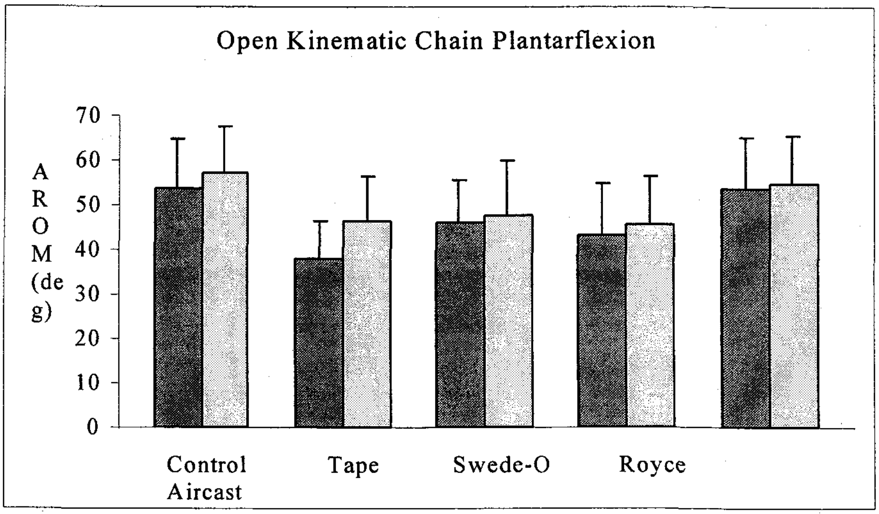

Figure 2.6 Active range of motion plantarflexion means ± SD. Pre/Post Exercise open kinematic chain, $p < .001$.

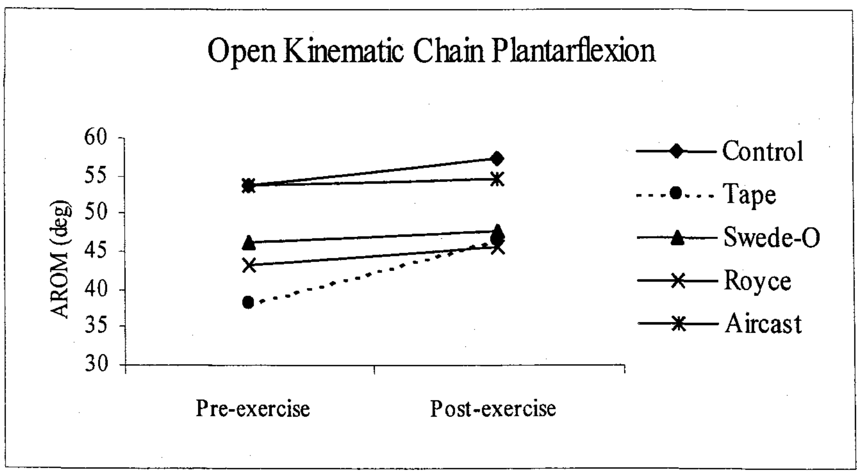

Figure 2.7 Active range of motion plantarflexion interactions, p = .001.

Significant differences in the dorsiflexion measurements were observed among the ankle orthoses (F = 4.6, p = .003), and between the pre-exercise and postexercise conditions (F = 56.6, p = .0001) (Figure 2.8). Pairwise differences collapsed across exercise were present between the control (14.5 ± 4.8 deg) and tape (8.8 ± 5.1 deg) (p = .022) and the control and Swede-O conditions (7.7 ± 4.4 deg) (p = .003). A significant ankle orthosis x exercise interaction was present (F = 2.5, p = .049) (Figure 2.9).

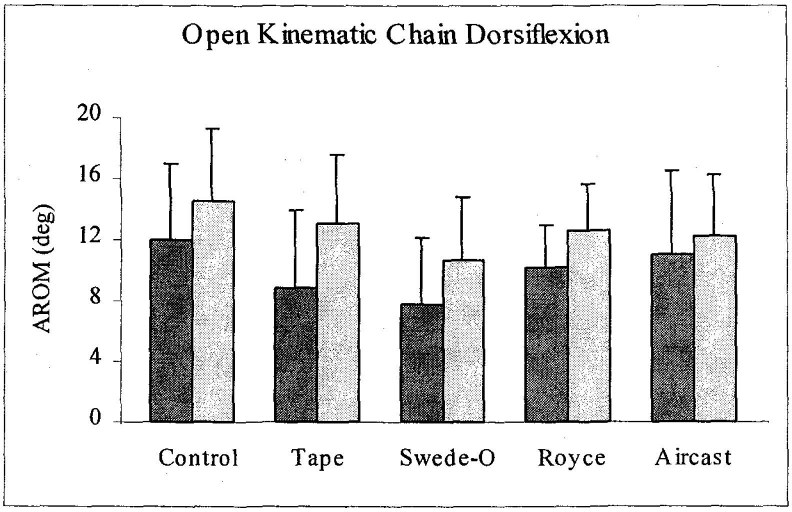

Figure 2.8 Active range of motion dorsiflexion means ± SD. Pre/Post Exercise open kinematic chain, p =.003.

2.4.3 Visual Analog Scale Ratings

The comparison of the subjects' ratings of the ankle orthoses indicated that in terms of comfort, subjects most preferred Royce, followed by Aircast, Swede-O, and ankle taping. In their ratings of orthosis support, confidence and overall rating,

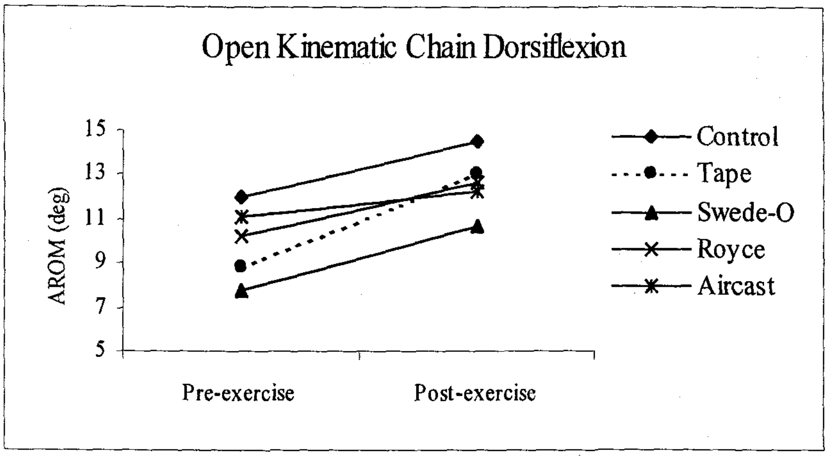

Figure 2.9 Active range of motion dorsiflexion interactions, p = .049.

the subjects most preferred ankle taping and Royce, followed by Swede-O and Aircast. Subjects' visual analog scale scores were grouped to form an average score for each evaluation variable and orthosis. Group averages resulted in ankle taping and the Royce conditions being most highly rated, with Swede-O and Aircast rated less highly (Table 2.3).

Table 2.3 Subjects' Visual Analog Scale Brace Ratings. Group average ratings for bracing conditions, where "1" = highest and "4" = lowest rank.

	Comfort	Support	Confidence	Overall	Average
Tape	4	1	1	1	1.75
Royce	1	2	2	2	1.75
Swede-O	3	3	3	3	3.00
Aircast	2	4	4	4	3.50

Upon completion of the study, subjects were allowed to select one pair of the three commercially-available ankle orthoses that they wore during the study as compensation for their participation. Ten of 15 subjects (66.7%) chose the Royce Medical Speed Brace, five subjects (33.3%) chose the Swede-O Ankle-Lok, and no subjects selected the Aircast Sport-Stirrup orthosis.

2.4.4 Open vs. Closed Kinematic Chain Measurements

The Pearson product moment correlation between the maximum inversion angle during tilted-treadmill running and inversion AROM measurements indicated no relationship between these two dependent variables (r = -.0003) (Figure 2.10).

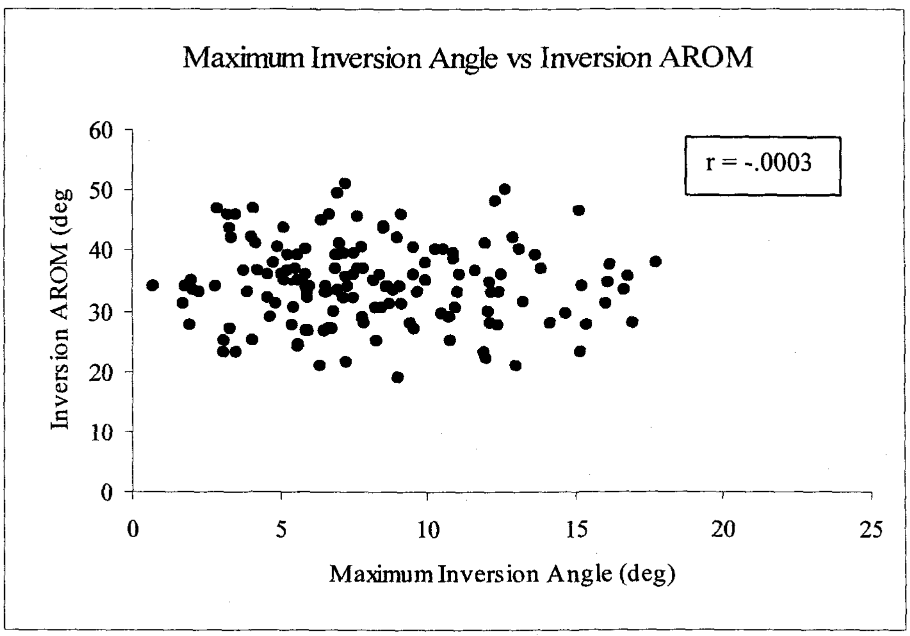

Figure 2.10 Maximum inversion vs active range of motion inversion means. Scatterplot of closed chain versus open chain measurements of subtalar joint inversion.

2.5 Discussion

We did not find statistically significant different MAXINV angles among the ankle orthoses selected for this study. Our results are similar to those of Simpson et al.[26] who tested Aircast, Malleoloc and Swede-O ankle orthoses in comparison with a control condition in a three-dimensional kinematic lateral motion study, and found no significant differences between the restrictive abilities of the bracing conditions and the control condition. In fact, Simpson and associates reported that inversion was least during the control condition when compared with the three ankle braces they tested.[26]

Our results differed from those reported by Martin and Harter[36], who found significant differences between a semirigid orthosis (Aircast) and lace-up brace (Swede-O) and the control condition during laterally-tilted treadmill running. While they used a similar protocol with a laterally-tilted treadmill, their study was performed under two-dimensional kinematic analysis at half of the framing rate (60 hz) of our study. Subjects also ran slightly slower (14.6 kph vs 16.2 kph in this study) on the treadmill, but performed a more vigorous exercise bout involving obstacle course running and jumping in their study. Differences between the results of the two studies may also be due to the higher running speed and thus increased loading rate in the current study. Given the viscoelastic properties of human tissues, the increased loading rate in the present study may have resulted in increased joint stiffness and therefore decreased the ROM that was permitted.

The absence of significant differences between the MAXINV angles permitted by the ankle orthoses in our study may be attributed to several factors. First, it may be possible that each of the modes of prophylaxis was similarly effective in limiting subtalar ROM under this particular set of exercise and testing conditions in this study. Second, there may have been an insufficient intensity or duration of exercise to create a treatment effect upon the ankle orthoses.

Another possible explanation is that there may have been measurement error in marker alignment and replacement when markers were detached during the exercise bout or treadmill running. However, we controlled for potential marker location errors by using a template for marker placement for use during as well as between testing sessions.

During treadmill running in the control condition, several subjects appeared to modify their gait patterns in comparison with their running gait patterns while wearing one of the orthoses. This factor could possibly have influenced the maximum inversion findings in this study; however, this observed variation in stride pattern cannot be substantiated. Our observations are given credence by the findings of Xia and Robinson[29] who reported that their subjects who wore less stable footwear designed to increase inversion angles actually changed their gait pattern to compensate for the perceived decreased stability, and demonstrated less inversion than with a more stable shoe designed to limit inversion.

The significant differences in TCA@MAXINV values between the Swede-O brace and the rest of the experimental conditions were indeed curious. Inversion ankle sprains commonly occur in a combination of inversion and plantarflexion, as the joint is less stable in plantarflexion when the wedge-shaped talus is outside of the mortise formed by the tibia and fibula. The fact that MAXINV occurred so early in the stance phase of gait did not permit much eccentric lowering of the foot from its dorsi-flexed position at foot contact. Additionally, the fact that the talocrural joint was still near its close-packed (most stable) position of dorsi-flexion may well explain why the magnitude of the maximum inversion angles calculated during tilted-treadmill running were lower than expected.

We did not anticipate finding significant differences in maximum inversion angular velocity (MAXAV) between the control condition and both the tape and Swede-O conditions. We expected that MAXAV in the control condition would have been greater than in all of the orthoses because of the lack of external subtalar restraint.[7] However, when analyzed in conjunction with trends seen in the maximum inversion angle findings, the MAXAV values make more sense. The pre-exercise to post-exercise consistency of the MAXAV in the two semirigid orthotic conditions (Royce and Aircast) suggests similarly controlled rates of motion restraint as the subtalar joint inverts.

The finding of significant differences among ankle orthoses for the open kinetic chain measurements was expected. All of the bracing conditions significantly restricted ankle inversion between pre and post-exercise when compared with the control. Of particular interest, the increase between pre-exercise and postexercise for all four AROM measurements with the ankle taping condition suggests that its motion control diminished after only 20 minutes of exercise. The change in the restrictive abilities of the closed basketweave ankle taping in the open kinematic chain measurement is clearly seen in the interaction effects in Figures 2.3, 2.5, 2.7 and 2.9. This finding is supported by previous studies[1,9-12,15,17,18,20,22,23,25,28] that have consistently indicated that the restrictive benefit of tape decreases with exercise.

The maximum inversion angles measured during treadmill running (8.2 ± 4.0 deg) and the open chain AROM inversion angles measured with a goniometer (34.5 ± 6.2 deg) were not related (r = -0.0003). The compressive forces present during closed kinetic chain activity are known to increase joint stability and thus may explain why MAXINV under dynamic varus loads was so much less in magnitude than inversion AROM measured under open kinetic chain circumstances. The nonlinear relationship of these two variables supports our contention that reports of the motion controlling properties of ankle orthoses measured in open kinetic chain environments should not be used to infer the response characteristics of these same orthoses under dynamic, physiologic loads.

2.6 Conclusions

- The four ankle orthoses selected for evaluation in this study did not provide a level of inversion restraint during treadmill running that was significantly different from the control (unbraced) condition. While differences were observed among the ankle orthoses' capabilities to restrain inversion, these differences were not statistically significant ($p = .10$).

- The maximum inversion angles measured <u>during</u> treadmill running (8.2 ± 4.0 deg) and the open chain AROM inversion angles measured with a goniometer (34.5 ± 6.2 deg) were not related ($r = -0.0003$). The compressive forces present during closed kinetic chain activity are known to increase joint stability and thus may explain why MAXINV under dynamic varus loads was so much less in magnitude than inversion AROM measured under open kinetic chain conditions. The nonlinear relationship of these two variables supports our contention that reports of the motion controlling properties of ankle orthoses measured in open kinetic chain environments should not be used to infer the response characteristics of these same orthoses under dynamic, physiologic loads.
- We found as others have previously that ankle taping does indeed significantly lose its restrictive properties during the course of exercise as indicated during open kinematic chain AROM measurements.
- We found no significant differences in the inversion control of a new hybrid brace that combines the features of several types of orthoses and the more established and research-tested ankle orthoses (Swede-O and Aircast) employed in our study.

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CHAPTER 3

THE INFLUENCE OF ANKLE ORTHOSES ON POSTURAL STABILITY

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3.1 Abstract

Ankle injuries are the most commonly sustained lesions in sports, accounting for greater than 15% of all sports injuries worldwide. Currently, there are a wide variety of ankle orthoses used regularly to protect the ankle from injury. Previous research has suggested that the prophylactic effect of ankle orthoses may extend beyond their ability to limit pathological ranges of motion to an enhancement of proprioception. The purpose of this study was to compare a control (non-braced) condition with the influence of ankle taping and three ankle orthoses on postural stability during unilateral stance before and after a vigorous exercise bout. Using eyes open and eyes closed conditions (to eliminate visual input to overall kinesthesia) in a balance test, we sought to identify the effects of ankle orthoses on postural stability. We recruited 14 healthy subjects (8 males and 6 females) who ranged in age from 20 to 34 years (mean age, 22.9 ± 4.0 years) from the student population at our university. We used a three-way (ankle orthoses x pre/post exercise x eyes open/closed x subjects) repeated measures ANOVA design. Three measures of postural stability were obtained from a Biodex Balance System: medio-lateral sway index (MLSI), anterior/posterior sway index (APSI), and overall sway index (OSI) during unilateral stance testing were used to make comparisons between experimental conditions. In addition, talocrural and subtalar joint active ranges of motion were measured with a goniometer before and after the exercise bout. The ankle orthoses we evaluated did not influence postural stability as measured by medio-lateral sway index, anterior/posterior sway index, or overall

sway index. Removal of visual perception via blindfolding resulted in significant decreases in all three measures of postural stability ($p = .001$). There was poor association among the closed chain postural stability parameters and the open chain AROM measures. These correlations ranged from $r = .04$ to $.17$, indicating minimal relationship between the amount of AROM permitted by the orthoses and postural stability as quantified by the Biodex Stability System.

3.2 Introduction

Ankle injuries remain the most frequent injury in sports, accounting for more than 15% of all sports injuries worldwide.[1,2] This high incidence of ankle sprains has given rise to numerous investigations into the means by which ankle orthoses provide motion control, reduced injury frequency and severity, and improved biomechanical stabilization of the ankle.[3-7]

Postural stability can be defined as the ability of the body to maintain its line of gravity, projected downward from the center of mass, within the base of support through the equilibration of forces ($\Sigma \mathbf{F} = 0$) and body segment alignment.[2] Postural stability is regulated by vestibular, visual and somatic input, or perceptions. Vestibular perception, originating from the labyrinth system of the inner ear, is more constant, but may be affected by visual impairment, e.g., loss of depth perception.[8] In order to assess the extent of the somatic and vestibular contributions to proprioception and neuromuscular control at the ankle, visual perception can be altered or eliminated during the evaluation of postural stability.

In their classic study, Freeman and colleagues[9] suggested that partial deafferentation of the mechanoreceptors of the lateral ankle ligament complex caused by sprain may lead to a proprioceptive deficit through decreased somatosensory input. More recently, Feuerbach et al.[3] employed a ligament anesthetization protocol to imitate the partial deafferentation that often accompanies ankle sprains. Using postural sway as their dependent measure, these authors concluded that the ankle ligament mechanoreceptors had little contribution to joint proprioception.

Some researchers believe that ankle bracing and taping may increase proprioceptive awareness by enhancing somatosensation and afferent feedback.[3,10] Several recent studies have assessed the contribution of ankle bracing to proprioceptive ability by investigating the effects of wearing ankle orthoses on postural control.[4-6,11] Feuerbach and Grabiner[5] measured the influence of a semirigid orthoses on postural control and observed that their healthy subjects had demonstrated significantly decreased mediolateral postural sway during unilateral stance while wearing a semirigid orthosis (Aircast).

In contrast, Bennell and Goldie[4] observed that their uninjured subjects had significantly more postural sway ($p < 0.05$) during a one-legged balance test while wearing ankle tape or braces than in an unbraced control condition. The confounding nature of the results of these two recent studies demonstrates the need for further research to identify the means by which, if at all, ankle orthoses facilitate improved somatosensation, and in turn, postural stability.

Previous research has shown that after as little as 10 to 20 minutes of vigorous exercise, closed basketweave ankle taping does not retain a significant level of ankle range of motion restraint when compared with control (no tape) conditions.[12-14] Despite these findings, ankle taping continues to be a popular method of injury prevention used by certified athletic trainers and others.

Several epidemiological studies have reported reduced ankle injury frequency and severity, among those athletes who had their ankles taped compared to those athletes who wore no tape or brace.[15,16] It has been speculated that the prophylactic benefit of tape beyond the first 20 minutes of exercise may be a function of enhance joint proprioception rather than its capacity to control pathological ranges of motion at the subtalar and talocrural joints.

Baier and Hopf[7] recently concluded that ankle orthoses reduced postural sway in subjects with chronic ankle instability by controlling medio-lateral sway velocities. These authors suggested that medio-lateral sway was significantly reduced through the application of two different ankle orthoses, a rigid orthosis, and a flexible orthosis, but did not specify the nature of the contribution(s) that the use of ankle orthoses brings to postural sway. This potential benefit to postural control needs to be further investigated in pre-exercise and postexercise settings.

The purpose of this study was to compare a control (non-braced) condition with the influence of ankle taping and three ankle orthoses on postural stability during unilateral stance before and after an exercise bout. Using eyes open and eyes closed conditions (to eliminate visual input to overall kinesthesia) in a balance test, we sought to identify the effects of ankle orthoses on postural stability.

3.3 Methods

Fourteen university students (8 men, 6 women; mean age 22.9 ± 4.0 years) volunteered to participate in this study. Leg dominance (13 of 14 preferred to kick a soccer ball with their right foot), height (mean ± SD, 173.0 ± 7.6 cm) and weight (mean ± SD, 71.1 ± 10.4 kg) were all recorded. Unilateral postural stability testing in this study was performed on the right leg only; the inclusion of one left foot-dominant subject in the experiment was not considered to be a confounding factor. Previous research by Hoffman and colleagues[17] found no significant difference in unilateral postural stability between the dominant and non-dominant legs of healthy subjects.

For inclusion in the study, each subject was required to have no history of greater than a grade 1 (mild) ankle sprain. Subjects needed to possess a negative anterior drawer sign at their right ankle, defined by Cox and colleagues[18] as no greater than 2 mm difference in talar displacement in neutral position in comparison with the opposite (left) ankle. Prior to participation in this study, we obtained informed consent from each subject in accordance with institutional guidelines regarding the protection of human subjects.

During the screening session prior to inclusion and the start of the study, subjects were given unlimited practice time to become familiar with the procedures associated with single limb balance testing with a Biodex Balance System (Biodex, Inc., Shirley, NY). Subjects performed both eyes open and eyes closed practice sessions during which time we located their proper foot placement for postural stability testing according to manufacturer's instructions. Subjects were also given the unlimited opportunity to practice stationary cycling and slide boarding.

Each subject participated in five experimental sessions that were completed within a maximum period of 14 days. A different ankle orthosis or control condition (no brace or tape) was applied to both ankles of the subject in each session. The order of assignment of the five ankle orthoses was counterbalanced to control for learning effects.

We used standard athletic tape (3.8 cm Zonas porous, Johnson and Johnson, New Brunswick, NJ) for all closed basketweave taping procedures. All taping was performed by a certified athletic trainer not otherwise associated with the study. Spray adherent, heel and lace pads, and underwrap were used in conjunction with the taping. The ankle taping technique used was a combination of the Gibney basketweave and figure-8 heel locks, modified from Rarick.[14]

For the lace-up bracing condition, a new pair of Swede-O-Universal® Ankle Lok braces with plastic inserts (Swede-O-Universal, North Branch, MN) were worn over the athletic socks supplied to the subjects by the investigators. Once each brace was properly fitted and applied, it was not adjusted for the duration of the experimental session.

Each subject also wore a new pair of Sport-Stirrup® ankle braces (Aircast, Inc., Summit NJ) during the study. These orthoses were applied over the subjects' socks and worn on both ankles during the testing session. The same procedure was followed for the testing session involving the Speed Brace® (Royce Medical Products, Camarillo, CA), a hybrid brace that combines a lace-up design with semirigid medial and lateral sides, and Velcro™ heel-locking straps.

During each testing session, brace sizing and application was completed by one of us (RAJ), and then the subject's plantarflexion, dorsiflexion, inversion and eversion active ranges of motion (AROM) were measured with a hand-held goniometer prior to any activity. This process established the subtalar and talocrural joint ranges for each of the experimental conditions in an open kinetic chain environment before and after the exercise bout took place. Throughout the course of the study, all AROM measurements were taken by the same individual (RAH), following established goniometric techniques.[19]

Subjects' postural stability was then tested using a Biodex Balance System whose assessment parameters determine the amount of time spent at predetermined levels of balance during each experimental trial. The Biodex system monitors and calculates postural sway as stability indices in the anterior/posterior and the medio-lateral directions. The system's software also records and combines the extent to which the movement in these directions occurs in order to calculate an overall sway index (OSI).

The postural stability tests were administered in a series of 15 second trials, three with the eyes open and then three with the eyes closed. Through a pilot study with two subjects, we determined the appropriate levels of platform stability to be used in our investigation. During the eyes open tests, the stability of the Biodex platform was set at level 4 (of eight possible stability levels, with level 1 being the least stable). For the eyes closed trials, the stability of the platform was set to level 8 (the highest level of stability). During the eyes closed testing segment, subjects were blindfolded and also asked to close their eyes to remove all visual input. For this experimental condition, all subjects were placed in the safety harness that accompanies the Biodex system as to protect them from injury in case of a fall.

The pre-exercise balance testing data served as a baseline for post-exercise balance comparisons. From the postural stability tests, three dependent variables were analyzed. Specifically, the device's output parameters of medio-lateral stability index (MLSI), anterior/posterior stability index (APSI) and overall sway index (OSI) were selected for analysis following the recommendations of Arnold and Schmitz.[20]

Subjects then performed 20 minutes of exercise alternating between five minute segments of stationary cycling and slide boarding, always beginning with biking. Subjects rode a stationary bicycle (Model 868, Monark Exercise AB, Vansbro, Sweden) at a self-selected pace between 70 and 90 rpm with a constant resistance of 1.5 N. Slide boarding was performed using a 213 cm x 58 cm slide board (Fitter International, Calgary, Canada). The slide board exercise bout was paced using a metronome with a LED display at a rate of 40 slides (cycles) per minute.

Upon completion of the exercise regimen, subjects returned to the Biodex platform to repeat the balance testing protocol. Subjects performed three 15-second eyes-open trials and three 15-second eyes-closed trials.

Data from the six pre-exercise and six post-exercise trials (three eyes open and three eyes closed) obtained during the balance testing for each subject under each of the five experimental conditions were used to quantify the proprioceptive contribution to stability. The stability indices measured in the pre/post exercise sessions were used to compare the efficacy of the ankle orthoses. Three-trial averages were calculated for the three selected Biodex dependent variables.

Data analyses were performed using univariate three-way (Ankle Orthoses x Pre/Post-Exercise x Eyes Open/Eyes Closed x Subjects) (5 x 2 x 2 x 14) repeated measures analysis of variance (ANOVA) to determine the existence of differences among the dependent variables. Differences were accepted as significant at the alpha level of 0.05. In the presence of significant main effects, post hoc analyses were performed using Fisher LSD pairwise comparisons. Counterbalancing of the order of ankle orthosis exposure was employed to control for fatigue and possible learning effects. All statistical analyses were performed using SPSS 10.0 software (SPSS, Inc, Chicago, IL).

There were two separate measurement components in the study. The dependent variables measured closed chain, one-legged standing postural stability were of primary interest. The formulae used to calculate these three dependent variables, MLSI, APSI and OSI, are presented in Figure 3.1. Of secondary interest were the open-chain measures of ankle inversion, eversion, plantarflexion and dorsiflexion AROM, and their relationship to the postural stability provided by the orthoses in the same plane of motion.

Anteriorposterior Stability Index

$$APSI = \sqrt{\frac{\Sigma\ (0 - Y)^2}{\#\ samples}}$$

Mediolateral Stability Index

$$MLSI = \sqrt{\frac{\Sigma\ (0 - X)^2}{\#\ samples}}$$

Overall Stability Index

$$OSI = \sqrt{\frac{\Sigma\ (0 - Y)^2 + \Sigma\ (0 - X)^2}{\#\ samples}}$$

Figure 3.1 Biodex stability measure equations (Arnold and Schmitz[20]). Y = distance moved in anterior/posterior directions, X = distance moved in medio-lateral directions.

3.4 Results

3.4.1 Postural Stability Parameters

We found no statistically significant differences in any of the three measures of postural stability to be specifically attributed to the ankle orthoses (range of p values from 0.42 to 0.67).

We found a significant difference ($F = 36.7$, $p = <.001$) in medio-lateral stability index (MLSI) between the eyes-open and eyes-closed conditions. In the eyes-open testing mode, the control condition (mean ± SD, 1.50 ± .4) demonstrated the lowest (best) MLSI values (Figure 3.2). The MLSI values under the eyes-closed conditions were the best with the Swede-O and Royce orthoses, 2.12 ± .5 and 2.04 ± .5, respectively (Figure 3.3). There was also a significant interaction (F = 5.2, p = .001) present between the ankle orthoses and eyes open/closed conditions.

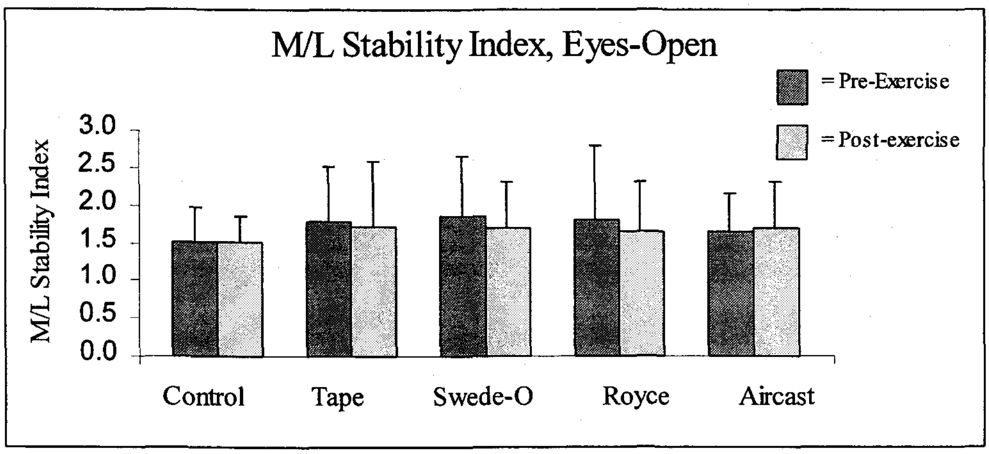

Figure 3.2 Medio-lateral stability index, eyes-open, (mean ± SD).

In the eyes-open condition in the medio-lateral stability index, the control condition displayed the lowest (best) mean stability scores for both pre-exercise (1.55 ± .45) and postexercise (1.50 ± .36). In the eyes-open testing there was a general increase in stability after exercise in each of the experimental conditions (Figure 3.2). In the eyes-closed testing, there was an increase in stability (numerical decrease) in all bracing but not in the control condition (Figure 3.3).

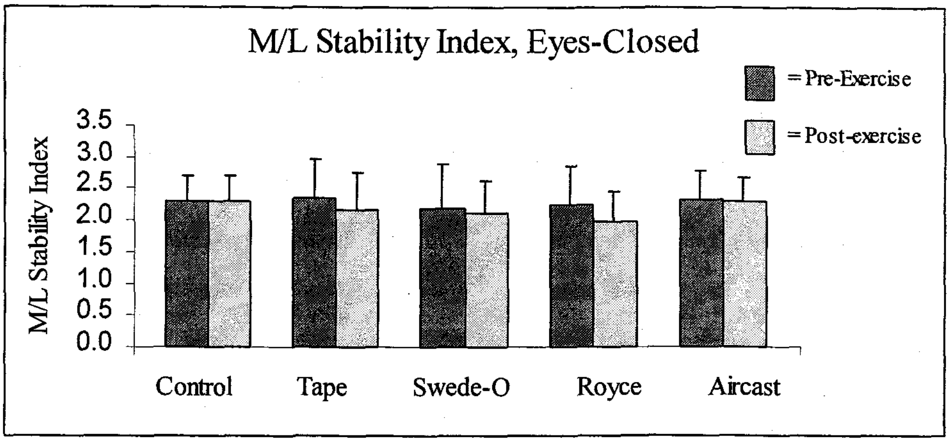

Figure 3.3 Medio-lateral stability index, eyes-closed, (mean ± SD).

There were significant differences ($F = 113.9$, $p < .001$) in anterior/posterior sway index (APSI) between the eyes-open (Figure 3.4) and eyes closed conditions. There were also significantly more anterior/posterior sway differences in the postexercise tests than in the pre-exercise balance tests. We also found that in the

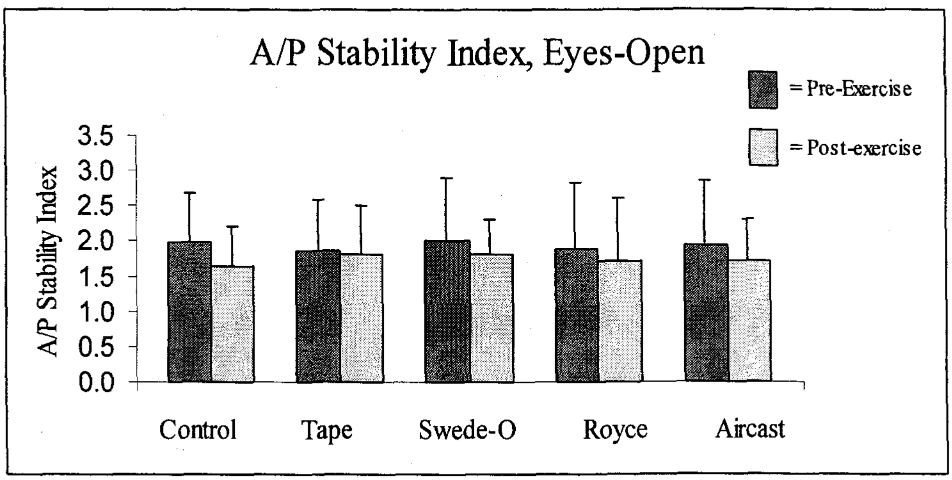

Figure 3.4 Anterior/posterior stability index, eyes-open, (mean ± SD).

APSI eyes-closed, post-exercise testing results, the three ankle bracing conditions (Swede-O, Royce, and Aircast) demonstrated the lowest (most stable) post-exercise APSI measurements (Figure 3.5).

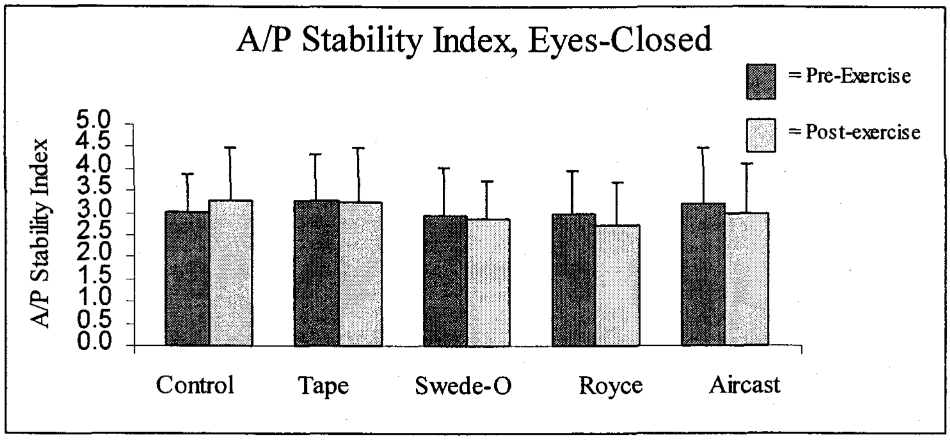

Figure 3.5 Anterior/posterior stability index, eyes-closed, (mean ± SD).

Overall stability index (OSI) values were significantly different (F = 108.7, p < .0001) between the eyes-open and eyes-closed conditions. The OSI means were also significantly different (F = 11.3, p = .005) between the pre-exercise andpostexercise conditions. There was also a significant ankle orthosis x eyes open/closed interaction (F = 3.4, p = .015). For the eyes-open testing condition (Figure 3.6), the control condition resulted in the best (numerically lowest) OSI scores in both the pre-exercise (2.43 ± .73) and post-exercise tests (2.14 ± .6). In the eyes-closed tests, the Swede-O (3.47 ± .9) and the Royce (3.35 ± .97) orthoses displaying the best OSI scores in the post-exercise condition (Figure 3.7).

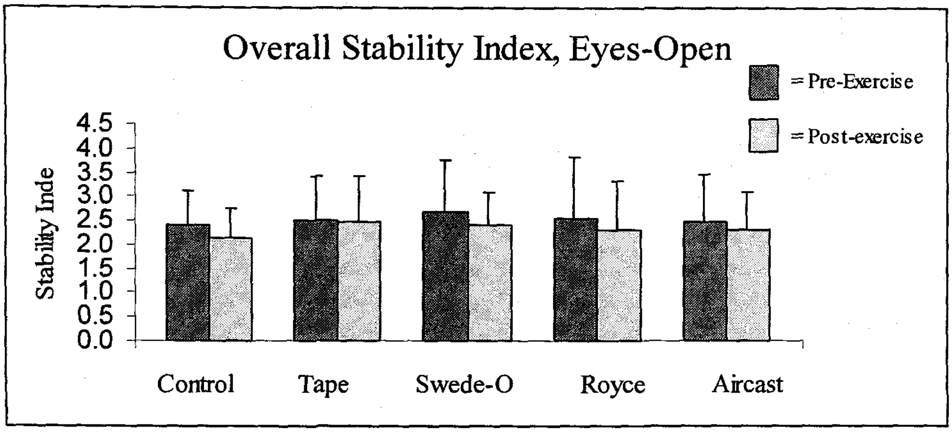

Figure 3.6 Overall stability index, eyes-open (mean ± SD).

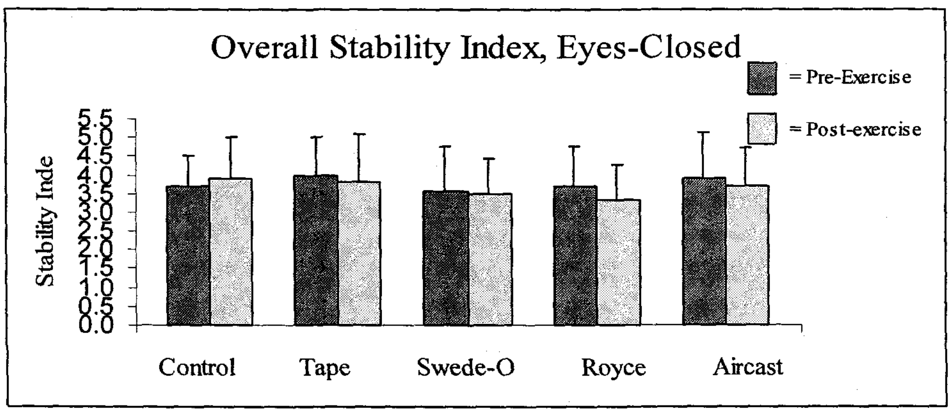

Figure 3.7 Overall stability index, eyes-closed, (mean ± SD).

3.4.2 Relationship of Postural Stability to Ankle Active Range of Motion

There was no significant relationship found between the mediolateral postural stability index and the inversion active range of motion measurements (r = .136, p = .109). The Pearson product moment correlation between medio-lateral stability and AROM inversion is shown in Figure 3.8.

Table 3.1 Biodex Medio-lateral Stability Index Scores (mean ± SD).

Medio-Lateral Stability Index		
Condition	Eyes Open	Eyes Closed
Control Pre	1.55 ± .45	2.33 ± .40
Control Post	1.50 ± .36	2.35 ± .40
Tape Pre	1.83 ± .75	2.42 ± .62
Tape Post	1.74 ± .88	2.23 ± .58
Swede-O Pre	1.85 ± .81	2.19 ± .69
Swede-O Post	1.70 ± .60	2.12 ± .50
Royce Pre	1.85 ± .99	2.29 ± .62
Royce Post	1.69 ± .68	2.04 ± .46
Aircast Pre	1.68 ± .49	2.35 ± .46
Aircast Post	1.66 ± .63	2.28 ± .36

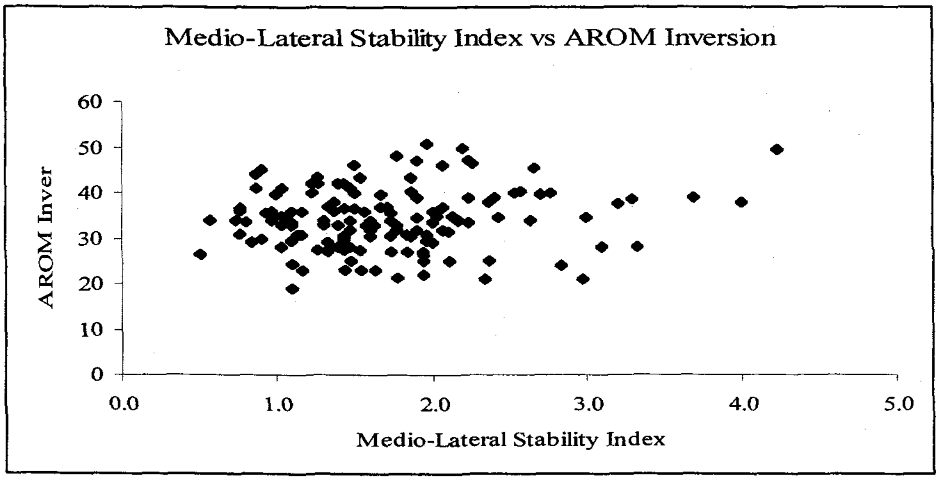

Figure 3.8 Medio-lateral stability index vs AROM inversion, r = .136.

3.5 Discussion

We designed an experiment to determine if the wearing of ankle tape and three different ankle braces would positively influence postural stability compared to no tape/brace (control) in subjects that had no history of significant ankle sprain. Postural stability as quantified by three parameters from the Biodex Balance System was no better when wearing a particular orthosis than without an ankle protective device ($p = .42$).

The findings of significant differences between the eyes-open and eyes closed testing conditions, came as no surprise to us. The removal of visual input during the eyes-closed condition had significant negative effects on the medio-lateral, anterior/posterior, and overall stability indices.

The interesting findings were the significant differences between pre and post-exercise in the OSI and APSI measurements. These results suggest that with exercise comes increased stability in the anterior/posterior direction.

We know from Arnold and Schmitz[20] that the OSI and APSI are closely related, so our results indicate that postural stability increased in the anterior/posterior plane after exercise. Our findings support the work of Arnold and Schmitz[20] and we would suggest that future research using the Biodex should limit examination of stability to the MLSI and APSI.

Refshauge and colleagues[21] compared the ability of injured and healthy subjects to perceive passive plantarflexion and dorsiflexion movements at the ankle. These authors suggested that the benefit of ankle taping did not come from enhanced proprioception in anterior-posterior plane during ankle movement. Similarly, we found that in the ankle taping condition there was limited change in the APSI from the pre-exercise to the post-exercise testing. However, in the MLSI values after exercise, the ankle taping did not result in decreased postural stability and would therefore indicate that ankle taping may have a proprioceptive benefit after exercise.

In unilateral postural stability testing, medio-lateral testing is more important than anterior/posterior testing based on the human anatomical configuration. The length of the foot is much greater than the width of the foot and while there is a substantial amount of musculature in the lower leg controlling anterior/posterior movement of the body, there is minimal musculature controlling medio-lateral movement. Therefore, the positive proprioceptive contributions of the ankle orthoses to postural control should be found more directly in the mediolateral plane during one-legged standing.

While some authors[3,7] have suggested that there are possible positive contributions of cutaneous receptors for afferent feedback in control of ankle joint position sense and subsequent proprioception, we found no significant differences in any of the variables measured between our control condition and the variety of orthoses we tested. In the eyes-open condition, our results would seem to indicate that in the control condition, subjects sensed a decreased level of stability which resulted in a heightened awareness and attention to the balancing task due to the increased risk of injury. This observation is given credence by the findings of Xia and Robinson[22] who reported that their subjects who wore less stable footwear designed to increase inversion angles actually changed their gait pattern to compensate for the perceived decreased stability, and demonstrated less inversion than with a more stable shoe designed to limit inversion. In our study, all of these orthoses showed higher medio-lateral stability index (decreased stability) scores than the control condition.

In the eyes-open testing results, it was interesting to note that in every testing condition all three stability index measurements (OSI, MLSI, and APSI) displayed trends of slightly improved postural stability from the pre-exercise to the post-exercise condition. However, in the eyes-closed testing, all of the orthoses showed slightly improved postural stability after exercise, while the control condition showed no change in postural stability.

Arnold and Schmitz's[20] concluded that the OSI measurement is very closely related to the APSI. We found a very strong correlation (r = .95) between OSI and APSI, supporting Arnold and Schmitz[20]. When examining these same trends in the eyes-open condition, in the MLSI, only the Swede-O and the Royce bracing conditions showed slight improvements in stability (0.14 and 0.17 respectively) across exercise. In the eyes-closed condition (MLSI), noticeable increases in the SI were seen in the ankle taping (0.17) and Royce (0.24) bracing conditions.

3.6 Conclusions

- The ankle orthoses we evaluated did not influence postural stability as measured by medio-lateral sway index, anteroposterior sway index, or overall sway index.
- Removal of visual perception resulted in significant decreases in all three measures of postural stability when the subjects were blindfolded ($p = .001$).
- There was weak association among the closed chain postural stability parameters and the open chain AROM measures. These correlations ranged from $r = .04$ to .17, indicating minimal relationship between the amount of AROM permitted by the orthoses and postural sway.
- Our findings supported previous research by Arnold and Schmitz[20] who concluded that the OSI is closely related to the APSI measure and receives little contribution from the MLSI.

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CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1 Summary

The purpose of this study was to test the subtalar and talocrural motion restraining capabilities of selected ankle orthoses running at 16.2 km/h on a laterally-tilted treadmill before and after 20 minutes of exercise. The secondary purpose of this study was to compare a control (non-braced) condition with the influence of ankle taping and three ankle orthoses on postural stability during unilateral stance before and after a vigorous exercise bout. Using eyes open and eyes closed conditions (to eliminate visual input to overall kinesthesia) in a balance test, we sought to identify the effects of ankle orthoses on postural stability.

We compared the abilities of three commercially-available ankle orthoses and traditional ankle taping with a control (unbraced) condition to restrict subtalar inversion during laterally-tilted treadmill running at 16.2 km/h. We did not find significant main effect for the ankle orthoses, either before or after exercise. The inversion (varus) loads applied to the foot and ankle during the treadmill running were submaximal and perhaps were not of sufficient magnitude or rate so as to allow for differentiation of the motion control and/or restraining properties of the selected orthoses.

In open kinematic chain AROM measurements, subtalar inversion was shown to be significantly restricted by the bracing conditions compared to the control condition. We found as others have previously that ankle taping did indeed significantly lose its restrictive properties during the course of exercise as indicated by the significant changes (increases) in open kinematic chain AROM measurements.

The MAXINV angles measured during treadmill running (8.2 ± 4.0 deg) and open chain inversion AROM measured with a goniometer (34.5 ± 6.2 deg) were not related ($r = -0.0003$). The compressive forces present during closed kinetic chain activity are known to increase joint stability and thus may explain why MAXINV under dynamic varus loads was so much less in magnitude than inversion AROM measured under open kinetic chain conditions. The nonlinear relationship of these two variables supports our contention that reports of the motion controlling properties of ankle orthoses measured in open kinetic chain environments should not be used to infer the response characteristics of these same orthoses under dynamic, physiologic loads.

We hoped to gain some insight into the hypothesized proprioceptive contributions of ankle orthoses to postural stability and control. We found no statistically significant differences in any of the three measures of postural stability to be specifically attributed to the ankle orthoses (range of p values from 0.42 to 0.67). We found significant results between the eyes-open and eyes-closed testing situations in this study. We also found a significant overall improvement in postural stability after exercise. This may indicate that indeed there is a proprioceptive effect given by the bracing conditions that was elicited when limiting visual input.

Finally, we found no significant differences between a new hybrid brace that combines the features of several types of orthoses and the more established and research-tested ankle orthoses (Swede-O and Aircast) employed in our study.

4.2 Suggestions for Future Research

While we designed the exercise protocol for this study to maintain control and consistency of the exercise level across subjects and conditions, we may not have placed sufficient mechanical stresses on the ankle orthoses during 20 minutes of stationary bicycling and slide boarding to create an exercise treatment effect. We suggest that if using exercise to examine pre/post exercise contributions of ankle braces to ROM restriction or proprioception, researchers should utilize a more vigorous, fully weight-bearing multi-directional exercise regiment.

Indications that ankle orthoses may have a proprioceptive benefit need to be examined further. Future research should incorporate a larger subject population than was present in this study, if using the Biodex system for balance testing. Three-dimensional kinematic analysis of the balance testing would help to assess the types of sway correction strategies used by subjects in the different bracing and visual conditions.

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APPENDICES

APPENDIX A

IRB APPLICATION

1. Significance of the Study

Ankle injuries are the most commonly sustained injuries in all of sports, comprising approximately 15% of all sports injuries worldwide. The inversion ankle sprain or "rolling of the ankle" is by far the most common ankle injury. Many protective methods and devices are used to prevent this type of ankle injury or re-injury. Much research has been conducted to assess the benefits of many of types of bracing. However, little research regarding the restrictive abilities of these bracing techniques has been performed in dynamic exercise settings. Research in the present study will allow for three-dimensional analysis of some of the most common ankle bracing techniques to be evaluated under normal activity impact situations. Our study will also evaluate the ankle motion control provided by these braces using an infrared digital camera motion tracking system that is twice as fast as systems used in the past. This will allow for greater accuracy in assessing ankle motion and brace control. We will also examine the potential benefit of added joint position sense and kinesthetic awareness from ankle bracing. The results of the assessment in this testing setting will allow the results of this study to be applied to everyday ankle injury prevention and rehabilitation strategies in both the sport and recreational environments.

2. Methods and Procedures

There will be five separate testing sessions for each subject in this study. Each testing session will take place at the Sports Medicine Research Laboratory in the Women's Building at Oregon State University. The subject's activities in each session will be identical, with exception of the assigned ankle bracing condition in which the subject is placed. The five bracing conditions are: a control condition (unbraced), ankle taping, two different lace-up ankle braces (Swede-O and McDavid), and a semi-rigid brace. After the assigned ankle prophylactic device is applied to the subject's ankles, active range of motion of the right ankle will be measured while the subject lies on an examination table. These values will provide baseline measures for each of the ankle bracing conditions before exercise. This process will be repeated immediately after the exercise bout.

After a five minute stationary bicycle warm-up at 60 to 90 rpm, data collection will be performed by two methods: three-dimensional motion analysis (MacReflex Motion Analysis System, Qualysis Inc., Santa Rosa, CA) and postural stability measurement (Biodex Stability Systems, Biodex, Shirley, NY). During the three-dimensional motion analysis, subjects will be asked to run on a 6° laterally-tilted treadmill for 20 seconds, at 6:30 minute per mile pace. As the subject is running, the computerized motion analysis system records the angular position values that are found at the ankle during the running cycle. The ankle joint positions are immediately analyzed, plotted on a computer monitor screen, and saved in memory. Subjects will then proceed to the postural stability measurement.

The postural stability measurements will be obtained under two experimental conditions: eyes open and eyes closed. This allows for comparison and isolation of neurosensory control. For the eyes closed condition, we will use the overhead suspension system and safety harness feature of the Biodex system to prevent any accidental falls. During each of the postural stability segments, the amount of time that the subject spends on balance during single leg standing will be assessed electronically by the balance machine.

After the initial motion analysis and balance testing have been performed, subjects will participate in 20 minutes of vigorous exercise involving obstacle course running and stationary cycling in an indoor gym in the Women's Building. Rest periods will be given to the subjects as needed, based on their individual fitness levels. Range of motion measurements, three-dimensional motion analysis, and postural stability measures will be re-tested after the exercise bout. This experimental protocol will be repeated five times (each time with a different ankle device) within a 14-day period.

3. Benefits and/or Risks to the Subjects

Subjects will benefit from participation in knowing that they have been part of a study that will increase the overall body of knowledge related to ankle injury prevention and may lead to recommendations regarding the effectiveness of ankle taping and bracing. At the completion of the study, each subject will also receive one pair of the ankle brace of their choice to use in their own ankle injury prevention plan.

Subjects will be exposed to minimal risk of injury through participation in this study. There is a minimal level of strain placed on the ankle ligaments during the short duration of treadmill running, as the tilt of the treadmill is equivalent to the slope experienced while running on the side of a typical city street. Subjects will also be required to perform vigorous exercise for 20 minutes, but rest periods will be provided when necessary. The possibility of a muscle injury or post-exercise muscle soreness exists, but pre-exercise warm-up and post-exercise cool-down periods have been included to minimize these risks.

4. Description of Subjects

The subject population in this study will include 12 healthy male and female college students (>18 years old). Subjects will be recruited for participation from the student population of this university. Subjects must not have suffered a serious ankle injury to either ankle or have greater than normal range of motion in either ankle. Subjects must not be currently competing in intercollegiate athletics, because if an athlete sustains an injury in their sport, they will be lost to this five-session experiment.

5. Informed Consent Document

See Appendix B.

6. Methods of Obtaining Informed Consent

A meeting will be held with each of the potential subjects at which the experimental protocol will be described to them. Explanation of the components of the study will be performed in the Sports Medicine Laboratory in the Women's Building, so that the subject will be able to see and become familiar with the machines and equipment on which they will be tested. On the first date of testing, each subject will be given a copy of the informed consent document to read and ask questions regarding the protocol or any of the experimental procedures. Following any discussion the subject will be asked to sign the Informed Consent Document. A copy of the signed document will be given to each subject and the original kept by the investigator.

7. Methods to Protect Subject Confidentiality

Each subject will have their identity remain confidential. The results of the study may be published, but subject's identities will not be published. Each subject will be assigned a code number, and only the investigators listed in conjunction with this study on the informed consent document will have access to these codes.

8. Copies of Any Questionnaire, Survey, or Testing Instrument

Not Applicable.

9. Other Approvals

Not Applicable.

APPENDIX B

INFORMED CONSENT DOCUMENT

A. <u>Title:</u> **Influence of Ankle Prophylactic Devices on Postural Stability and Ankle Joint Motion Before and After Exercise**

B. <u>Investigators:</u> Ryan A. Jorden
Rod A. Harter, Ph.D., ATC

C. <u>Purpose:</u> **To determine whether ankle protection devices (braces and tape) are successful in limiting ankle joint range of motion during dynamic activities and whether these devices have the ability to aid in postural stability. To determine whether the abilities and contributions of these devices have a capacity to protect and aid the ankle before and after vigorous exercise.**

D. <u>Procedures:</u> **I understand that as a participant in this study the following things will happen:**

1. <u>Pre-study Screening.</u>
   a. If I have suffered a serious ankle injury to either ankle or if my ankle has greater than normal range of motion, I will not be asked to participate in the study.
   b. If I am not older than 18 years old, I will not be asked to participate in this study. If I am a male older than 40, or female older than 50, I will not be asked to participate.
   c. If I am currently competing in intercollegiate athletics, I will not be asked to participate in this study.

2. <u>What participants will do during the study.</u>
   a. My participation will involve five testing sessions on five different days with at least one day in between sessions. The five sessions must be completed within a two-week period. For each of the sessions: I will have my ankles checked for range of motion and then I will be placed in one of five conditions (ankle tape, semirigid brace, two types of lace-up brace, or no restriction). I will be required to warm up for five minutes on a bicycle ergometer and then perform a one-legged balance test on a balance measuring machine. I will then be required to run (6:00 minute per mile pace) on a slightly side-tilted treadmill for 20 seconds. Then I will vigorously exercise for 20 minutes following a prescribed agility course and I will be given rest periods if they are needed. I will then be re-tested on the balance machine and on the treadmill.

3. <u>Foreseeable risks or discomforts.</u>
   a. I understand that there is a level of strain placed on the ankle ligaments during the short duration of treadmill running, but that the stress is no greater than that of running on a cambered road.
   b. There is also a requirement for vigorous exercise for a duration of 20 minutes with may result in muscle injury or post-exercise muscle soreness. Warm-up and cool-down periods have been included in the testing procedure to reduce this risk.

4. **Benefits to be expected from the research.**
   a. The information gained from this research will benefit the overall body of knowledge and may lead to concrete recommendations regarding the effectiveness of ankle taping and bracing. At the completion of the study I will be the recipient of my choice of one pair of the ankle braces used in the study.

E. **Confidentiality.**
   1. The results of this study may be published, but my name and identity will not be revealed in publications. I will be assigned a code number and the only people to have access to the code will be the investigators.

F. **Compensation for Injury.**
   1. I understand that Oregon State University does not provide a research subject with compensation or medical treatment in the event the subject is injured as a result of participation in this research project.

G. **Voluntary Participation Statement.**
   1. I understand that my participation in this study is completely voluntary and that I may either refuse to participate or withdraw from the study at any time without penalty. I understand that if I withdraw from the study before I have completed the five experimental sessions required, I will not receive a pair of ankle braces as compensation for my participation.

H. **If You Have Questions.**
   1. I understand that any questions that I may have about this research study or about the procedures that I am required to be part of be directed to Ryan A. Jorden, 103 Gill Coliseum, Oregon State University, Corvallis, Oregon at (541) 737-7489 or Dr. Rod A. Harter, Langton Hall 226, Oregon State University, Corvallis, Oregon at (541) 737-6801.
   2. If I have any questions regarding my rights as a research subject participating in this study, I should contact Mary Nunn, Director of Sponsored Programs, OSU Research Office, (541) 737-0670.

My signature below indicates that I have read and that I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

______________________	______________________
Subject's Signature	**Subject's Name (Printed)**
______________________	______________________
Date Signed	**Subject's Phone Number**
______________________	______________________
Signature of Principal Investigator	**Date Signed**

APPENDIX C

Ankle Brace Study 2000
Subject Initial Screening and Demographic Information

Subject Name: ______________________ **Telephone:** ______________

Address: ____

City: ______________________ **State:** ______ **Zip:** __________

E-mail address: ______________________ **Date of birth:** __________

Present age: ________ **Gender:** ❑ male ❑ female **Shoe size:** __________

Hgt (ft): ________ Hgt (cm): ________ **Wgt (lbs):** ________ Wgt (kg): ________

Dominant limb: ❑ right ❑ left **Foot type:** ❑ Egyptian ❑ Greek ❑ Square

Arch type: ❑ normal ❑ pes cavus ❑ pes planus **Fick angle:** __________

Hx:

____

____

Date of initial screening: ______________________

Anterior drawer test:	**Right**:	WNL	1+	2+	3+	**Left**:	WNL	1+	2+	3+
Inversion talar tilt:	**Right**:	WNL	1+	2+	3+	**Left**:	WNL	1+	2+	3+
Eversion talar tilt:	**Right**:	WNL	1+	2+	3+	**Left**:	WNL	1+	2+	3+

CONDITION:	**DATE:**
1. Control	______________
2. Closed basket weave taping	______________
3. Swede-O brace	______________
4. Aircast brace	______________
5. Royce Medical brace	______________

APPENDIX D

Ankle Injury Prevention Study - Winter Term 2000

Subject: ______________________ Date: __________________

Condition: ______________________ Session: 1 2 3 4 5

Pre-exercise:	PF	________	Post-exercise: PF	________
	DF	________	DF	________
	INV	________	INV	________
	EV	________	EV	________

Ankle Prophylaxis Evaluation:

Comfort - On a scale of 0 to 10, with 0 being "very uncomfortable" and 10 being "extremely comfortable", please evaluate the ankle injury prevention device you wore in today's session by making a vertical slash on the line:

0 ____ 10

very uncomfortable — extremely comfortable

Support - On a scale of 0 to 10, with 0 being "no ankle support" and 10 being "excellent ankle support", please evaluate the ankle injury prevention device you wore in today's session by making a vertical slash on the line:

0 ____ 10

no ankle support — excellent ankle support

Confidence in capability to prevent injury - On a scale of 0 to 10, with 0 being "no confidence" and 10 being "total confidence", please evaluate the ankle injury prevention device you wore in today's session by making a vertical slash on the line:

0 ____ 10

no confidence — total confidence

Overall rating - On a scale of 0 to 10, with 0 being "very poor" and 10 being "excellent", please evaluate the ankle injury prevention device you wore in today's session by making a vertical slash on the line:

0 ____ 10

very poor — excellent

APPENDIX E

REVIEW OF LITERATURE

There has been a substantial amount of research into the efficacy of ankle orthoses use in the prevention of ankle injuries and in the control of postural equilibrium. Epidemiological research has investigated ankle injury rates in comparison with the injury rates with ankle orthoses. Others have studied ankle range of motion restriction and the effects of bracing on athletic performance. Still other research has aimed at examining the link between ankle braces and kinesthesia. The combination of these various directions of research have given an increased understanding of the possible benefits of ankle bracing as a protective aid to the ankle joint ligament complex, and to proprioception.

Epidemiological studies have also been performed in order to qualify the benefits of ankle prophylactic devices. Rovere et al.[46] compared the effectiveness of tape and ankle orthoses to reduce ankle injuries in NCAA Division I football players over a four and a half-year period. These authors found that lace-up ankle stabilizers were more effective than ankle taping in preventing ankle injuries. Sitler et al. [48] reported that semirigid ankle stabilizers significantly reduced the frequency of ankle injuries in United States Military Academy cadets playing basketball. The identification of the actual means by which injury prevention occurs with these braces is yet to be determined.

Several studies have shown a number of commercially-available ankle braces to produce injury rates lower than or equal to those observed with ankle taping techniques.[10,24-26,46,53] Rovere et al.[46] reported that the injury rate for ankle inversion sprains while wearing lace-up ankle braces was 0.25 (1 injury in 400 exposures), compared with an injury rate of 0.42 (1 injury in 240 exposures) with ankle taping. The rate for more severe inversion ankle sprains (grades 2 and 3) was three times greater among the athletes who had their ankles taped compared with those who wore the ankle stabilizers. Rovere et al.[46] also documented seven ankle fractures during their four-year study and all of these occurred in the taped group.

Sitler et al.[48] reported 1 injury per 625 exposures in their ankle brace group, a rate significantly less than the 1 injury per 193 exposures in their control group. These authors monitored 13,430 exposures by intramural basketball players to injury and used braces versus non-braced conditions to decrease the pre-event preparation required for games and practices that would have been necessary if ankle taping had been used as a comparitor.

While the results of these two studies demonstrated differences in the protective abilities of ankle taping and the available ankle braces, these studies did not provide sufficient justification for the use of one type of ankle injury prophylaxis over another.

Anderson et al.[2] studied a nonrigid ankle brace under conditions simulating an unexpected fall using an inversion platform. Their results exhibited a significant reduction in both maximum inversion angle as well as inversion angular velocity, both before and after exercise while wearing the ankle orthosis.

Few studies have utilized closed kinematic chain locomotor activities to investigate the dynamic restraint provided by taping and prophylactic orthoses.[14,36,3947] Laughman et al.[31] used electrogoniometers to measure ankle ROM while walking on a sideslope and concluded that taping restricted motions associated with ankle sprains. Conversely, other studies have found tape to lose its restrictive ability following vigorous exercise.[35,36,43] Martin and Harter[36] utilized biomechanical motion analysis in order to determine ankle inversion during closed-chain laterally-tilted treadmill walking and running. Martin and Harter reported that following exercise, the taped ankles allowed inversion ROM not statistically different than the control (no tape) condition.

Simpson et al.[47] tested semirigid and lace-up braces in comparison with a nonbraced condition using high-speed kinematics during a repeated lateral cutting exercise. These authors found that based on the kinematic data, none of the bracing conditions restricted subtalar inversion in comparison with the nonbraced condition. DeClercq[14] found kinematically that wearing a semirigid orthoses during running at 4.5 m/s, significantly limited the total subtalar eversion range as well as maximum eversion velocity.

Several different measurement techniques have been used to demonstrate that ankle taping loses its ability to restrict ROM, during vigorous exercise. Using electromyography (EMG), Karlson and Andreasson[27] found that ankle taping reduced the reaction time for ankle evertors during an inversion action. These authors also suggested that there must be another benefit from ankle taping other than the short-duration increase in mechanical stability. This benefit is likely a proprioceptive advantage.

Postural Stability Testing

Neuromuscular control has been shown to be a contributing factor to the regulation of the ankle in preventing inversion ankle sprains.[5] Konradsen et al.[30] corroborated the findings of Ashton-Miller et al.[5] and suggested that in instances of sudden ankle-foot inversion, only the strength of the ankle musculature and the protection provided by an external support can protect the ankle from inversion injuries.

Baumhauer and colleagues[7] sought to determine anatomical and strength predictors for ankle injuries. These authors found no significant differences between injured and uninjured ankles for joint laxity, anatomical foot and ankle alignment, ligament stability or isokinetic strength. However, the eversion-to-inversion ratio was significantly greater and different for injured subjects. This strength imbalance demonstrated an increased level of inversion ankle sprains.

Most research regarding postural stability has investigated center of pressure and sway using force platforms. In conjunction with the muscular protection of the ankle, it is important to gain an understanding of the capacity of various braces to aid in ankle inversion protection. The bracing techniques will likely aid in stabilization of the ankle but it is yet to be determined to what extent each brace will limit ankle inversion or influence postural stability throughout a vigorous exercise session. We know that tape loses its restrictive capacity during 10 to 20 minutes of exercise, but it is unknown what effect (and for how long) tape has on proprioception and postural stability.

Bernier et al.[9] did not expect to find a poor relationship between mechanical instability and postural sway in individuals with ankle instability. These authors suggested that factors other that damaged mechanoreceptors may cause functional instability, and that muscle and skin afferents may be providing adequate feedback in closed chain exercises and compression settings. Docherty et al.[15] also downplayed joint mechanoreceptor contribution to position sense and suggested that muscle spindle sensitivity or central mechanisms related to muscle spindles may be a controlling factor of joint position control.

Kinzey et al.[29] found that average AP and ML center-of-pressure positions were increased during brace wearing. These authors expected to find that the wearing of braces would lower the average ML and AP center-of-pressure values. They hypothesized that it may be possible that the movement averages were a response to enhanced proprioception which led to repositioning the center-of-pressure in a more stable position. Bennell and Goldie[8] found subjects to be significantly less stable when wearing either tape or bracing conditions. These findings depict the uncertainty of the contribution of ankle orthoses to kinesthesia.

Arnold and Schmitz[4] evaluated normal patterns of stability on the Biodex Stability System. These authors found that uninjured subjects spent almost 85% of the time between the 0° and 5° zones on the Biodex Stability System. They also found that 95% of the variance that was present in the overall stability index was accounted for by the anterior/posterior stability index as a result of Biodex stability index calculation.

Testerman and Vander Griend[51] utilized the Biodex Stability System to examine proprioception in individuals with confirmed ankle instability (stress radiographs). Subjects were tested on varying levels of platform stability. These authors concluded that the Biodex may be an good and objective device for measuring proprioceptive function.

Types of Bracing

There are many different commercially available braces that are currently used in locomotor activity levels ranging from recreational to the professional. However, most laboratory comparisons of these braces were tested under static and/or non-physiologic loads, thus limiting the validity as well as the generalizability of the results. It remains to be seen if the various types of braces are equally protective. The ability of each brace to increase the stiffness of the ankle and aid in the reduction of postural sway will likely influence the prophylactic benefit of each particular brace. With a lack of conclusive results, taping continues to be a popular method of prophylaxis that is used in many sports settings.

To date there has not been a study that has thoroughly investigated the activity of the ankle and its control, with various prophylactic techniques in a closed-chain dynamic three-dimensional activity situation. This study will be performed in this type of setting, will also assess postural stability control, and will aid in making recommendations regarding the efficacy of ankle prophylaxes in limiting ankle and subtalar joint range of motion under dynamic loads.

Methodology

Research studies have suggested that there is a direct correlation between various lower extremity injuries and locomotive patterns that are part of walking and running gait cycles.[12,50] Specifically there has been a significant amount of investigation into the activities about the ankle joint and foot and the direct relationship between exaggerated motion of the foot and overuse injuries. Many of these studies have been performed using kinematic analysis in an effort to assess foot and ankle motion in order to aid in injury prevention and to specifically identify contributing factors to lower extremity and foot injuries.

In locomotor movements it is essential for the foot and ankle complex to be a very adaptable structure. This complex is required to perform flexible activities in adjusting to terrain, become semi-rigid when acting as a spring or cushion for the body and to become a stable rigid segment to support body weight during the stance phase. As a result of the adaptability of the foot and ankle complex, there is a propensity for excessive motion to occur.[45]

Movement activities of the foot and ankle directly effect and are directly effected by the biomechanics of the lower extremities that accompany locomotor movement. Femoral and tibial rotation is inherently involved with ankle and foot motion. As the stance phase begins, the tibia is slightly medially rotated. As stance progresses there is medial rotation of the lower leg segment until just before midstance. After midstance, the lower limb rotates laterally until the end of the stance phase at toe-off. As these rotations are occurring in the lower limb, they are directly related to movement that is occurring in the ankle and foot. The combined movements of the lower leg and of the ankle/foot complex allow for a decrease in the forces that are present in the lower extremity by extending the time that the foot is in contact with the ground during stance. This movement in the foot from supination to pronation and then back to supination allows for a longer stance phase to occur while aiding in the braking and propulsive aspects of stance.[44]

More specifically, the subtalar joint is a hinge joint involved in inversion and eversion movement about the ankle. The subtalar joint participates in motion in the three cardinal planes of the body and allows for pronation and supination to occur.[45] During walking and running, the normal motion during the stance phase involves the subtalar joint starting in a slightly supinated position at heel strike and then rotating into a position of pronation as the stance phase progresses towards midstance. Maximal pronation occurs sometime before 50% of the stance phase has progressed and then the foot moves into a supinated position until toe-off.

Rearfoot motion is widely accepted as a measurable means to assess pronation during walking and running. Pronation as described previously is both beneficial and essential to a "normal" stance phase during walking. However, excessive subtalar movement especially in pronation has been directly correlated in clinical studies to contribute to lower extremity injuries, including shin splints, and knee pain. Subsequently, studies have focused on examining the degree of pronation that is present during running. Clinical researchers have not found success in using static measures to determine the ranges of motion in the lower extremities and foot. These static, open-chain measures do not translate to the accurate prediction of rearfoot pronation during running and walking.[40]

Kinematic analysis is essential to the investigation of rearfoot motion in order to assess levels of pronation and to determine a relationship to injuries associated with running. Lemke et al.[32] found that there were no statistical differences between tibial, calcaneal and rearfoot motions when compared during treadmill and overground walking and indicated that locomotion on a treadmill is therefore a valid simulator of overground locomotion.

A majority of the kinematic analyses that have been performed involving rearfoot motion have been done in a two-dimensional framework. However, there are a couple of major variables that can contribute to error in measurement within two-dimensional analyses. Angles that are measured in 2D are calculated about a fixed coordinate axes, which is outside of the triplanar movement of the body. Thus, 2D measurements result in relationships of angles that are not reflective of the actual movements of the lower extremities during dynamic movement.

It has been shown that angular values measured from a posterior view in two-dimensional analysis are sensitive to the alignment angle of the camera. The angular abduction of the foot contributes to inaccuracies in angular calculations, since the camera-filming plane is no longer perpendicular to the sagittal plane of motion during footfall. The influence of normal physiological rotations of the lower extremity and foot during running results in projection and calculation errors in two-dimensional rearfoot motion.[3] Some research has indicated that the differences between two and three-dimensional analyses of rearfoot motion are minimal if the two-dimensional analysis is constrained to the first 60% of the stance phase.[13] However, others have found that with increased abduction of the foot, a more pronated angle will be found in the early part of the stance phase and a more supinated angle will be seen in the later part of the stance phase when using two-dimensional analysis.[3] Up to 40 percent errors have been calculated in angular deviation of less than 10 percent from the projected 2D plane.[49]

Recently, McClay and Manal[38] suggested that caution be used when interpreting 2D rearfoot variables at heel strike and toe off, as well as times to peak values. McClay and Manal[38] indicate that differences can be magnified between the use of two-dimensional and three-dimensional analyses. This is in part due to the slower camera speeds utilized in the past studies (60Hz), versus the current sampling frequencies (120 Hz) available in this study. While 60 Hz data collection was accurate, it may not allow for accurate depiction of the whole event due to missed points at higher rates of running speeds. The increase in data sampling frequency in this study will permit increased depth of investigation by way of providing two times more data and a more accurate investigation and assessment of the rearfoot motion than was previously possible.

APPENDIX F

SUBJECT DATA

TREADMILL RUNNING MAXINV ANGLES

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	10.938	5.086	9.689	9.966	8.257	7.517	8.719	12.014	5.987	9.570
Subj #2	9.059	8.589	5.174	7.842	6.940	5.608	3.280	5.922	6.940	5.608
Subj #3	7.574	7.542	6.634	6.012	12.051	9.565	3.123	5.462	7.240	10.521
Subj #4	12.987	8.418	15.397	16.864	12.399	12.080	12.582	16.079	11.949	12.235
Subj #5	6.442	2.024	5.887	2.863	0.739	2.119	4.257	1.764	4.652	8.562
Subj #6	7.076	4.797	6.689	7.182	7.341	12.509	7.855	7.293	8.460	12.177
Subj #7	14.742	15.269	15.229	14.219	9.062	8.777	12.193	16.739	13.920	11.058
Subj #8	3.329	3.529	6.405	5.531	5.662	4.680	1.987	4.904	3.158	4.045
Subj #9	12.691	12.370	10.572	8.207	6.981	9.990	2.915	1.846	8.915	1.828
Subj #10	15.190	21.799	16.957	17.799	13.691	16.215	10.959	10.319	16.166	9.458
Subj #11	5.902	5.621	8.276	9.086	10.806	7.787	9.188	8.647	7.888	6.842
Subj #12	3.347	3.383	4.619	2.323	5.600	3.943	5.320	4.226	3.810	4.102
Subj #13	11.029	11.144	13.033	13.318	10.816	13.205	5.402	6.043	6.005	7.547
Subj #14	7.695	7.249	6.816	6.697	5.889	9.585	6.999	7.666	7.184	6.966
Subj #15	4.941	3.527	11.678	9.205	5.196	6.623	6.616	6.528	5.300	4.162
Means	8.863	8.023	9.537	9.141	8.095	8.680	6.760	7.697	7.838	7.645
Stdev	3.897	5.311	4.067	4.626	3.421	3.818	3.435	4.473	3.664	3.231

SUBJECT DATA

MAXAV

Subject	Control Pre	Control Post	Tape Pre	Tape Post	Swede0 Pre	Swede0 Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	123.561	117.259	53.565	46.366	57.867	93.253	58.161	55.977	44.802	37.519
Subj #2	40.538	5.845	32.878	-14.140	43.825	27.305	20.565	33.544	43.825	40.361
Subj #3	20.752	14.422	35.194	33.724	58.510	45.639	45.469	56.979	38.365	30.805
Subj #4	44.187	26.379	64.479	75.361	38.543	38.120	55.201	63.009	28.600	52.962
Subj #5	81.333	70.767	85.349	85.738	78.695	78.889	75.282	63.829	104.353	97.661
Subj #6	71.556	64.192	119.014	84.051	105.761	110.434	89.734	86.618	113.661	109.029
Subj #7	54.671	54.056	91.175	89.085	76.418	34.895	97.931	70.876	55.061	37.558
Subj #8	77.247	71.144	56.448	103.529	37.977	82.295	40.701	85.766	53.817	61.370
Subj #9	60.580	47.865	68.194	123.891	50.177	54.480	62.400	82.112	47.608	71.666
Subj #10	159.950	175.187	168.329	211.739	153.434	218.959	112.542	110.656	144.131	86.937
Subj #11	46.310	29.328	107.282	99.112	79.230	102.714	77.572	57.379	79.885	110.132
Subj #12	43.346	42.517	78.965	85.585	67.249	51.141	62.215	59.948	68.071	88.539
Subj #13	49.348	26.501	63.298	45.201	89.986	86.076	49.176	46.688	20.651	30.794
Subj #14	27.452	34.885	64.021	127.961	76.308	106.788	115.394	111.961	26.622	28.899
Subj #15	48.799	72.112	115.739	76.176	109.285	160.499	92.696	59.504	27.641	13.509
Means	63.309	56.831	80.262	84.892	74.884	86.099	70.336	69.656	59.806	59.849
STDev	36.560	43.196	35.753	50.488	30.991	51.298	27.326	22.007	36.112	31.950

SUBJECT DATA

TCA@MAXINV

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	80.168	83.036	80.762	81.094	84.321	85.780	83.615	82.794	80.958	79.528
Subj #2	80.851	78.329	76.498	75.276	79.155	77.587	78.224	78.846	78.153	76.586
Subj #3	80.570	81.205	81.201	86.071	81.983	78.636	83.187	83.539	80.262	82.469
Subj #4	80.527	81.949	81.823	83.016	80.723	80.118	80.256	75.219	80.698	82.351
Subj #5	88.796	86.210	87.930	86.042	88.470	89.668	88.123	87.938	88.511	86.489
Subj #6	83.637	84.978	86.695	84.858	89.269	89.693	84.059	85.116	84.234	86.239
Subj #7	82.608	77.997	84.197	85.290	88.866	87.643	87.956	87.563	83.118	79.902
Subj #8	88.406	89.221	81.393	82.315	90.086	88.234	83.294	85.382	87.829	87.401
Subj #9	82.523	83.684	85.790	85.493	87.999	87.689	85.252	86.461	85.953	83.761
Subj #10	75.151	76.920	77.449	80.588	82.339	80.479	84.507	84.727	75.328	78.925
Subj #11	84.533	82.022	85.449	85.818	86.626	86.782	86.746	87.676	83.711	84.310
Subj #12	82.247	83.229	81.338	83.450	84.425	83.279	83.211	79.382	85.989	84.419
Subj #13	85.538	84.843	84.296	82.851	88.540	89.297	87.627	83.114	87.424	87.315
Subj #14	79.671	79.784	77.379	80.439	85.241	84.372	81.964	81.421	77.690	77.209
Subj #15	87.132	87.510	85.661	83.927	87.978	88.075	86.219	84.446	85.603	86.655
Means	82.824	82.728	82.524	83.102	85.735	85.155	84.283	83.575	83.031	82.904
Dorsiflexion	7.176	7.272	7.476	6.898	4.265	4.845	5.717	6.425	6.969	7.096
STDev	3.654	3.541	3.568	2.911	3.438	4.165	2.833	3.616	4.029	3.702

SUBJECT DATA

BIODEX MEDIOLATERAL SWAY INDICES

EYES	OPEN									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**Swede O Pre**	**Swede O Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	1.0	1.0	1.3	1.0	1.4	1.1	1.0	0.9	1.4	1.2
Subj #2	1.4	1.5	1.9	2.6	2.4	2.0	1.5	1.2	1.7	2.2
Subj #3	1.7	1.8	1.6	2.1	1.9	1.8	1.4	1.3	1.8	2.0
Subj #4	1.3	1.6	1.5	0.9	1.4	1.4	1.4	1.8	1.5	1.1
Subj #5	0.9	1.0	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.9
Subj #6	1.5	1.4	1.3	1.9	1.7	1.6	1.7	1.7	1.7	2.4
Subj #7	1.1	1.1	1.2	1.4	1.1	1.2	1.5	1.1	1.3	1.8
Subj #8	1.9	1.6	2.3	1.6	2.8	2.0	1.3	2.0	2.1	1.5
Subj #9	2.2	1.8	2.5	2.1	2.0	2.4	2.2	2.6	2.2	1.5
Subj #10	2.3	1.9	3.3	4.0	3.7	3.2	3.3	2.8	1.9	3.1
Subj #11	1.3	1.1	1.9	1.1	0.8	1.3	1.1	1.6	1.0	0.9
Subj #12	1.3	1.4	1.5	1.0	1.3	1.6	1.5	1.0	1.4	1.2
Subj #13	1.9	2.0	3.0	2.1	2.4	1.5	3.0	2.2	1.9	1.6
Subj #14	2.1	2.0	1.7	2.1	2.0	1.9	4.2	2.7	2.7	1.9
Subj #15	1.0	1.5	1.1	1.3			1.2	0.9	1.1	2.1
Mean	1.5	1.5	1.8	1.7	1.8	1.7	1.8	1.6	1.6	1.7
STDev	0.45	0.36	0.75	0.88	0.81	0.60	0.99	0.68	0.49	0.63

EYES	CLOSED									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**Swede O Pre**	**Swede O Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	1.9	2.4	2.8	2.4	2.2	2.2	2.1	2.1	2.3	1.4
Subj #2	2.3	3.0	2.7	3.0	3.1	2.9	2.5	2.5	3.1	2.3
Subj #3	2.2	2.3	2.6	2.4	1.6	1.6	2.3	1.9	2.7	2.5
Subj #4	2.1	2.0	1.8	1.5	2.6	1.6	2.4	2.0	2.0	2.1
Subj #5	1.8	1.8	1.4	1.3	1.2	1.2	1.2	1.7	1.7	2.2
Subj #6	2.5	2.8	2.4	3.1	2.5	2.3	1.7	1.9	2.6	2.7
Subj #7	2.2	2.2	2.2	1.7	1.9	1.9	2.0	1.2	2.2	2.4
Subj #8	2.7	2.9	2.3	2.7	2.8	2.5	1.9	2.1	2.9	2.7
Subj #9	2.2	2.2	2.2	2.1	1.9	2.2	2.6	1.9	1.7	2.0
Subj #10	3.0	2.9	3.7	2.9	3.1	2.8	3.1	2.5	2.8	2.7
Subj #11	2.4	1.8	1.7	1.7	1.1	1.5	1.7	1.7	1.7	1.8
Subj #12	2.1	2.0	2.6	2.1	1.4	2.0	2.1	1.7	2.4	2.1
Subj #13	3.2	2.3	3.4	2.6	2.8	2.6	3.5	2.6	2.5	2.5
Subj #14	2.1	2.2	2.0	1.7	2.5	2.4	3.0	2.9	2.3	2.3
Subj #15	1.8	1.8	1.2	1.4			1.5	1.3	2.0	2.7
Mean	2.3	2.3	2.3	2.2	2.2	2.1	2.2	2.0	2.3	2.3
STDev	0.40	0.40	0.62	0.58	0.69	0.50	0.62	0.46	0.46	0.36

SUBJECT DATA

BIODEX ANTERIOR/POSTERIOR SWAY INDICES

EYES	OPEN									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**SwedeO Pre**	**SwedeO Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	2.0	1.0	1.1	1.1	1.5	1.6	1.0	1.0	1.2	1.4
Subj #2	1.7	1.8	1.9	2.7	2.0	1.7	1.7	1.5	1.5	1.5
Subj #3	2.1	2.9	1.9	2.1	2.7	2.2	1.5	1.6	2.4	1.8
Subj #4	1.4	1.3	1.6	1.4	1.2	1.3	2.2	1.1	1.5	1.1
Subj #5	0.8	1.0	0.7	0.8	0.7	0.8	1.2	0.6	1.5	0.9
Subj #6	3.5	2.1	2.4	3.2	2.4	1.4	1.4	1.7	2.3	2.8
Subj #7	1.2	1.3	1.6	2.2	1.7	2.0	1.9	1.9	1.5	2.0
Subj #8	2.2	1.9	2.0	2.3	4.3	2.1	2.3	2.1	3.9	2.1
Subj #9	2.4	1.7	2.4	2.3	2.1	2.4	2.8	3.1	2.6	1.5
Subj #10	1.5	2.2	1.3	1.2	1.3	1.7	1.3	1.1	1.3	2.1
Subj #11	2.3	1.3	2.3	1.1	1.2	1.5	1.7	1.7	1.2	1.3
Subj #12	1.7	1.6	2.1	1.7	1.7	1.9	1.5	1.5	1.4	1.5
Subj #13	3.2	1.0	3.8	1.4	3.0	2.3	1.9	1.5	1.5	0.9
Subj #14	2.1	2.1	1.9	1.9	2.2	2.5	4.7	4.1	3.9	2.8
Subj #15	1.6	1.4	1.0	2.1			1.2	1.2	1.4	1.7
Mean	2.0	1.6	1.9	1.8	2.0	1.8	1.9	1.7	1.9	1.7
STDev	0.71	0.56	0.72	0.69	0.91	0.49	0.94	0.89	0.92	0.60

EYES	CLOSED									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**SwedeO Pre**	**SwedeO Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	2.9	2.6	2.3	3.5	2.6	2.3	2.8	2.4	2.8	2.5
Subj #2	3.0	3.0	4.1	4.4	3.6	3.2	3.3	2.7	4.9	1.9
Subj #3	2.7	3.2	3.7	4.3	2.3	2.1	3.1	2.4	2.7	4.3
Subj #4	2.5	3.4	2.1	1.7	2.9	3.0	3.0	3.1	3.0	2.3
Subj #5	1.7	1.5	1.7	1.5	1.5	1.2	1.4	1.9	1.2	1.7
Subj #6	3.9	3.8	3.2	4.1	3.6	2.9	2.6	2.3	2.9	3.3
Subj #7	4.2	3.2	5.1	2.5	2.2	2.8	2.7	2.2	2.7	2.9
Subj #8	4.3	6.3	4.3	5.5	5.6	3.5	3.0	3.7	3.7	4.4
Subj #9	2.8	2.2	4.3	4.1	2.8	2.5	4.7	2.4	3.3	2.6
Subj #10	2.2	2.4	3.1	2.2	1.7	2.4	2.1	2.2	4.4	1.9
Subj #11	2.3	3.2	2.2	2.6	1.8	2.3	2.2	2.4	2.4	1.7
Subj #12	2.5	3.1	3.3	2.3	2.7	3.0	2.4	2.1	2.2	2.2
Subj #13	4.1	5.1	4.2	4.6	3.8	4.6	3.9	3.0	2.7	4.0
Subj #14	3.8	3.2	3.5	3.0	3.9	4.3	5.1	5.7	6.3	5.1
Subj #15	2.5	3.0	2.3	2.4			2.4	2.5	3.0	3.9
Mean	3.0	3.3	3.3	3.3	2.9	2.9	3.0	2.7	3.2	3.0
STDev	0.84	1.19	1.03	1.22	1.09	0.87	0.99	0.96	1.26	1.13

SUBJECT DATA

BIODEX OVERALL STABILITY INDICES

EYES	OPEN									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**Swede O Pre**	**Swede O Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	2.1	1.3	1.6	1.4	2.0	1.8	1.2	1.2	1.8	1.7
Subj #2	2.1	2.3	2.6	3.6	2.9	2.6	2.2	1.8	2.2	2.5
Subj #3	2.5	3.3	2.4	2.8	3.2	2.8	1.8	1.9	2.8	2.5
Subj #4	1.8	1.9	2.1	1.7	1.8	1.8	2.4	2.0	2.0	1.4
Subj #5	1.1	1.3	0.7	0.8	1.1	1.0	1.3	0.9	1.6	1.2
Subj #6	3.7	2.4	2.6	3.6	2.8	2.1	2.1	2.3	2.8	3.6
Subj #7	1.6	1.5	1.9	2.5	1.9	2.2	2.3	2.1	1.9	2.6
Subj #8	2.8	2.3	3.0	2.7	5.1	2.8	2.6	2.8	4.3	2.5
Subj #9	3.2	2.3	3.4	3.0	2.8	3.3	3.5	4.0	3.4	2.0
Subj #10	2.6	2.9	3.5	4.1	3.9	3.5	3.5	2.9	2.2	3.6
Subj #11	2.5	1.5	2.8	1.4	1.3	1.9	1.9	2.2	1.5	1.5
Subj #12	1.9	2.0	2.4	1.9	2.1	2.4	2.0	1.8	1.9	1.8
Subj #13	3.5	2.1	4.6	2.4	3.7	2.7	3.5	2.4	2.3	1.7
Subj #14	2.8	2.8	2.4	2.7	2.9	2.9	6.2	4.9	4.6	3.2
Subj #15	1.8	1.9	1.4	2.4			1.5	1.4	1.7	2.5
Mean	2.4	2.1	2.5	2.5	2.7	2.4	2.5	2.3	2.5	2.3
STDev	0.73	0.60	0.92	0.95	1.09	0.67	1.28	1.03	0.97	0.80
EYES	CLOSED									
Subject	**Control Pre**	**Control Post**	**Tape Pre**	**Tape Post**	**Swede O Pre**	**Swede O Post**	**Royce Pre**	**Royce Post**	**Aircast Pre**	**Aircast Post**
Subj #1	3.3	3.5	3.4	4.3	3.3	3.0	4.0	3.1	3.5	3.0
Subj #2	3.7	4.2	4.7	5.1	4.8	4.3	4.0	3.6	5.6	2.9
Subj #3	3.3	3.8	4.4	4.8	2.7	2.5	3.7	3.0	3.8	4.8
Subj #4	3.1	3.8	2.7	2.1	3.8	3.3	3.6	3.6	3.5	2.9
Subj #5	2.4	2.2	2.0	1.9	1.8	1.6	1.7	2.4	1.9	2.7
Subj #6	4.6	4.6	3.9	5.1	4.3	3.6	3.0	2.8	3.7	4.2
Subj #7	4.6	3.7	5.5	2.9	2.8	3.2	3.3	2.9	3.4	3.7
Subj #8	4.9	6.8	4.7	6.0	6.2	4.2	3.4	4.1	4.5	5.1
Subj #9	3.4	2.9	4.8	4.4	3.2	3.2	5.2	2.9	3.7	3.2
Subj #10	3.5	3.7	4.7	3.5	3.4	3.5	3.7	3.2	5.2	3.1
Subj #11	3.1	3.5	2.7	3.0	2.0	2.6	2.7	2.7	2.9	2.3
Subj #12	3.1	3.5	4.1	3.0	2.9	3.6	3.0	2.6	3.1	2.9
Subj #13	5.0	5.5	5.4	5.2	4.6	5.2	5.3	3.9	3.5	4.6
Subj #14	4.2	3.7	4.0	3.3	4.5	4.8	5.8	6.3	6.7	5.5
Subj #15	3.1	3.4	2.5	2.7			2.7	2.7	3.5	4.6
Mean	3.7	3.9	4.0	3.8	3.6	3.5	3.7	3.3	3.9	3.7
STDev	0.80	1.11	1.05	1.25	1.19	0.95	1.09	0.97	1.22	1.02

SUBJECT DATA

AROM INVERSION

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	39.5	36	33	35	30.5	36	34	41	33	36
Subj #2	42	43.5	43.5	40.5	39	35	46	40	37	39
Subj #3	39.5	32	33	32	22	27	23	27.5	21.5	29.5
Subj #4	42	36	27.5	35.5	27.5	30	36	31	23	33
Subj #5	45	35	26.5	34	34	33.5	36.5	31	36	44
Subj #6	41	38	27	32	34	33	37	35.5	30.5	34.5
Subj #7	29.5	34	23	28	19	31	28	33.5	37	33
Subj #8	27	23	21	30.5	24	29	27.5	31	25	25
Subj #9	50	48	40	35	33.5	38	47	34	33.5	34
Subj #10	46.5	47	28	38	39	37.5	38.5	40	34.5	28
Subj #11	34	24.5	25	34	29	29	31	34	28	30
Subj #12	43.5	42	32	33	37	33	36.5	41	36.5	42
Subj #13	30.5	36	21	31.5	25	40	34.5	34	26.5	32
Subj #14	37	51	27	46	36	40.5	49.5	45.5	39.5	39
Subj #15	40.5	46	36.5	46	35	34	33	26.5	39	47
Mean	39.2	38.1	29.6	35.4	31.0	33.8	35.9	35.0	32.0	35.1
STDev	6.5	8.2	6.7	5.2	6.3	4.1	7.3	5.4	5.9	6.1

SUBJECT DATA

AROM EVERSION

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	22	17.5	16.5	22	23	18	17	18	21	23
Subj #2	25	25	19.5	22.5	13	21	20	18	24	20
Subj #3	21	19	19	22.5	15	17.5	11	13.5	14	21
Subj #4	23.5	18.5	19.5	22	23	21	18.5	13.5	21	21.5
Subj #5	22	24	21	29	24	18	15	17.5	25	23
Subj #6	23	22.5	16	22	18.5	23	15	15	19.5	17
Subj #7	32	32.5	23.5	22	26.5	20	24	27	29.5	33
Subj #8	24.5	26	18	22	25	25.5	17	16.5	21.5	26
Subj #9	17.5	18.5	8	14	18.5	21	14	17	22	20
Subj #10	24	26	24	26.5	25	24	23	19	26.5	23
Subj #11	21.5	15	16	18.5	15	18	12.5	20	21.5	24
Subj #12	18	20	18.5	17.5	14	16.5	16	21	20	20
Subj #13	22	16	17	24	13	15.5	19	18	16	16.5
Subj #14	24.5	21	16.5	18	19.5	17	12.5	17.5	25.5	21
Subj #15	17.5	11	9	12	10	15	10	15	21	14
Mean	22.5	20.8	17.5	21.0	18.9	19.4	16.3	17.8	21.9	21.5
STDev	3.6	5.3	4.4	4.4	5.3	3.1	4.1	3.3	3.9	4.4

SUBJECT DATA

AROM PLANTARFLEXION

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	49	57	25	43	41.5	51.5	60	59	61.5	58
Subj #2	58.5	68.5	40	42	42	40	39	41	57.5	56.5
Subj #3	41	43.5	42	40	25	22	33	32	47	43
Subj #4	41	50	46	52.5	43.5	42	35	44	44	46.5
Subj #5	48.5	50	32	47	45	48	26	30	41	53
Subj #6	40.5	54	36	46	49	45	34	36.5	59.5	59.5
Subj #7	71	74	39.5	42	46.5	49.5	55.5	54	72	71
Subj #8	61	60	47.5	53	59	63	46	48.5	59	61
Subj #9	42.5	42	30	41	41.5	41.5	35.5	37	40	37.5
Subj #10	69	69	36	56	53.5	69.5	60.5	58	65	68
Subj #11	64.5	66.5	49	64	61.5	62	55	59.5	67	67.5
Subj #12	49.5	46.5	32	27	45.5	46.5	43.5	51	42.5	41.5
Subj #13	50.5	51	23.5	35.5	36.5	35	32	32	41	42
Subj #14	50	57	40	45.5	44	39	39	44	42	48.5
Subj #15	70.5	70	51	64	59	61.5	56	59.5	66	66.5
Mean	53.8	57.3	38.0	46.6	46.2	47.7	43.3	45.7	53.7	54.7
STDev	11.1	10.3	8.4	10.0	9.4	12.4	11.4	10.8	11.5	11.0

SUBJECT DATA

AROM DORSIFLEXION

Subject	Control Pre	Control Post	Tape Pre	Tape Post	SwedeO Pre	SwedeO Post	Royce Pre	Royce Post	Aircast Pre	Aircast Post
Subj #1	14	16	6.5	14	3	7.5	11	13	8	9.5
Subj #2	13	15	10	17	6	15	9	12	9	16
Subj #3	8.5	9.5	10	12	7.5	10	12	11	5	7
Subj #4	8.5	11	9.5	11	6.5	10	12	12	12	12.5
Subj #5	20	23.5	13.5	19.5	18	17	17	16	23	19.5
Subj #6	11.5	18	11.5	12	7.5	10.5	10	12	8	6
Subj #7	20	20	17	21.5	13.5	15	10.5	15.5	15	18
Subj #8	7.5	15	10	14	13.5	18.5	11	15	12	13
Subj #9	9.5	13	10.5	9	10	11	10	14	10	14
Subj #10	7.5	12	5.5	11	4	8.5	9	10	8	6
Subj #11	3.5	5	1	4	2.5	4.5	6.5	7.5	1	5.5
Subj #12	14.5	17	18	17.5	9	12	13	18	12.5	12.5
Subj #13	16.5	17	4	13.5	4	6	7.5	15	15	21
Subj #14	17.5	17	4	10.5	6.5	8	5.5	8.5	18	15.5
Subj #15	8	8.5	1.5	9.5	4	7	8.5	10	9	8
Mean	12.0	14.5	8.8	13.1	7.7	10.7	10.2	12.6	11.0	12.3
STDev	5.0	4.8	5.1	4.5	4.4	4.1	2.8	3.0	5.4	5.1

SUBJECT DATA

SUBJECTS' VAS RATINGS

Condition	Subject	Comfort	Support	Confidence	Overall	Overall Rank
Tape	Subj #1	71	85	88	87	2
	Subj #2	59	46	56	55	3
	Subj #3	100	76	50	70	3
	Subj #4	81	82	81	79	1
	Subj #5	23	96	96	75	2
	Subj #6	71	81	63	68	2
	Subj #7	34	78	47	54	1
	Subj #8	79	53	73	69	1
	Subj #9	2	63	19	27	2
	Subj #10	36	65	51	51	4
	Subj #11	62	70	49	64	3
	Subj #12	51	74	73	65	1
	Subj #13	22	74	74	61	3
	Subj #14	91	92	91	92	1
	Subj #15	69	95	90	85	1
	Average	56.7	75.3	66.7	66.8	2.0
SwedeO	Subj #1	38	60	60	47	4
	Subj #2	33	37	31	31	4
	Subj #3	73	88	88	87	1
	Subj #4	56	71	69	69	2
	Subj #5	87	25	32	44	4
	Subj #6	69	65	64	65	3
	Subj #7	56	44	27	48	2
	Subj #8	23	59	67	31	4
	Subj #9	13	54	48	20	3
	Subj #10	91	79	78	88	1
	Subj #11	67	63	63	66	2
	Subj #12	48	70	67	58	3
	Subj #13	47	53	57	53	4
	Subj #14	87	84	82	86	2
	Subj #15	81	63	54	64	3
	Average	57.9	61.0	59.1	57.1	2.8
Royce	Subj #1	93	87	90	91	1
	Subj #2	64	63	63	65	1
	Subj #3	100	56	57	76	2
	Subj #4	67	63	62	63	3
	Subj #5	98	97	96	96	1
	Subj #6	78	79	79	81	1
	Subj #7	70	26	22	39	3
	Subj #8	71	52	62	59	2
	Subj #9	52	57	24	43	1
	Subj #10	54	73	78	65	3
	Subj #11	86	59	54	67	1
	Subj #12	66	58	55	60	2
	Subj #13	61	83	80	85	1
	Subj #14	92	89	82	85	3
	Subj #15	71	64	42	54	4
	Average	74.9	67.1	63.1	68.6	1.9
Aircast	Subj #1	80	90	89	84	3
	Subj #2	64	57	59	61	2
	Subj #3	79	14	11	35	4
	Subj #4	75	60	60	62	4
	Subj #5	66	42	51	60	3
	Subj #6	58	72	42	58	4
	Subj #7	67	21	13	38	4
	Subj #8	79	39	42	51	3
	Subj #9	40	22	5	19	4
	Subj #10	88	70	72	81	2
	Subj #11	79	40	27	46	4
	Subj #12	72	24	26	42	4
	Subj #13	85	53	62	62	2
	Subj #14	76	74	85	83	4
	Subj #15	92	66	78	73	2
	Average	73.3	49.6	48.1	57.0	3.3