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The effects of prolonged prophylactic ankle bracing on dynamic postural control

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The Effects of Prolonged Prophylactic Ankle Bracing on Dynamic Postural Control

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ABSTRACT

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on Dynamic Postural Control

Brinn M. Spencer, ATC

Context: Studies in the past have been conducted regarding ankle braces and their efficacy, cost effectiveness and their effects on functional performance, but there is a lack of literature regarding how extended use of prophylactic bracing may affect dynamic postural control. *Objective:* The purpose of this study was to determine if the use of a prophylactic ankle brace over the course of an entire volleyball season would impair dynamic postural control. *Design:* The design of this study was a 3x8 factorial design. The independent variables were time (pre-season, mid-season and post-season) and direction (anterior, posterior, medial, lateral, anteromedial, anterolateral, posteromedial, posterolateral). The dependent variable was reach distance in eight directions, as measured by the star excursion balance test (SEBT). *Setting:* A Division III athletic facility and athletic training room. *Patients or Other Participants:* This study included 12 members of a Division III women's volleyball team. The average age was 17.25 $\pm$ 1.54 years. Average height was 68.08 $\pm$ 2.42 centimeters and average weight was 78.86 $\pm$ 19.55 kilograms. Patients were excluded if they had suffered a lower extremity injury in the six months prior to pre-season testing, had a history of lower extremity surgery in the year leading up to pre-season testing, had visual, vestibular or neurological conditions, or if they were taking a medication that may have affected their balance. They were also excluded if they were participating in a balance training program.. *Intervention:* All volleyball players wore Active Ankle braces for all practices and games during the competitive season consisting of 12 weeks. All subjects who met the inclusion criteria were pre-tested on the Star Excursion Balance Test prior to the 2005 volleyball season to determine a level of dynamic postural control. They were also tested during the pre-testing period for ankle ligament laxity, ankle muscle strength, arch index and with and without the brace. They were tested on the SEBT again at a mid-point in the season and then again after the season. *Main Outcome Measures:* There will be a significant difference between the eight reach directions for pre, mid and post testing. *Results:* A significant main effect was noted for direction ($F_{1,11}$, P = .000, ES = .739, ß = 1.00), and for the interaction of time and direction ($F_{1,11}$, P = .028, ES = .149, ß = .927). There was not a significant main effect for time ($F_{1,11}$, P = .059, ES = .227, ß = .556). Results of pairwise comparisons for time and direction indicated a significant difference for pre-test Anterior and mid-test Anterior (p = .006), pre-test anteromedial and mid-test anteromedial (P = .048), pre-test medial and mid-test medial (p = .046), pre-test anterior and post-test anterior (P = .001), pre-test medial and post-test medial (p = .044) and pre-test anterolateral and post-test anteolateral (P = .006).There were significant differences observed between pre to mid testing in the anterior (p = .006), anteromedial (p = .048) and medial (p = .046) directions. There was not a significant difference for any of the reach directions between mid to post testing. *Conclusions:* Long term prophylactic ankle brace use may cause a decrease in dynamic postural control as measured by the SEBT.

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INTRODUCTION

Ankle sprains are commonplace in athletics.[1,2,3,4,5,6] They are especially evident in sports that involve jumping and cutting, such as volleyball.[7] In an attempt to prevent injury, volleyball administrators have addressed the issue by suggesting rule changes that would make contact less common. However, preventative techniques using a prophylactic ankle brace or tape appear to be more feasible.

Because the use of a prophylactic ankle brace has become common in sports, several authors have investigated the use of ankle bracing with regard to efficacy,[8,9,10] restriction of range of motion,[10,11,12,13,] and their effects on functional performance[14,15]. Only a few studies, which will be discussed, have investigated the effects of short term ankle brace use, after immediate wear,[9,10,13,14] four days[16] or eight weeks[17] on postural control. Furthermore, the majority of these studies only examined static or semi-dynamic postural control.[9,15,18] With volleyball being a dynamic sport,[7,19] it is imperative to evaluate postural control dynamically. In addition, since prophylactic ankle brace use occurs in volleyball,[7,19] one should also evaluate the prolonged use during a competitive season.[20]

It has been hypothesized that, "ankle musculature and ligament function may possibly be influenced when an ankle brace is worn for months or years,"[20] and that the ligaments and musculature may be changed or weakened.[6,7,21] Thus, it may be postulated that dynamic postural control might be compromised because the muscles and mechanoreceptors surrounding the ankle are main contributors of maintaining postural stability.[22] The long term use of external ankle stabilizers has been questioned by some clinicians because it is suggested that supporting an otherwise healthy ankle would lead to a diminished neuromuscular response and weakness in the surrounding muscles. Also, the stabilizing structures may actually remodel themselves in a manner in which they would become dependent on external support. [2] Therefore, the purpose of this study is to determine the effects of prolonged prophylactic ankle bracing on dynamic postural control.

METHODS

This study was a 3x8 factorial design. The independent variables were time (pre-season, mid-season and post-season), and direction (anterior, posterior, medial, lateral, anteromedial, anterolateral, posteromedial and posterolateral) The dependent variable was reach distance for the eight excursions for postural control using the dominant leg. The star excursion balance test includes eight excursions: 1) anterior; 2) posterior; 3) medial; 4) lateral; 5) anteromedial; 6) anterolateral; 7) posteromedial and 8) posterolateral.

Pre-testing measurements were a 2x8 factorial design where subjects were tested on the SEBT unbraced, and again braced on the next day. The independent variables were bracing, with two levels: brace and no brace, and direction with eight reach directions. The dependent variable was reach distance for the eight excursions for postural control using the dominant leg. The star excursion balance test includes eight excursions: 1) anterior; 2) posterior; 3) medial; 4) lateral; 5) anteromedial; 6) anterolateral; 7) posteromedial and 8) posterolateral.

Pre-test measures such as height, weight, limb dominance, previous medical history, ankle ligament laxity, anatomic foot type and ankle muscle strength were taken to describe the subject population and determine inclusion/exclusion criteria; and for correlations between SEBT measurements.

Subjects

Eighteen members of a Division III women's volleyball team at Waynesburg College were potential subjects. However six quit the team after pre-testing and were, therefore, excluded. One subject was eliminated due to hip surgery performed within the last year. Twelve subjects completed the entire study. The average age was 17.25 ± 1.54 years. Average height was 68.08 ± 2.42 centimeters and average weight was 78.86 ± 19.55 kilograms. They were included in the study if they had no previous history of a lower extremity injury or surgery in the six months prior to testing. They were also free of neurological, vestibular and visual disorders in the six months prior to testing and were not taking any medications that may have affected balance. Subjects were excluded if they were a current participant in a balance training program. Subjects signed an informed consent form (Table C1) a HIPPA form (Table C2) and completed a demographic and inclusion questionnaire (Table C3). This study was approved by West Virginia University's Institutional Review Board (IRB) for the Protection of Human Subjects.

Instrumentation

Balance is a motor skill [23] that has often been used to measure lower extremity function. [24] It is defined by Cote et al. [24] as, "the process of maintaining the center of gravity within the body's base of support." In order to maintain balance, or postural control, the body is constantly moving and adjusting in an effort to keep the center of gravity over the base of support. [25] Maintaining postural control is perceived to be an effortless task, when in reality, it requires the complex coordination of activities of sensory, biomechanical and motor components.

Assessments of postural control have received much attention by the athletic training and orthopedic community since the work of Freeman. [26,27] Measuring postural control can establish levels of function which is important for injury prevention and rehabilitation. [28] In the past, postural control has been assessed using static or semi-dynamic measures such as the Romberg test or forceplates. [23] However, these static tests have been criticized because they may not be sensitive enough to detect deficits in motor control related to compromised functional activity and athletic performance. Based on this, dynamic measures of postural control have been emphasized recently.

The star excursion balance test (SEBT) has been determined to be a reliable and valid measure of dynamic postural control for research and clinical applications. [28,29,30,31,32] Hertel et al. [30] and Kinzey and Armstrong [33] have investigated the reliability of the SEBT and their results indicated high intrarater reliability ($ICC_{2,1}$ = .81-.96) and ($ICC_{2,1}$ = .67-.87), respectively. Gribble [29] also investigated the SEBT and noted a high interrater reliability (.35-.84, .81-.93) but observed significant learning effects. In Hertel et al.'s [30] study, learning effects were noted in the lateral, posterior, posteromedial and posterolateral directions. They hypothesize that, because subjects were not able to easily visualize the targets, they were forced to rely more heavily on the somatosensory and vestibular systems. Also, the trials were done repetitively, and the subjects were not allowed rest between trials. In this study, $ICC_{2,1}$ = .95 with a range .87 to .98.

In conjunction with reliability, it is also simple and inexpensive. [24] The test challenges the individuals limits of stability by quantifying maximal lower extremity reach in eight directions. Olmstead et al.[23] state that adequate performance on the SEBT requires accurate messages obtained from the somatosensory, visual and vestibular systems and proper execution of movements necessary in maintenance of postural control such as ankle dorsiflexion, knee flexion and hip flexion. Other necessary factors are pre-programmed reactions, nerve-conduction velocity, joint range of motion and adequate muscle strength. [23]

For the purposes of research, it is necessary for measurements to be normalized to an individual's leg length. Gribble [28] investigated the contributions of various factors such as leg length, height, foot type and range of motion on performance on the SEBT. Their findings indicate that foot type and deficits in hip flexion did not impact performance, but differences in gender indicated that measurements should be normalized to leg length. When this was completed, there were no significant differences between genders. Normalization according to leg length allows for comparison among subjects.

The ankle brace used by the Waynesburg College women's volleyball team is a semi-rigid, stirrup brace. [34] (Figure C1) The brand name of this particular brace is the Active Ankle. (Active Ankle Systems Inc., Louisville, KY) All team members will wear the same type of brace supplied by the athletic department.

Orientation Procedures

Prior to the study, the coach and individuals of the women's volleyball team at Waynesburg College were contacted to establish a date for an orientation meeting to determine interest in participation. At this meeting, subjects were provided with an explanation of the purpose of the study. They were given an informed consent form explaining their rights as a research subject, a HIPPA form and a demographic/inclusion questionnaire to establish medical history. Potential subjects voluntarily filled out the informed consent, HIPPA form and the demographic/inclusion questionnaire. The principal investigator reviewed the completed demographic/inclusion questionnaires and determined which subjects were eligible to participate in the study. Eligible subjects were contacted and established a date and time for pre-season testing.

Subjects were asked to perform the SEBT to the best of their ability. Subjects were also be given instructions on how to apply the ankle braces to ensure that all braces are applied in a similar fashion. (Table C5) Subjects were be monitored throughout the season to make sure they continued to follow the brace application directions.

Interventions

Subjects all wore the semi-rigid Active Ankle brand of semi-rigid ankle brace They were given instructions about how to properly apply the braces to ensure every subject applied the brace in a uniform manner, as per manufacturer's specifications. They were also monitored throughout the season to ensure that they were applying the braces in the manner in which they were instructed.

Subjects were tested using the SEBT prior to the beginning of practice sessions. Subjects were tested again at a mid-point in the season (approximately six weeks) and once more following the last competition. Pre-Testing measurements of height, weight, limb dominance, anatomic foot type, ligament laxity and ankle muscle strength were also assessed.

Pre-test, Mid-test and Post-test procedures for the Star Excursion Balance Test

All testing was administered by the principal investigator in the athletic training room at Waynesburg College one week prior to the start of the season, at the mid-point of the season and within one week following the end of the season. Prior to the administration of each test, subjects were given an explanation of what the SEBT entails and were allowed to practice. The SEBT (Figure C2) consists of a star shaped pattern taped to the floor. The projections or excursions are at 45° increments. Prior to beginning the trials, the subject's dominant leg, determined by the leg with which they would kick a soccer ball, was measured to allow for the SEBT to be normalized to leg length. Leg length was measured bilaterally with a measuring tape with the subject lying supine. The measurement was from the anterior superior iliac spine (ASIS) to the medial maleolus of the same leg. Measurements were recorded on the pre-test measurements data collection form. (Table C4)

Each subject placed their dominant foot in the middle of the star and was asked to reach as far as possible with their non-dominant foot in each of the eight excursions while maintaining a single leg stance. They were asked to make a light touch when they had reached maximally, and the principal investigator noted and recorded the measurement. Subjects had a practice session in which they performed each excursion six times, followed by a one minute rest period. [34] Trials were discarded if the subject could not maintain their balance, if their support leg was lifted from the center of the star, or if the leg used for the light touch was determined by the principal investigator to have provided support. Subjects performed three trials in each excursion. [34] The starting excursion was randomized by the subject choosing one of eight index cards labeled with all eight excursions. They then completed each of the excursions in a clockwise, or counterclockwise manner, depending if the dominant leg was the right or the left. There was a 15 second rest period in between each excursion (Table C6).

Additional Pre-test Measurement Procedures

Pre-test measurements consisted of previous history of lateral ankle sprain, height, weight, limb dominance, leg length, ankle ligament laxity, anatomic foot type and ankle invertor and evertor strength. The contributions of these factors to performance on the SEBT have been studied in the past, with conflicting results. [6,7,21,28]

Height, weight and previous medical history were established during pre-participation examinations performed by the Waynesburg College athletic training staff and team physician. Limb dominance was included on the demographic questionnaire. Leg length was measured and recorded on the data collection table shown in Table C3 as previously described by measuring the distance between the ASIS and medial maleolus bilaterally.

Hertel et al [35] investigated talocrural joint laxity in patients with a history of lateral ankle sprains and healthy subjects as a control. Ligament laxity in this study was assessed in the same manner, by three physical examination tests (Figure C3). The anterior drawer test is an assessment tool for measuring anterior displacement of the talus within the mortise and stresses the anterior talofibular ligament. The talar tilt test stresses the anterior talofibular and calcaneofibular ligaments and measures excessive inversion of the talus within the mortise. The medial subtalar glide test measures excessive medial translation of the calcaneus on the talus in the transverse plane. Ankle laxity for each test was graded on a four-point scale for laxity where zero equals no laxity, one equals mild, two equals moderate and three equals gross laxity.[36]

Subjects were seated supine on an examination table while the principal investigator performed the three laxity tests. The anterior drawer test is performed by having the examiner place one hand cupping the calcaneus with the other stabilizing the lower leg. The examiner then oscillates the calcaneus forward attempting to distract the talus from the mortise. The talar tilt test is performed in a similar manner with one hand of the examiner holding the calcaneus and the other hand stabilizing the lower leg. The examiner then inverts the talus within the mortise to assess for end feel. The medial subtalar glide test is performed with the examiner holding the talus in subtalar neutral with one hand and gliding the calcaneus medially on the fixed talus (Table C7).

Anatomic foot type, either pronation or supination, were assessed using the arch index (AI). The AI is a technique for assessing foot type that uses foot tracings, measurements and a formula to determine foot type based on established guidelines. Arch Index was described by Sandrey et al., [37] Cavanagh, [38] and Hawes [39] and determined to be reliable (.86 $\pm$ .02). Subjects laid prone on an examination table and had the bottom of their dominant foot rolled with washable ink. Subjects were then asked to place their foot in the center of a piece of legal paper and asked to step down with their full body weight (Table C8). This was performed next to a wall to allow subjects to maintain their balance. From the imprints, measurements were taken. These measurements were described by McPoil [40] and Hawes et al. [39] Measurements were taken of foot length (back of heel to tip of longest toe), first metatarsal length (back of heel to medial prominence of first toe), fifth metatarsal length (back of heel to prominence of fifth toe), ball width

(width of the line drawn between first and fifth metarsophalangeal joint lines), heel width (width at the widest part of the heel), and mid-foot arch (the narrowest point at the mid-foot) (Figure C3). AI was then determined by calculating mid-foot arch/(forefoot arch + mid-foot arch + rearfoot arch). A measurement less than .21 is considered to be a high arch (supinator), .21-.26 is considered to be normal, and greater than .26 is considered to be a low arch (pronator).[38]

Ankle muscle strength for inversion and eversion was assessed using isometric manual muscle testing. These muscle tests are described by Kendall.[36] By placing a body part in a specific position, it is possible to accurately assess the strength of a specific muscle and detect any substitutions or secondary movements. Subjects were seated on an examination table. The examiner placed one hand on the lower leg to help stabilize the patient, and placed the other hand on the subject's lateral foot. The subject was asked to hold their ankle in either eversion or inversion while the examiner tried to "break" the contraction. This was performed by providing firm, even resistance to the contraction of the muscle. Muscle strength was assessed by determining the amount of resistance the ankle can withstand.[36] (Table C9) A grading scale from 0-5 was used to assign the muscle a level of strength or weakness, with 0 representing zero and 5 representing normal [36] Within the 0-5 there are also grades of 1 (trace), 2- (poor-), 2 (poor), 2+ (poor +), 3- (fair -), 3 (fair), 3+ (fair +), 4- (good -), 4 (good) and 4+ (good +).[36] A zero grade means that there is no evidence of any muscle contraction. Trace grades represent a feeble contraction or visibility of the tendon, but there is no actual movement of the body part. A poor grade is the ability of the muscle to move the body part partially through the arc of motion. A fair grade means the muscle can hold the body part in the test position against the force of gravity. Normal and good grades mean that the muscle can hold the test position against gravity and with moderate or strong pressure, respectively.[36]

Data Analysis

The average scores calculated from the three trials for each excursion (anterior excursion, anteromedial excursion, medial excursion, medial excursion, posteromedial excursion, posterior excursion, posterolateral excursion, lateral excursion and anterolateral excursion) were recorded as the subject's dynamic balance test scores. This was done for both the braced and unbraced conditions in only the pre-test measures, and unbraced for mid-test and post-test. Additionally, the leg length of the subject's dominant extremity was used to normalize their dynamic balance scores (excursion length/leg length x 100 for a percentage of an excursion distance in relation to the subject's leg length) to be used for data analysis.

Statistical Analysis

Data obtained for the dominant extremity was analyzed for the subjects. Descriptive analysis consisted of means and standard deviations for the demographics of all subjects and means and standard deviations for pre-test measures, pre-test, mid-test and post-test data for the SEBT. A two-way repeated measures ANOVA was conducted for braced and unbraced conditions and direction. The level of significance was set at $p \leq 0.05$. Intraclass correlation coefficients $ICC_{2,1}$ were conducted to determine the reliability of pre-test measures using the SEBT. A two way Repeated Measures Analysis of Variance (ANOVA) was conducted to determine main effects for direction, time and interaction of direction and time. Pairwise comparisons were conducted for any significant main effects of interaction. The P-value was set at $P \leq .05$ for both tests. Pearson Product Moment correlations were conducted to determine any relationships between demographic information measurements and performance on the SEBT. A Pearson Product Moment Correlation was conducted to determine any relationships between any of the pre-test demographic measures.

RESULTS

All means and standard deviations for reach distances are illustrated in Table D1. Results from the 2 x 8 repeated measures ANOVA for the pre-test conditions showed a statistically significant main effect for condition ($F_{1,11}$, P = .026, ES = .374, ß = .646) and direction ($F_{1,11}$, P =.001, ES = .973, ß = 1.00). All other results were not statically significant. Pairwise comparisons showed statistically significant differences in the anterior (P = .035), posterolateral (P = .021), lateral (P =.030) and anterolateral (P = .004) directions. Table D2 illustrates the results of the 2 x 8 ANOVA and pairwise comparisons. Results from the 3 x 8 repeated measures ANOVA revealed a significant main effect for direction ($F_{1,11}$, P = .000, ES = .739, ß = 1.00). There was also a significant interaction effect observed for time and direction ($F_{1,11}$, P = .028, ES = .149, ß = .927). There was not a significant main effect for time. ($F_{1,11}$, P = .059, ES = .227, ß = .556). A table illustrating the information regarding main effects of time, direction and their interaction can be found in Table D3. Results of pairwise comparisons for time and direction indicated a significant difference for pre-test anterior and mid-test anterior (P = .006), pre-test anteromedial and mid-test anteromedial (P = .048), pre-test medial and mid-test medial (p = .046), pre-test anterior and post-test anterior (P = .001), pre-test medial and post-test medial (p = .044) and pre-test anterolateral and post-test anteolateral

(P = .006)(Table D4). Tables illustrating these pairwise comparison results for pre to mid-tests, mid to post-tests and pre to post-tests can be found in Table D5, D6 and D7, respectively. There were no significant differences between mid to post tests in any of the eight directions.

Correlations of pre-test demographic measures and performance on the SEBT are represented in Table D8. Correlations between pre-test measures are listed in Table D9. Descriptive statistics for ligament laxity, ankle strength and AI can be found in Table D10.

DISCUSSION

It was hypothesized that there would be a significant difference in dynamic postural control from the pre-test measurements to the post-test measurements. While this can not be accepted completely as stated, the first hypothesis is accepted. There was a significant difference between the pre and post tests in the anterior direction, as well as the medial and anterolateral direction. Three other hypotheses were also accepted. There was a statistically significant difference between the pre and mid tests in the anterior, anteromedial and medial directions. The hypotheses stating there would be a statistically significant difference between the pre and mid tests for poteromedial, posterior, posterolateral, lateral and anterolateral are rejected. The remaining hypotheses predicting a statistically significant difference between mid and post tests were rejected. None of the reach directions yielded significant differences. It should be noted that, while not statistically significant for the anteromedial, posterior, posteromedial, posterolateral and lateral directions, there was a 2.78 in. average decrease in reach distance from pre to post-testing.

Star Excursion Balance Test

A possible explanation why only a few reach directions were statistically significant while others were not may be because some reach directions are easier to perform than others. If some reach directions were easier, there may be less of a decrease in reach distance because dynamic postural control may not be comprimised. It was expected that there would be a statistically significant decrease in all of the reach directions, rather than only three. Earl and Hertel [41] found that there are distinct neruo-recruitment patterns and specific muscle activations that are direction dependent. Gribble [29] suggests that this may indicate specific neuromuscular control patterns for each of the eight directions to maintain one's balance during the SEBT. With regard to the current study, it is possible that the ankle braces may have limited certain motions and therefore only inhibited certain neuromuscular control patterns, thus only causing significant decreases in particular excursions. In this study, bracing appeared to have limited anterior, posterolateral, lateral and anterolateral excursions. Cordova and Ingersoll [2] found that, the peroneus longus stretch reflex amplitude increases after brace application, which may indicate that reach directions involving concentric eversion and eccentric inversion may be affected differently. In addition to specific neuromuscular control patterns being used for particular reach directions, Earl and Hertel [41] also found that certain lower extremity muscles were utilized more during certain reach directions. For example, the quadriceps and hamstrings were activated for all of the excursions, but the quadriceps were activated more for the anterior excursions. Increased vastus lateralis activity was found during the medial and posteromedial excursions.

Differences in range of motion at the ankle and knee were also found when subjects were performing the SEBT. [41] The anteromedial excursion required the greatest amount of knee flexion. The anterior, anteromedial, medial and posteromedial excursions also required adequate knee flexion. The posterolateral and lateral excursions produced the least amount of knee flexion. At the ankle, the anterior, anteromedial and medial excursions produced more dorsiflexion than all other excursions. With this in mind, a possible explanation for no significant decrease in certain excursions could be a subject's lack of hip, knee or ankle flexibility or strength. Although hip and knee muscle strength and ranges of motion were not tested in the current study, ankle evertor and invertor strength was. The sample had a mean score of 4.75 out of a possible 5 for inversion and a 4.83 for eversion. Since the current sample did not appear to have any strength deficits, it is unlikely that ankle strength was a factor. However, hip and knee musculature and ankle range of motion may have been.

It is also possible that the certain excursions are more important or used more often in particular sports. Piegaro [42] suggests that anteromedial, posteromedial, posterolateral and anterolateral reach directions appear to be the most important because they are complex movements that occur in multiple planes, including anterior, posterior, medial and lateral. Similar to many sports, volleyball requires ability in agility, quick changes of direction, speed, balance, dynamic postural control, flexibility and multi-planar movements.[43] The eight reach directions in the SEBT mimic some of the multi-planar movements that a volleyball player would have to perform during practice or competition.[43] The nature of volleyball requires explosive lateral and forward/backward movements and jumping. Performing these types of movements nearly everyday during practices and competition may have supported certain neuromuscular recruitment patterns, while others may have been neglected. It is possible that their practice sessions throughout the season may have helped them perform better in particular excursions, or inhibited their performance in others.

Gribble et al. [29] also suggest that subjects with chronic ankle instability perform poorer than those subjects who do not have a history of chronic ankle instability. The current sample did not appear to have chronically unstable ankles. The means for laxity measures were .167, .750 and .250 (with 3 representing gross laxity and 0 representing none) for anterior drawer, talar tilt and medial subtalar glide tests, respectively.

Another pre-test measurement of this study was anatomic foot-type as measured by the AI. Through AI, a subject was labeled as a pronator or a supinator. Subtalar pronation and supination are critical for adapting to ground surfaces, shock absorption and transition to a rigid lever for propulsion.[24] A normal foot can transition effectively between pronation and supination to allow for adaptations and stability, however excessive pronation or supination may negatively affect foot mobility and can make it more difficult for the foot and lower leg to function properly in the closed kinetic chain. Since the foot is a relatively small base of support for the entire body it is reasonable that even small biomechanical alterations may adversely affect the body's ability to maintain balance and could affect a person's postural control strategeies.[24] Although Gribble and Kaminski[28] noted that foot type did not affect performance on the SEBT, Cote et al [24] found a main effect for foot type. More specifically, they found supinators with significantly less sway or variability from center of pressure than pronators. It was noted that pronators, supinators and normal foot types had similar reach distances in the anterolateral, medial and posteromedial excursions, but supinators were able to achieve further reach distances than pronators in the lateral and posterolateral excursions. Because supinators have greater pressure placed on the lateral aspect of the foot, it is reasonable that a subject with a supinated foot would perform better on lateral excursions. Likewise, a pronated foot tends to collapse medially and has decreased rigid support. Therefore, this may account for supinators' decreased reach distances in the lateral excursions. In this study's sample, the majority of the subjects were supinators (eight) while only three of the subjects were considered pronators and one was neutral. If supinators do, in fact, have less sway during the SEBT, it is possible that this caused better performance on the SEBT, explaining why all of the reach directions were decreased, but only three were statistically significant.

Brace Use

There was a statistically significant main effect for time and the interaction of time and direction. This indicates that the majority of subjects experienced a decrease in reach distance between the time periods of pre and mid and pre and post-tests. This is important because previous brace use studies usually ranged from four days [25] or eight weeks and took place in a controlled enviornment. [17] Most studies of this type have been after immediate wear, [9,10,12,13,18,20,44,45,46] while others have been systematic reviews investigating compilations of what other researchers have found.[15] The only two studies that were found to allow for any differences between bracing and testing were studies by Palmieri [16] and Cordova et al. [17]. Palmieri et al.'s [16] study examined the effects of brace use on mean frequency amplitude and anterior/posterior center of pressure, as subjects in the experimental group wore the brace for approximately eight hours a day for four days.

They found that there were no changes in mean frequency amplitude for medial/lateral and anterior/posterior center of pressure changes and add that changes may have been observed had the study taken place over a longer period of time. Although the current study did not measure medial/lateral and anterior/posterior center of pressure, changes in these measures would indicate how a subject would perform on the SEBT. Greater changes in center of pressure would indicate greater postural sway, and the potential for decreased dynamic postural control. Cordova et al. [17] examined the effects of eight weeks of brace use on peroneal latency in a sudden inversion moment. They concluded that the peroneus longus stretch reflex was not affected positively or negatively by eight weeks of brace use and added that proprioceptive input provided by mechanoreceptors in the peroneus longus were not compromised by long-term use of ankle braces. Based on their findings they advocate 'long term' brace use, citing no differences in peroneus longus latency.

The current study, however, is the first study conducted over an entire volleyball season (12 weeks) and in a clinical setting, rather than a controlled enviornment. A statistical significance between the pre and post-test times (12 weeks) and pre and mid-tests (six weeks) suggests that perhaps other studies have not been conducted over a long enough period of time to allow for changes in dependent measures. Furthermore, there was a statistically significant interaction for time and direction, to indicate that the combination of time and direction were significant in this study. The combination of the 12 weeks elapsed and the brace use is speculated to have been the cause for significant decreases in the excursion directions. This shows the importance of this study is in that it was conducted over an entire volleyball season which more closely mimics the realistic use of an ankle brace for an athlete. It is also important to note that this study was not performed in a laboratory but over the course of an athletic season. During practice sessions, the volleyball players went about their normal practice and conditioning programs moving in diagonal, forward/backward and lateral movements. It may be beneficial to know if the active ankle restricted any or all of these motions, or just inversion and eversion.

There are a variety of types, styles, and prices of prophylactic ankle braces on the market today. A common factor among all of them is the accepted mechanism of action which has been established to be biomechanically limiting ankle inversion and eversion range of motion; specifically limiting frontal plane motion of the subtalar joint.[4,8,10,11,12,20,34,47] If ankle braces do, in fact, limit frontal plane motion at the subtalar joint, this would effectively limit ankle inversion and eversion. Therefore, it is feasible that certain excursions depend on frontal plane motion of the subtalar joint may have been reduced because of the prolonged limitation of inversion and eversion. Most of the braces allow for normal ankle plantarflexion and dorsiflexion. Since these motions were not limited, excursions that depended on plantarflexion and dorsiflexion or saggital plane motion would not have decreased. It is also possible that neuromuscular responses could have been reduced for particular patterns that would have been limited by brace wear. In EMG amplitude studies examining peroneal latency after taping [48] and bracing [49] there was decreased EMG amplitudes which suggests taping and bracing can be detrimental to neuromuscular responses.

When comparing braced and unbraced performance on the SEBT, it was found that there was a main effect for direction and there were statistically significant decreases in the anterior, posterolateral, lateral and anterolateral directions. Coincidentally, there was also a significant decrease in anterior and anteromedial from pre-testing to post-testing. Because anterior and anteromedial excursions were significantly decreased with brace wear, it is possible these motions were restricted with brace use. The changes from pre to mid testing and pre to post testing were similar, with the exception of the anteromedial excursion. Thus, over the course of the season those motions decreased and that was reflected in performance on the SEBT.

Based on individual factors concerning the SEBT, ankle bracing and the combination of the two, it is reasonable that only particular excursions decreased significantly. Since this is the first study to actually take place over the course of an entire volleyball season, it has important clinical applications for clinicians and athletes in advocating the use of prophylactic ankle bracing. It may be more important to take the athletes individual needs into consideration, especially if they have no previous history of ankle injuries. Decreasing dynamic postural control in an otherwise injury free athlete may predispose them to suffering ankle injuries in the course of their everyday lives when they are not wearing the braces. If a coach mandates the use of ankle bracing for practice and competition, decreases in dynamic postural control towards the end of the season may predispose the athlete to injury in off-season training or in their everyday lives. If ankle braces are worn to prevent injury, it should be in conjunction with an ankle strengthening program that incorporates proprioception and dynamic postural control. This will help prevent ankle injury on and off the court.

CONCLUSIONS

The results of this study indicate that long term use of prophylactic braces may decrease postural control. There was a statistically significant decrease in reach direction between pre and post testing, and pre to mid but not from mid to post. Although only four of the eight reach directions showed statistically significant decreases in reach distance, inspection of the mean reach directions reveals decreases in all of the directions. The intent of this study is not to claim that ankle braces should not be used prophylactically, but based on the results it may be beneficial to incorporate other means to prevent injury. Further research should be conducted to determine if combining an ankle strengthening program which includes proprioception with ankle brace use may prevent ankle sprains while maintaining ankle strength and dynamic postural control. In conclusion, long term prophylactic ankle brace use may decrease dynamic postural control.

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APPENDICES

APPENDIX A

THE PROBLEM

Research Question

Ankle injuries are common in most sports, but volleyball players are especially susceptible to injury. Inversion ankle sprains, in particular, are the most common acute injuries in volleyball.[7,19] The nature of volleyball requires rapid side to side movements and constant jumping. These requirements put an athlete at a greater risk of ankle injury because of the high demands imposed on the ankle. Observations as an undergraduate athletic trainer indicated that many of the ankle injuries treated in the athletic training room were those suffered by volleyball players.

Recently a number of prophylactic ankle braces have surfaced on the market that are intended to reduce the incidence of ankle sprains before they have a chance to occur. “The use of commercially available ankle braces has become widespread because of the ease of application and cost effectiveness.”[2] While it is widely accepted that ankle bracing and taping can prevent ankle injury,[2,7,8,15] more research is necessary to determine if these ankle braces may have an adverse effect by actually decreasing an athlete’s balance and proprioception, therefore decreasing dynamic postural control.

Many volleyball teams require their players to wear protective ankle braces at all practice sessions and games. With this constant support, the question arises if the muscles surrounding the ankle joint need to work less to stabilize the lower extremity. Cordova and Ingersoll[2] noted that the muscles that support and control the ankle joint may not need to work as hard to stabilize the lower extremity and perform their role as a dynamic restraint against external forces. Because the primary mechanism of injury of an ankle sprain is concomitant talocrural plantar flexion with talocalcaneal inversion, the peroneus longus acts as the key defense mechanism against an inversion moment."[2,15] If the muscles surrounding the ankle, particularly the peroneus longus, in fact, are working less to achieve this stability, it is possible that dynamic postural control may decrease throughout the season due to decreased use of these muscles and/or dependence on external support. The long term use of external ankle stabilizers has been questioned by some clinicians because it is suggested that supporting an otherwise healthy ankle would lead to a diminished neuromuscular response and weakness in the surrounding muscles. Also, the stabilizing structures may actually remodel themselves in a manner in which they would become dependent on external support.[2] These decreases in dynamic postural control may be reflected in decreased post-season test scores on the Star Excursion Balance Test as compared to those scores collected in pre-season.

I have observed in both my undergraduate experience and my post graduate experience that many volleyball teams are required to wear prophylactic braces. The immediate question that came to mind was: do these braces have the potential to actually decrease an athlete's dynamic postural control when they are worn over the course of a season?

Experimental Hypotheses

1. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the anterior excursion as compared to the pre-test measurements.

2. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the posterior excursion as compared to the pre-test measurements.

3. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the medial excursion as compared to the pre-test measurements.

4. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the lateral direction as compared to the pre-test measurements.

5. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the anteromedial direction as compared to the pre-test measurements.

6. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the anterolateral excursion as compared to the pre-test measurements.

7. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the posteromedial excursion as compared to the pre-test measurements.

8. There will be a significant difference in the post-test measurements on the Star Excursion Balance Test in the posterolateral excursion as compared to the pre-test measurements.

9. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anterior excursion as compared to the pre-test measurements.

10. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posterior excursion as compared to the pre-test measurements.

11. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the medial excursion as compared to the pre-test measurements.

12. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the lateral excursion as compared to the pre-test measurements.

13. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anteromedial excursion as compared to the pre-test measurements.

14. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anterolateral excursion as compared to the pre-test measurements.

15. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posteromedial excursion as compared to the pre-test measurements.

16. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posterolateral excursion as compared to the pre-test measurements.

17. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anterior excursion as compared to the post-test measurements.

18. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posterior excursion as compared to the post-test measurements.

19. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the medial excursion as compared to the post-test measurements.

20. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the lateral excursion as compared to the post-test measurements.

21. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anteromedial excursion as compared to the post-test measurements.

22. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the anterolateral excursion as compared to the post-test measurements.

23. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posteromedial excursion as compared to the post-test measurements.

24. There will be a significant difference in the mid-test measurements on the Star Excursion Balance Test in the posterolateral excursion as compared to the post-test measurements.

Assumptions

1. All subjects will perform the Star Excursion Balance Test to the best of their ability.

2. All subjects will meet the inclusion criteria.

3. No subjects will meet the exclusion criteria. Subjects will be excluded if they:
   a) have sustained an ankle, knee or hip injury in the past six months
   b) have a history of wearing an ankle prophylactic brace in the time leading up to pre-testing.

4. The Star Excursion Balance Test is a valid and reliable measure of dynamic postural control.

5. All athletes will be compliant with wearing their prophylactic brace during practice sessions and games.

6. The principal investigator will be reliable in recording measurements for the Star Excursion Balance Test.

Delimitations

1. Only female members of the Waynesburg College volleyball team participated. Therefore, this study may not be generalizeable to the entire population.

2. The only measurement was dynamic postural control.

3. Only the Star Excursion Balance Test was used to measure dynamic postural control.

Operational Definitions

1. Ankle Brace- An external ankle supportive device designed to prevent ankle injury by restricting range of motion during activity.

2. Balance- Process of maintaining the center of gravity within the body's base of support. [43,50,51,52]

3. Dynamic Postural Control- Maintaining a stable base of support while the center of gravity is changing during a prescribed movement. [28,43,51]

4. Dynamic Postural Stability- The extent to which a person can lean or reach without moving the feet and continue to maintain balance. [23,43]

5. Functional Reach- Reaching of a limb while challenging an individual's limits of stability. [23,43]

6. Golgi Tendon Organ- A proprioceptor, activated near the intermediate range of motion, that transmits information regarding changes in muscle tension to the central nervous system. [53,54]

7. Joint Position Sense- Perception of posture of the joint, or the spatial relation of joints constituting segments. [53,54,55]

8. Kinesthesia- Precise sensorimotor functions that detect movement threshold or the sensation of movement and joint motion detection spatially between body segments. [53,55,56]

9. Mechanoreceptor- Encapsulated nerve endings located in musculotendinous tissue, including the golgi tendon organ, that provide information about the relative position of the joint. [55]

10. Muscle Spindle- Type of mechanoreceptor that consists of specialized afferent nerve endings that are wrapped around modified muscle fibers and is sensitive to changes in muscle length. [55,57]

11. Prophylactic- Tending to prevent or ward off. [58]

12. Proprioception- Recognition of sensation of joint movement and of joint position sense. [43,51]

13. Sensory Motor System- Maintains functional joint stability through complementary relationships between static and dynamic restraints. [59]

14. Star Excursion Balance Test- A testing procedure in which the subject maintains their base of support with one leg while maximally reaching in eight directions (anterior, posterior, medial, lateral, anteromedial, anterolateral, posteromedial and posterolateral) with the opposite leg without compromising the base of support of the stance leg. [30,43]

15. Volleyball- A game played by volleying an inflated ball over a net, consisting of sharp medial and lateral movements, forward and backward movements and jumping.[7]

Limitations

1. A potential limitation to this study is subject attrition.

Significance of the Study

This study will be important because it will further investigate the effects of consistent ankle bracing. If dynamic postural control is significantly decreased, athletes may be more susceptible to ankle sprains after the season, and outside of practice sessions and games. Therefore other preventative measures need to be taken to build internal ankle strength and balance, rather than relying on external factors, that may have adverse effects long term. Other preventative measures that have been clinically validated are technical training programs and proprioceptive programs. [7]

Through this study, it may help determine what steps need to be taken to decrease the incidence of ankle sprains in volleyball players. If it is indicated that ankle bracing is insufficient for protection, further studies may be prompted to determine the best form of prevention. Also, if prophylactic ankle bracing is determined to be ineffective or harmful, high schools and universities may be able to find more cost-effective ways of prevention, since purchasing braces for entire volleyball programs can be expensive. Technical and proprioceptive training programs, for instance, would be far less expensive than ankle taping or bracing. Olmstead et. al.[4] noted that ankle taping would be 3.05 times as expensive as ankle bracing over the course of a competitive season. Results from Garrick and Requa [60] stated that the cost of taping 26 athletes for an entire season would cost $2,778, while bracing these athletes would cost $910.

Although previous studies have been conducted that examine the effects of constant prophylactic ankle bracing and taping on static or semi-dynamic postural control, the longest time period in a study for bracing was eight weeks. This clinical study will begin in late August and continue through the beginning of November, and will last approximately 12 weeks. Therefore, it may present a more accurate picture of the long term effects of constant ankle bracing on changes in dynamic postural control. For teams who wear ankle braces at every practice session and game this study will be beneficial because it may give greater insight into the potential effects. If dynamic postural control is found to be compromised, perhaps, it would be beneficial to look for better alternative measures. Also, if decreases in postural control are demonstrated, this study can be a basis for education of coaches, athletes and athletic trainers about alternative preventative measures. For example, bracing may need to be buttressed with ankle strengthening programs and proprioception training included in practices in an attempt to deter changes in postural control.

APPENDIX B

Literature Review

Introduction

Ankle sprains are the most common injury affecting athletes. [1,2,3,4,5,6] They occur seven times more frequently than all other ankle injuries [4] and are estimated to account for 15% of all injuries occurring in organized sports. [2] In particular, volleyball players are at significant risk for inversion ankle sprains. They are the most common acute injury in volleyball. [7] Due to the ubiquitous nature of ankle sprains, athletic trainers, coaches and researchers are constantly searching for the most effective means of prevention.

In the past two decades, research regarding effectiveness of prophylactic ankle taping and bracing has been abundant. There seems to be a general consensus that ankle taping and bracing are an effective preventative measure to avoid inversion ankle sprains. Likewise, many studies have been devoted to the mechanisms by which braces prevent ankle sprains. These studies often pertain to the restriction of range of motion, [4.] sensory stimulation of mechanoreceptors, [2] and increasing the time in which forces are applied to the ankle joint. However, few studies have investigated the effects of long term brace application on dynamic postural stability. This literature review will include information pertaining to subtalar joint anatomy, biomechanics of the subtalar joint, the epidemiology of lateral ankle sprains in both the active population and in volleyball players, etiology, types and mechanisms of action of ankle braces, dynamic postural control, and similar studies regarding the effects of bracing on static and semi-dynamic postural control.

Subtalar Joint Anatomy

The ankle consists of numerous bony articulations, musculotendonous and ligamentous structures, and neurovascular components. When examining all aspects of ankle injuries and prevention, understanding of the subtalar joint anatomy, function and biomechanics is crucial. The subtalar joint allows for pronation (dorsiflexion, eversion, and external rotation) and supination (plantar flexion, inversion, and internal rotaion) which is the primary mechanism of injury of lateral ankle sprains. [3]

Bony anatomy: The subtalar joint is the articulation between the talus superiorly and the calcaneus and navicular inferiorly. [3,61,62] One of its main functions is to convert torque between the lower leg and the foot, [3] and "is critical for dampening the rotational forces imposed by the body weight while maintaining contact of the foot with the supporting surface." [62] The articulation has been compared to that of a 'ball and socket' joint with the head of the talus forming the ball and the anterior calcaneal and proximal navicular surfaces forming the socket along with the calcaneonavicular ligament. [3] The talus is the second largest bone among the tarsals. It serves to support the tibia while it rests on the calcaneus and has been referred to as "the mechanical keystone at the apex of the foot." [61] The calcaneus is the largest of the tarsals and, "provides a firm, yet elastic, support for body weight as it transferred through the talus." [61] It also provides a rigid lever for the gastrocnemius/soleus complex for forward propulsion. [61]

The subtalar joint can be divided into anterior and posterior portions or chambers. They have separate ligamentous joint capsules and the sinus tarsi and canalis tarsi separate the two. [3,61] The head of the talus, the anterior-superior facets, the sustentaculum tali of the calcaneus, and the concave proximal surface of the tarsal navicular form the anterior subtalar joint which is also referred to as the talocalcaneonavicular joint. The inferior posterior facet of the talus and the superior posterior facet of the calcaneus make up the posterior subtalar joint. [3] The division between these chambers is formed by the tarsal canal. [61,62]

Ligamentous anatomy: There are three major functions of ligaments. Ligaments and the surrounding capsule are full of innervations and contain many proprioceptive organs. Therefore, the first function of ligaments is to provide proprioceptive feedback necessary for joint function. The second function is to limit excessive motion, thereby increasing stability. The third function of the ankle ligaments is to act as guides to direct motion. [22] Although there are numerous ligaments in the ankle and foot, for the purposes of this section, only the lateral ligaments of the ankle will be described because they are most commonly injured in an inversion ankle sprain.[22,63]

The lateral ligaments can be divided into three groups:1) deep ligaments; 2) peripheral ligaments; and 3) retinacula [3] The deep ligaments are comprised of the cervical and interosseous ligaments which act together to stabilize the subtalar joint and also form a barrier between the anterior and posterior joint capsules.[3,62] The ligaments of the subtalar joint consist of the calcaneofibular ligament (CFL), the lateral talocalcaneal (LTCL) and the fibulotalocalcaneal (FTCL).[3] Fibers of the inferior extensor retinacula are believed to provide stability to the lateral subtalar joint, but substantial support significantly affecting subtalar joint stability have only been demonstrated by one of the three roots. [3]

The ATFL is the weakest of the lateral ligaments and is usually the first ligament to fail in an inversion moment.[3,22,62,63] It functions as the primary restraint against foot plantar flexion and internal rotation.[63] Due to its position anatomically, the ATFL is the most important ligament in limiting talofibular instability. It is taut in plantar flexion and acts as the primary stabilizer to protect against excessive ankle inversion in plantar flexion in non weight bearing. [22,63] The ATFL exists within the capsule, blending with the anterior capsule [64] and is six to ten mm in width, [63] two to five mm thick, [63,22] and ten to twelve mm in length. [63,22] "It originates about one cm proximal to the tip of the lateral malleolus, and then inserts into the lateral talus just beyond the articular surface, about 18 mm proximal to the subtalar joint." [22,63,64] The ATFL forms an angle of approximately 75° with respect to the floor when the ankle is in the neutral position. [63]

The CFL is larger and stronger than the ATFL, but is the second weakest lateral ligament. [3,22,62,63] It serves to indirectly aid in enhancing talofibular stability because of its anatomical position. Unlike the ATFL, the CFL is a rounded extra-articular ligament.[63] The CFL spans the entire ankle and subtalar joint, [64] and is approximately six to eight mm in diameter and [22,63] 20-25 mm long, [63] There is some discrepancy in the literature about the exact location of its origin. Safran [22] states that it originates from the tip of the lateral malleolus, but Hinterman [64] believes that it originates on the anterior edge of the distal fibula and is centered 8.5 mm from the tip, just below the origin of the ATFL. The two agree, however, on its insertion that fans out 10-40° on the lateral aspect of the calcaneus. [22,63,64] Hinterman [64] and Benedict [63] report that the insertion begins approximately 13 mm distal to the subtalar joint. Safran [22] cites a study measuring the angle between the CFL and the ATFL using 50 cadavers. The average angle was found to be 105°, which is consistent with Benedict's report.[22,63] The CFL becomes taut as the foot is moved into dorsiflexion.[63]

The posterior talofibular ligament (PTFL) is the strongest of the lateral ligaments and is rarely injured because it is only taut in severe dorsiflexion.[22,62] It originates on the medial surface of the lateral malleolus, [64] more specifically the digital fossa of the fibula [22] and travels horizontally posterior to the lateral tubercle on the posterior aspect of the talus. [22,64]

The lateral talocrural ligament (LTCL) is not usually included with the previously mentioned lateral ligaments of the ankle, but it does play a role in ankle and subtalar joint stability.[22] Although smaller and weaker than the CFL, the LTCL aids in preventing excessive subtalar joint motion. [3] It originates on the lateral tubercle of the talus and courses obliquely, crossing the posterior subtalar joint, [3,64] inferiorly and posteriorly to its attachment on the lateral surface of the calcaneus.[22,61] The LTCL runs parallel and anterior to the CFL, and is sometimes reported to be continuous with fibers of the ATFL and CFL. [3,22,61,64]

Although the deltoid ligament (DL) is a medial ligament, it is important for ankle stability and helps check motion in the extremes of the joint range.[62] The deltoid is a strong, flat, fan-shaped ligament that is resistant to injury. Deltoid ruptures are rare, except in eversion injuries. The anterior portion is more susceptible to rupture.[63] Because the DL is so strong, it is more likely that the medial malleolus will avulse before the DL will rupture.[62,63] The DL as a whole originates at the medial malleolus and inserts on the navicular anteriorly and on the calcaneus and talus distal and posteriorly. [62] It has four divisions as described by Hinterman,[64] a superficial layer which spans the medial malleolus to the medial aspect of the calcaneus, and a deep layer further divided into three portions. The first is the anterior tibiotalar ligament, secondly the intermediate tibiotalar ligament and lastly the posterior tibiotalar ligament. [64]

Muscular anatomy: The muscles that cross the ankle joint are imperative for dynamic stability. There are many muscles in the lower leg and are divided into three compartments:1) anterior; 2) lateral; and 3) posterior.[3,61,64,65,66] The anterior compartment includes the tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius. [3,61,65,66] The lateral compartment is comprised of the peroneus longus and brevis. Finally, the posterior compartment is divided into superficial and deep portions. The superficial portion contains the gastrocnemius, soleus and plantaris muscles while the deep portion is made up of the popliteus, flexor hallucis longus, flexor digitorum longus and the tibialis posterior. [3,61,65,66] The following tables illustrates the muscles according to their respective compartments, their proximal and distal attachments, innervations and actions. Table B1 represents the anterior compartment. Table B2 illustrates the lateral compartment and Table B3 illustrates the posterior compartment. In the posterior compartment, the gastrocnemius, soleus and plantaris are considered superficial muscles, while the popliteus, flexor hallucis longus, flexor digitorum longus and tibialis posterior are deep muscles.

Table B1. Muscles of the Lower Leg: The Anterior Compartment [61,65]

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Tibialis Anterior	Lateral condyle and superior half of lateral surface of tibia and interosseous membrane	Medial and inferior surfaces of medial cuneiform and base of 1st met.	Deep Peroneal nerve (L4 & L5)	Dorsi-flexes ankle & inverts foot
Extensor Digitorum Longus	Lateral condyle of tibia and superior ¾ of medial surface of fibula and interosseous	Middle and distal phalanges of lateral 4 digits	Deep Peroneal nerve (L5 & S1)	Extends lateral 4 digits & dorsi-

	membrane			Flexes ankle
Extensor Hallucis Longus	Middle part of anterior surface of fibula and interosseous membrane	Dorsal aspect of base of distal phalynx of great toe	Deep Peroneal nerve (L5 & S1)	Extends great toe and dorsi-flexes ankle
Peroneus Tertius	Inferior 1/3 of anterior Surface of fibula and Interosseous Membrane	Dorsum of base of 5th metatarsal	Deep Peroneal nerve (L5 & S1)	Doris-flexes ankle & assists in foot eversion

Table B2. Muscles of the Lower leg: The Lateral Compartment [61,65]

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Peroneus Longus	Superior 2/3 and head of fibula	Base of 1st metatarsal & Medial cuneiform	Superficial Peroneal nerve	Everts foot and weak ankle plantar-flexor
Peroneus Brevis	Iinferior 2/3 of lateral surface of tibia	Dorsal surface of tuberosity on lateral base of 5th	Superficial Peroneal nerve	Everts foot and weak ankle plantar flexor

Table B3. Muscles of the Lower Leg: The Posterior Compartment [61,65]

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Gastrocnemius	lateral head: lateral Aspect of lateral Femoral condyle. Medial head: pop-liteal surface of femur	Posterior surface of calcaneus by Achilles tendon	Tibial nerve (S1 & S2)	Plantar-flexes ankle when knee is extended & raises heel during walking & flexes knee

Soleus	Posterior aspect Of fibular head, Superior ¼ of Posterior surface Of fibula and medial Border of tibia	Posterior surface of calcaneus by Achilles tendon	Tibial nerve (S1 & S2)	Plantar-flexes ankle
Plantaris	Inferior end of lateral Supracondylar line of Femur and oblique popliteal ligament	Posterior surface calcaneus by Achilles tendon	Tibial nerve (S1 & S2)	Weak plantar-flexor of ankle & knee flexor
Popliteus	Lateral surface Of lateral femoral Condyle and lateral Meniscus	Posterior surface of tibia	Tibial nerve (L4, L5 & S1)	Weak knee flexor
Flexor Hallucis Longus	Inferior 2/3 of posterior fibula and inferior portion Of interosseous membrane	Base of distal phalynx of great toe	Tibial nerve (S2 and S3)	Great toe flexor & weak ankle plantar-flexor supports medial longitudinal arch
Flexor Digitorum Longus	Posterior medial tibia	Bases of distal lateral 4 digits	Tibial nerve (S2 & S3)	Flexes lateral 4 digits & ankle plantar-flexor
Tibialis Posterior	Interosseous membrane, posterior tibia and posterior fibula	Navicular tuberosity, cuneiform and cuboid, bases of 2^{nd}- 5^{th} metatarsals	Tibial nerve (L4 & L5)	Ankle plantar-flexor and foot invertor

Neurovascular anatomy: The ankle complex is innervated by motor and sensory components that stem from the lumbar and sacral plexes.[3] The motor supply is comprised of the tibial, deep peroneal, and superficial nerves, while the sensory supply comes from the three aforementioned mixed nerves as well as two sensory nerves (the sural and saphenous nerves).[3]

The deep peroneal nerve is the nerve of the anterior compartment, and is one of two terminal branches of the common peroneal nerve. [3,65] It surfaces between the peroneus longus muscle and the neck of the fibula, and runs with the anterior tibial artery initially between the tibialis anterior and extensor digitorum longus, and then between the tibialis anterior and extensor hallucis longus. [3,65] The anterior tibial artery supplies blood to the anterior compartment. It is a smaller branch of the popliteal artery and, starts at the inferior border of the popliteus and runs anteriorly through a gap in the superior aspect of the interosseous membrane and descends on the anterior surface of this membrane between the tibialis anterior and extensor digitorum longus. [3,65] It terminates at the ankle joint, in between the malleoli, where it becomes the dorsalis pedis artery. [3,61,65]

The superficial peroneal nerve, a branch of the common peroneal nerve, innervates the lateral compartment. It has both sensory and motor components and supplies nearly all of the skin on the dorsum of the foot and the skin on the distal anterior portion of the leg. [65] The lateral compartment does not have its own artery, but is supplied by branches of the peroneal artery. [61,65]

The tibial nerve, one of the terminal branches of the sciatic nerve, supplies all of the muscles of the posterior compartment. It exits the popliteal fossa between the heads of the gastrocnemius and descends along the fibula underneath the soleus. At the ankle, the nerve lies between the flexor hallucis longus and the flexor digitorum longus tendons. [3,65] The posterior tibial artery, which is the larger terminal branch of the popliteal artery, begins at the popliteus muscle and passes underneath the origin of the soleus. After giving off its largest branch, the fibular artery, the posterior tibial artery passes over tibialis posterior.[3,65] The tibial nerve and veins accompany the posterior tibial artery. The fibular artery is another artery of the posterior compartment and is the most important branch of the tibial artery. [3,65] It begins at the popliteus and soleus, and descends diagonally toward the fibula and then passes along its medial side, usually encompassed by the flexor hallucis longus. It provides muscular branches to the popliteus and other muscles in the posterior and lateral compartments of the leg. [61,65]

Biomechanics

The foot and ankle have three major functions to accomplish during locomotor tasks such as walking and running. The first is to adapt to changing surfaces through frontal plane motion of the subtalar and midtarsal joints (pronation/supination) [67] The second function is to absorb the shock of foot strike and the last is to transer transverse plane rotation of the lower extremity to frontal plane rotation of the foot and then back again. [67] The ankle accomplishes this by moving about a combination of axes and combining dorsiflexion and plantarflexion with slight internal and external rotation and some anterior/posterior translation of the talus on the tibia. [62,64] Rotation of the talus occurs within the mortise in the transverse plane about a vertical axis and also in the frontal plane about the anteroposterior axis. [62] The motions that occur at the talocrural joint are plantarflexion, dorsiflexion, while inversion and eversion occur at the subtalar joint. Normal ankle joint range of motion is generally 20° of dorsiflexion, 30-50° of planterlfexion, 5-10° of eversion and 20-30° of inversion. [62]

Arthrokinematics: The talus is wider anteriorly than it is posteriorly and the lateral facet is much larger than its medial counterpart and its surface is situated slightly obliquely to the medial facet. Inman [68] "proposed that the body of the talus can be thought of as a segment of cone lying on its side with its base directed laterally and the cone should be visualized as 'truncated' or cut off on either end at slightly different angles." [62] Given this orientation, the fibula is allowed greater movement on the lateral facet than the tibia on the smaller medial facet. [62] The lateral malleolus must move more than the medial in ankle joint motion, which means "the ankle joint axis can not be fixed as it would be in a true hinge joint, but must change from dorsiflexion to plantarflexion" [62]

Kinetics: The lateral ligaments of the ankle become taught when the ankle is in inversion and plantarflexion. As mentioned previously, when the stress imposed upon these ligaments is greater than strain, failure occurs. The ATFL is the weakest of the lateral ligaments, and can only withstand 139 newtons, whereas the CFL can withstand 345.7 newtons (about 2-3.5 times greater).[69] These ligaments have an important role in joint stabilization. Their functions have been studied in cadavers by systematically releasing ligaments and determining the subsequent amount of laxity and talar tilt. [64,70] The degree of tilt tends to vary significantly, but there is a consensus among the studies cited by Hinterman [64] that some talar tilt occurs with the elimination of these ligaments. In living subjects, this laxity can be seen in a positive anterior drawer test where anterior displacement of the talus from the tibiofibular mortise occurs. [3]

Epidemiology

Athletes and physically active individuals have an inherent risk of injury during activity. It is estimated that 85% of all athletic injuries affect the joint capsule or surrounding ligamentous structures.[2] It has also been estimated that between one and two million people sustain an acute ankle injury every year, [11,12,14] and ankle sprains account for 25% of all time lost from competition due to injury. [1,22,71] Ankle ligament injuries are the most common injury incurred in athletics and account for about 25% of the injuries that occur in running and jumping sports. [14,44,64] The lateral ligaments are most commonly injured. Richie[1] states that 85% of all ankle sprains are lateral, while only 5% are to the medial structures.[1,20,64] Lateral ankle sprains are the most common acute injury in volleyball,[7] but are not as common as other sports such as basketball and soccer, which may be due to the non-contact nature of volleyball. The rate of acute ankle sprains in volleyball is about .9-1.0 per 1,000 player hours, which is similar to the rates of basketball and soccer. [19,20] Volleyball players are four times more likely to sustain an acute ankle sprain in competition than during practice sessions.[19] Bahr et al.[19] postulates that small actions can be taken such as rule changes, technical training and prophylactic taping or bracing to lead to a significant reduction in the incidence and severity of such injuries.

One of the consequences of sustaining an ankle sprain is residual mechanical and functional instability. [3,14,20,44] Twenty-forty percent of athletes will suffer symptoms of residual mechanical and functional instability after a lateral ankle sprain. Mechanical instability has been said to be due to an anatomic abnormality, for example, disruption of one or more lateral collateral ligaments of the ankle.[1] Bernier et al. [72] reported that seven out of nine subjects with ankle instability demonstrated laxity in the anterior talofibular ligament which is consistent with Hertel et al.'s [35] findings that 75% of subjects with a history of ankle sprain demonstrated laxity of the talocrural joint on stress fluoroscopy. Meyer et al. [59] noted subtalar injury in 80% of the 40 patients who suffered an acute lateral ankle sprain. Tibial varum, rearfoot varus and forefoot valgus are examples of biomechanical deformities that will create mechanical instability by setting up compensatory mechanisms that provoke a supination moment to the talocrural joint. [1]

Functional instability occurs about 34-42% of the time following a lateral ankle sprain [14] and is described as a condition in which a patient is likely to have recurring sprains and/or is likely to experience a feeling of giving way of the ankle [1] It results from mechanoreceptor damage to the lateral ligaments and/or muscles and tendons which subsequently causes subsequent partial de-afferentiation of the proprioceptive reflex. [1,14]

Chronic pain is another potential side-effect. On-going symptoms after lateral ankle sprains affect 55% to 72% of patients at 6 weeks to 18 months. A diagnosis of 'sprained ankle syndrome' has arisen due to the frequency of complications and breadth of longstanding symptoms after an ankle sprain. [3] Due to these changes in stability and residual side-effects, an athlete's chance of re-injuring a sprained ankle has been reported to be from 70-80% or twice as likely. [1,20,73] The commonplace nature of lateral ankle sprains and the alarmingly elevated risk of re-injury have led to the search for the most efficient and effective means for prevention, such as tape and brace application.

Etiology

Lateral ankle sprains most commonly occur when the ankle is excessively plantar flexed and inverted while an external rotation force is applied to the leg. [1,2,3,22,73] This inversion and internal rotation of the rearfoot, along with external rotation of the lower leg places strain on the lateral ligaments. If the strain exceeds the tensile properties of the ligaments, they will fail, causing ligamentous damage. [1,3] The plantarflexed ankle is also most susceptible to injury because, "the plantarflexed talus, with its narrow posterior body, is thrust forward between the malleoli and has less stability than its dorsiflexed position." [1] The ATFL is typically the first ligament to fail, followed by the CFL and then the PTFL which is commonly associated with severe ankle sprains and may be accompanied by fractures and/or dislocations. [3,4,22]

A few studies [6,7,21] have investigated potential risk factors that may predispose certain athletes to lateral ankle sprains. Beynnon et al.[21] points out intrinsic risk factors including gender, height, weight, limb dominance, anatomic foot type and size, generalized joint laxity, [6] range of motion of foot-ankle complex, muscle strength, [6] muscle reaction time and postural sway. Stasinopolous [7] and Beynnon et al. [21] agree that one of the most important predictors of an ankle sprain is a prior history of an ankle injury. There is a significant risk of re-injury in the six to 12 months following the initial ankle sprain. [7] Residual ankle instability is common after suffering a lateral ankle sprain. [3,14,20,44] Other proposed risk factors of chronic ankle instability are muscle weakness, ligament deficiency, joint adhesions, improper bony alignment at the ankle joint and proprioceptive deficits as a result of direct trauma to articular receptors. [6] Freeman [26] suggested that chronic ankle instability is due to partial deafferentiation of joint receptors at the injured joint. [26]

Volleyball players are at significant risk of lateral ankle sprains because they perform a variety of maneuvers that are unique to the sport, including blocking and spiking, which involve vertical jumps. [74] The area in which most blocking and spiking occurs is referred to as the 'conflict zone,'[7] which is an area about 50 cm wide under the net where players from opposing teams may come into contact. In addition, two or even three players often form blocks simultaneously, increasing the risk of coming into contact with other players.[7,19] Therefore, one of the most common mechanisms of lateral ankle sprains in volleyball is landing on another player's foot after a vertical jump.[7,19] In a study by Bahr et al.[19] examining incidence and mechanisms of injury in volleyball, they found that, out of a total of 54 ankle injuries, 86% occurred in the net zone; usually when landing after blocking or attacking. Of these injuries in the net zone, 52% were the result of landing on the foot of an opponent, 24% by landing on a teammate's foot and 13% from landing on the floor. Based on the etiological factors of lateral ankle sprains, it is understandable why so many researchers, athletic trainers and coaches are constantly exploring the most effective and cost-effective prophylactic solutions.

Types of Braces and Mechanisms of Action

Athletic trainers, coaches and athletes typically use ankle supports as a means for reducing the incidence of initial ankle injury or preventing recurrence.[34] As early as the 1940's, researchers have investigated the efficacy of ankle supports. In 1946 and 1959, Quigley examined effectiveness of ankle supports and found a considerable measure of protection by ankle wraps.[13] Recently, a variety of ankle braces have surfaced on the market as cost-effective alternatives to taping. They have become popular alternatives because of their ease of application, cost effectiveness and convenience. They are also adjustable during competition and cause little skin irritation.[2,8,47] The types of braces range from soft canvas or cloth lace-up to semi-rigid, molded-plastic orthoses made of plastic polymers and thermoplastic materials.[2,8,20,47,75] In a comparison among braces, Arnold and Docherty[34] concluded that, semirigid style braces (ie. those that combine fabric and rigid support) provided more support than soft (ie. fabric only) braces and semirigid braces with a stirrup style rigid support (ie the Air-Stirrup, Aircast, Summit, New Jersey) were more effective than semi-rigid braces with other types of rigid support. Also, tape and semirigid style braces performed similarly. These findings suggest that, due to convenience and cost issues, bracing may be a preferred form of support.

Although several clinical studies have shown reduced incidence of lateral ankle sprains by bracing, the precise mechanisms of action of these braces has eluded researchers. [20,75] One of the most widely accepted mechanisms of action is to biomechanically limit ankle inversion and eversion range of motion, specifically limiting frontal plane motion of the subtalar joint. [2,4,8,10,12,20,34,47] Cordova and Ingersoll [17] indicated that the greatest restriction of range of motion was by a semi-rigid brace, followed by a lace-up and then tape. Ubell et al. [12] proposed that ankle braces prevent forced ankle inversion by positioning the ankle in a neutral position, avoiding the inverted position that is common in an un-braced ankle after a vertical jump and prior to landing. Furthermore, the braces help eliminate inversion of the talus and calcaneus before impact. [12] Other commonly accepted mechanisms are enhancement of proprioceptive input to the central nervous system, increased neuromuscular control, enhanced kinesthesia and sensorimotor function through stimulation of cutaneous mechanoreceptors. The increased neuromotor control may help the peroneal muscles resist inversion moments and avoid or limit damage to the lateral ligaments.[2,4,8,20,34,47,75]

In a study by Cordova et al.,[15] examining potential mechanisms of action of ankle braces, ground reaction forces during running and lateral shuffles to simulate dynamic inversion were studied. They found that the braces did not affect the magnitude of the ground reaction forces, but actually increased the time in which the forces acted, thereby attenuating external forces applied to the ankle.

Olmstead et al. [4] demonstrated that bracing is more cost-effective, less time consuming and more convenient than taping. Taping is three times more expensive than bracing during the course of a competitive season. They found that taping 57 athletes with no prior history of an ankle sprain throughout the course of an entire season would cost $6091.00, whereas bracing those athletes would cost $1995.00. A typical volleyball team might have a roster of 25 athletes. Based on Olmstead et al.'s findings, it would cost roughly $997.00 to brace a volleyball team for an entire season.[4]

Proprioception, CNS Integration and Postural Control

Proprioception: Proprioceptive information plays a critical role in the body's ability to decipher internal cues used with feedforward control. Proprioception is afferent information gathered through specialized sensory receptors or mechanoreceptors. [76,77,78,79] Proprioception is an umbrella term that encompasses specialized tactile sensations including the detection of joint position, movement and rates of movement. [51,80] There is no single receptor that provides all proprioceptive information. There are four specialized types that work in conjunction to signal joint position sense and movement. The specialized receptors, such as mechanoreceptors are located in skin, muscle, bony articulations (joints) and ligaments. [51,80] They are further broken down according to their locations. Type I are found in the joint capsule and synovial fluid, and type II are found in the fat pads. Both of these types of mechanoreceptors are active at the beginnings of joint motion. Type III are found in ligaments and type IV are found in free nerve endings. These mechanoreceptors are active at the ends of joint range. [51,81] There are four specific types of mechanoreceptors that differ in their locations, adaptation rates and functions. These types are: 1) Ruffini receptors; 2) Pacinian corpuscles; 3) Golgi tendon organs (GTO's) and 4) muscle spindles. [51,76,80] Ruffini receptors are both static and dynamic receptors and are located in the joint capsule and ligaments. [51,76,80] They have a slow adaptation rate and function to detect joint pressure. [76] Pacinian corpuscles are located in the joint capsule and are considered to be dynamic receptors because of their rapidly adapting characteristics. [76] GTO's are located within musculotendinous tissue, spaced along the musculotendinous junction at varying intervals.[76] They serve to provide the central nervous system (CNS) with feedback regarding changes in muscle tension, primarily active. The GTO is thought to provide a protective mechanism from the development of excessive tension. [78,79] Muscle spindles are comprised of specialized afferent nerve endings wrapped around modified muscle fibers that are enclosed within a connective tissue capsule. [76] Muscle spindles provide information about muscle length and the rate of change in length. [76,79]

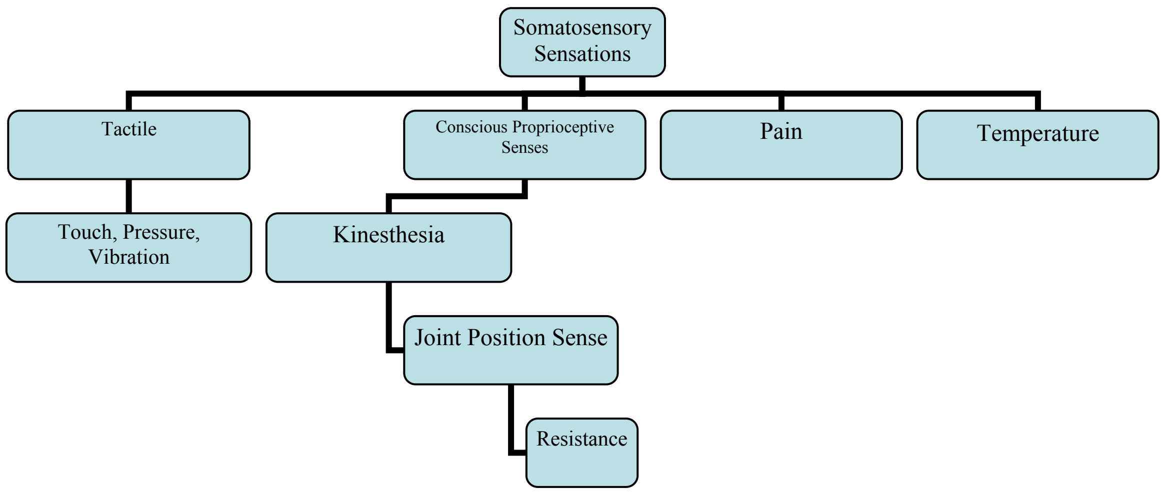
CNS Integration: The information provided by these mechanoreceptors and visual and vestibular information is integrated at the CNS and an efferent motor response is generated which is referred to as neuromotor control. Integration entails the summation, gating and modulation of sensory information resulting from combinations of inhibitory and excitatory synapses with the afferent neurons. [51,76,78,80] Integration is thought to begin at the spinal cord level, although afferent integration occurs along all levels of the CNS and is an integral component of coordinated, fluid motor control. The axons which convey proprioceptive information bifurcate once they enter the dorsal horn of the spinal cord and synapse with interneurons. Afferent integration at the spinal cord level depends on the connection of interneurons and neurons with higher CNS levels. The regions of the supraspinal CNS allow the modulation of sensory information provided by the periphery entering the ascending tracts. [51,76,78,80]

Two theories exist to describe the methods by which proprioceptive information from receptors is conveyed to the CNS. The labeled line theory assumes that every unique stimulus activates a specific receptor associated with a specific nerve fiber terminating at a specific point or points within the CNS. [76] Ensemble coding, the second theory, proposes that proprioceptive stimuli is forwarded to the CNS by traveling across a 'neural population' of receptors. It is then encoded and relayed to the CNS. [76] Most proprioceptive information, however, reaches higher CNS levels through the dorsal lateral or spinocerebellar tracts. These tracts are located on the posterior spinal cord and are responsible for transmitting signals to the somatosensory complex. The dorsal lateral tracts are associated with conscious sensory awareness, while the spinocerebellar tracts are thought to be responsible for nonconscious proprioception such as joint angles, muscle tension and limb postures utilized in reflexive, automatic and voluntary activities. [76] Parts of these tracts are also believed to relay an efferent copy of motor neuron drive back to the higher levels of the CNS. [76] The motor components of the sensorimotor system contribute to dynamic joint stability and include a central axis and two associate areas. The central axis corresponds to the spinal cord, brain stem and cerebral cortex, the three levels of motor control. Furthermore, the two associate areas are responsible for the modulation and regulation of motor commands and include the cerebellum and basil ganglia. The spinal cord level is responsible for direct motor responses to sensory information gathered by the periphery, known as reflexes and elementary patterns of motor coordination. [76] At the brain stem level, there are major circuits responsible for postural equilibrium and automatic body movements. In addition, some areas of the brain stem "directly regulate and modulate motor activities based on the integration of sensory information from visual, vestibular and somatosensory sources." [76] The cerebral cortex initiates and controls complex and discrete voluntary movements and is divided into three areas that project onto interneurons and motor neurons in the spinal cord. The primary motor cortex directs which muscles are necessary, the force needed and the direction of movement based on afferent information received from the periphery. The premotor area is involved in the preparation and organization of motor commands. The third area programs complex sequences of movement requiring groups of muscles. The associate areas include the cerebellum and basal ganglia and can not independently initiate motor activity. However, they are imperative for the execution of coordinated motor control. [76]

Postural Control: One of the most critical aspects of prevention of ankle injury is the ability to detect motion in the foot and, in response to these motions, make necessary postural adjustments. Similarly and equally as important is the ability to detect the position of the ankle joint before it makes contact with the ground. [82] Inability to achieve proper joint position may be attributed to loss of proprioceptive information from mechanoreceptors. [82] The function of the postural control system is to maintain postural equilibrium during all motor activities, and does so in three ways. [55] The first way is to determine the body's "position relative to the support surface and gravity and the positions of each segment relative to each other."[55] This is achieved through afferent information arising from vestibular, visual and somatosensory cues. Secondly, the information gathered from the three sources "must be integrated and processed to determine necessary motor commands, which are executed by muscles along the entire kinetic chain." [55] The last part of regulating postural control involves actually executing the commands made by the neuromuscular tissues. [55] Postural control occurs by two different systems. [55] The first system is feedback which is "stimulation of a corrective response within the corresponding system after sensory detection." [76,77] For example, an athlete stumbling over an unanticipated obstacle. [55] However, feedforward, the second of the two systems, "have been described as anticipatory actions occurring before the sensory detection of a homeostatic disruption." [76] Riemann [55] gives an example of a wrestler crouching in anticipation of an offensive attack by an opponent. Despite the clarity of the definitions, classifying an action as feedback or feedforward is not as clear-cut as it may seem, because in some circumstances a combination of both systems are utilized, such as during the maintenance of postural control.

The somatosensory system is an extremely complex subcomponent of the body's comprehensive motor control system. [76,78] This system includes the sensory, motor and central integration and processing components involved in maintaining joint homeostasis during body movement. [76] Maintaining joint stability is accomplished by "a complimentary relationship between static and dynamic components." [76,78] The static components include ligaments, joint capsule, cartilage, friction and bony geometry withing the articulation. The dynamic components are from the feedforward and feedback controls mentioned previously. The following diagram represents the divisions of somatosensory sensations. They are broken down into tactile, conscious proprioceptive senses, pain and temperature. The tactile division includes senses such as touch, tickle, pressure and vibration. Conscious proprioceptive senses include kinesthesia, joint position sense and resistance sensations. Other somatosensory sensations include pain and temperature perception.

Figure B1. Somatosensory Sensations [76]



Effectiveness of Ankle Braces

Rsearchers [10,12,13,20] have investigated other aspects of the effects of ankle bracing. Greene[10] compared the general effectiveness of athletic taping and semi-rigid braces in restricting inversion-eversion range of motion. Passive inversion and eversion were measured at five points: 1) before support; 2) before exercise; 3) 20 minutes into exercise; 4) 60 minutes into exercise and; 5) post exercise. The major conclusions of this study were that both taping and bracing were effective in providing inversion-eversion restriction before exercise. Taped ankles showed an initial restriction of 41% that reduced to 15% after three hours of exercise, and showed maximal losses in restriction at 20 minutes into exercise. The orthosis had a loss in eversion restriction after three hours of exercise, but no significant loss of inversion restriction was observed. This study indicated that braces can be more effective than taping in preventing range of motion restriction. In addition, neither taping nor bracing had negative effects on participants' vertical jumping ability.

Similarly, Myburgh et al. [13.] examined the effects of ankle taping and bracing on joint motion before during and after exercise. Two types of ankle supports and two types of tape were applied using the same method. Ranges of motion were measured using a goniometer with a digital display. Their conclusions were that elastic ankle guards provided no significant restriction of range of motion whereas tape strapping provided a significant restriction after 10 minutes of exercise, but this restriction deteriorated thereafter. After one hour of exercise, the restriction of range of motion was no longer statistically significant.

Ubell et al.[12] investigated the effects of ankle braces on preventing forced dynamic ankle inversion. They tested three braces, two semi-rigid and one lace up. Subjects were to resist forced dynamic ankle inversion of 24° as they landed on a platform on one foot. They found that all three of the braces tested were effective in decreasing the probability of forced inversion. They also determined that the semi-rigid orthoses were more effective than the lace up brace.

Bot and Mechelen [20] examined the effects of ankle bracing on functional athletic performance. They looked at past research that has tested functional tasks such as vertical jump height, running speed, agility and broad jump. Based on the studies they reviewed, they found that the majority of studies indicated that bracing has little to no detrimental effect on measures of vertical jump height, running speed, agility and broad jump.

A number of studies have been conducted that examine the effects of ankle injuries and taping and bracing on postural control. [9,15,18,44,45,46] Most of the studies conclude that athletes with a history of ankle sprains may have reduced postural control. [44] Other studies directly investigating the effects of ankle braces seem to have conflicting conclusions. For example, Benell and Goldie [18] evaluated postural control with an eyes-closed unilateral leg stance, and a force plate to measure medial/lateral ground reaction force in non-injured subjects and found that the use of tape or a brace had a detrimental effect on postural control. In contrast, Feuerbach and Grabiner [45] found that use of an Aircast improved unilateral postural control as measured by the Chattex Balance System in non-injured subjects. Kinzey [46] and Refshauge et al. [9] found that taping and bracing do not seem to enhance or inhibit proprioception. However, their studies differed in that Kinzey used healthy subjects and measured center or pressure during a modified romberg, while Refshauge used a healthy control and experimental group with a history of recurrent lateral ankle sprains. Refshauge measured the ability to perceive passive plantarflexion and dorsiflexion imposed by a linear servomotor. Although their methods differed, their findings may still suggest no significant effects on postural control.

Cordova, Ingersoll and Palmieri [15] summarize these confusing findings in their systematic literature review and conclude that, “the potential effects of ankle support on joint kinetics and joint kinematics during dynamic activity, and various sensorimotor measures are not well known.” The following table provides an outline of these studies, including brief descriptions of the purpose, instruments, procedures, and results/conclusions.

Table B4. The Effects of Ankle Bracing on Postural Control

Author	Purpose of study	Instruments	Procedure	Results/ Conclusions
Nakawaga & Hoffman[44]	Evaluate DPC & SPC in	NeuroCom Smart Balance	Subjects performed Unilateral leg stance	subjects w/ recurrent ankle sprains had greater excurs-

	patients with recurrent ankle sprains	Master	and lateral step onto foam pad. Total excursion was measured	ions in both static and dynamic conditions. Therefore, recurrent ankle sprains may be associated with reduced postural control
Refshauge et al.[9]	Determine if taping can enhance proprioceptive ability	Apparatus w/ linear servomotor with metal plate	Measurements of subjects' ability to perceive passive plantar flexion and dorsiflexion at 3 velocities in a taped and control condition	Taping was shown not to enhance proprioception in the dorsiflexion/ plantarflexion plane.
Cordova, Ingersoll & Palmieri[15]	Determine the role of external ankle support on joint kinetics, kinematics and sensorimotor function.	Medline and Sport Discus Databases	Systematic review of literature. Key words: ankle bracing, ankle support and ankle prophylaxis	The potential effects of ankle support on joint kinetics and kinematics are not well known.
Benell & Goldie[18]	Investigate the effects of 3 different ankle supports (tape, brace and elastic bandage) on postural control	One-legged stance and a force platform	The number of leg touch-downs were counted during a single leg stance in each of the conditions. Variability of medio-lateral GRF was measured by the force platform	The use of an elastic bandage had no significant effect on postural control, while the use of tape or brace had a significant detrimental effect. While wearing tape or brace, subjects touched down more frequently.
Freurbach & Grabiner[45]	Determine the effect of the air-cast stirrup on motor performance	Chattex Balance system	Amplitude & frequency of postural sway during unilateral leg stance was Measured	The aircase improved unilateral postural control indicated by decreases in some of the components of postural sway.
Kinzey[46]	Determine the Effects of various ankle appliances on postural control	One-legged modified romberg test with six variations	Center of pressure was monitored during each trial and transformed into total distance traveled, anterior-posterior position and medial lateral position	The results do not support disprove the concept that bracing enhances proprioception

One study by Palmieri et al. [16] speaks to the importance of the need for further investigation into the effects of ankle bracing over an extended period of time, and the evaluation of postural control dynamically. Their study examined the effects of four days of ankle bracing on static postural control. They used a control and experimental group and a strain-gauge force-plate system to measure medial-lateral and anteroposterior postural control during a single leg stance. Although their findings were not significant, they indicate that further research is necessary that looks at long term ankle bracing and dynamic postural control.[16]

Cordova et al. [17] examined the effects of eight weeks of brace use on peroneal latency in a sudden inversion moment. Braces were worn for approximately eight hours per day during the time of day subjects were active. They concluded that the peroneus longus stretch reflex was not affected positively or negatively by eight weeks of brace use and added that proprioceptive input provided by mechanoreceptors in the peroneus longus were not compromised by long-term use of ankle braces. Based on their findings they advocate 'long term' brace use, citing no differences in peroneus longus latency.

Summary

Lateral ankle sprains are the most common athletic injury, which has led to widespread use of prophylactic braces. Little research, however, had been devoted to examining the long term effects of ankle bracing on dynamic postural control. The ankle joint is very anatomically and biomechanically complex. It is comprised of numerous bones, muscles, ligaments and neurovascular structures that all work together to perform functional activities and maintain the body's center of gravity over a stable base of support. There is also heavy reliance on the central nervous system and its components to aid in dynamic postural control. Bracing has been proven effective in decreasing the incidence of ankle sprains, especially in individuals with chronic ankle instability, but more research is needed to examine the mechanisms by which braces work and long term effects on dynamic postural control.

APPENDIX C

ADDITIONAL METHODS

Table C1. Informed Consent Form

CONSENT AND INFORMATION FORM

THE EFFECTS OF PROPHYLACTIC BRACING OVER THE COURSE OF AN ENTIRE VOLLEYBALL SEASON ON DYNAMIC POSTURAL CONTROL

Introduction

I, ________________, have been invited to participate in this research study, which has been explained to me by Brinn Spencer, ATC. She is conducting this research under the supervision of Michelle A. Sandrey, PhD, ATC to fulfill the requirements for a master's thesis in Athletic Training in the School of Physical Education at West Virginia University.

Purpose of the Study

The purpose of this study is to determine the effects of prophylactic ankle bracing over the course of a volleyball season on dynamic postural control.

Description of Procedures

This study will be conducted in the Athletic Training Clinic Laboratory and old gym at Waynesburg College, Waynesburg, PA 15370.

Interventions

This informed consent form describes my rights as a research subject. The purpose of this study will be explained to me. I will be also given a demographic/inclusion criteria questionnaire and asked to complete it honestly. Completed forms will be kept confidential.

If I am an eligible subject, I will undergo three testing sessions to measure my dynamic postural control using the Star Excursion Balance Test (SEBT), height, weight, arch index and ankle strength. The SEBT consists of a star shaped pattern taped onto the floor with eight excursions at 45° angles. Before starting the SEBT, the principal investigator will measure my leg length with me lying on my back. A tape measure will be used to measure the distance between the front of the hip bone of one leg to the center of the same inner ankle.

Submission Date _________ Page 1 of 4 ___________ __________
Initials Date

THE EFFECTS OF PROPHYLACTIC BRACING OVER THE COURSE OF AN ENTIRE VOLLEYBALL SEASON ON DYNAMIC POSTURAL CONTROL

I will be asked to stand on my dominant foot in the center of the 'star' and use my non- dominant foot to reach as far as possible in each excursion direction. The eight lines on the grid will be labeled according to the direction of the leg that is moving will be placed. The moving leg will have to touch each line in the directions of front, front right corner, middle, back right corner, back, back left corner, left and front left corner. I will have a practice session consisting of six reaches in each direction, followed by one minute of rest.

I will then perform each excursion three times and each excursion will be measured in inches, recorded and averaged for one score in each direction. I will be given 15 seconds to rest in between directions. I will then return to a bilateral leg stance afterwards, while maintaining balance. I will perform all trials in a clockwise fashion if the reach leg is the left leg and a counterclockwise fashion if the reach leg is the right leg. Trials will be discarded and repeated if I am unable to maintain my balance, if my stance leg comes off the center of the star or if my reach leg touches the ground for more than a brief period to allow for measurement.

I understand that I will undergo two testing sessions before the 2005 volleyball season. One will be with a brace on, and one will be without a brace. These tests will be one day apart. I will also be tested on the SEBT at the mid-point, and one at the conclusion of the season. I will be asked for my full cooperation and to work to the best of my ability. My involvement in this will initially take approximately 15-20 for a pre-testing session prior to the first practice session. This will be followed by testing at the mid-point of the season, lasting approximately 15-20 minutes and a post-testing session, also lasting approximately 15-20 minutes, following the last practice session or game of the 2005 season.

After the initial testing, I agree to wear the prophylactic ankle brace during all competitions and practice sessions. I understand that the brace has to be applied consistently for all practices and games during the season. I also understand that I will be monitored throughout the season to ensure the correct application procedures and tightness protocol is followed. I understand the brace has to be applied in the following order (as per manufacturers directions) Step1. Adjust the large fastening strap by sliding it up for high top shoes, or down for low top shoes. Step 2. Place the active ankle inside the shoe with the logo positioned so that it will be on the outside of your ankle. Step 3. If your shoe has a removable insole or orthotic, place the Active Ankle under it. Step 4. Place your foot inside the shoe. Make sure to adjust the pivot points to be in line with your ankle bones. Step 5. Place the small strap in the back comfortably and without tension around the back of your ankle and secure it as low as possible to the Velcro on the inside. Step 6. Secure the large fastening strap firmly around the ankle.

Submission Date _________ Page 2 of 4 ___________ __________

Initials Date

THE EFFECTS OF PROPHYLACTIC BRACING OVER THE COURSE OF AN ENTIRE VOLLEYBALL SEASON ON DYNAMIC POSTURAL CONTROL

I agree to undergo pre-test measurements of ligament laxity, anatomic foot type (pronation or supination) and ankle evertor muscle (the muscles that move my foot outward) strength.

To test ligament laxity, I will sit on an examination table while the primary investigator performs three tests. These tests will be similar to ones my athletic trainer would perform if I injured my ankle.

To assess anatomic foot foot type, I agree to have the bottom of my foot rolled with a washable, non-toxic ink. I will then step down on one foot on a sheet of paper, using a wall for balance.

To assess ankle muscle strength, I agree to be tested using break muscle tests. I will sit on a table while the examiner asks me to hold my ankle in a certain position while the examiner attempts to 'break' the muscle contraction. This is done by the examiner resisting the position I have put my ankle in. I agree to perform the test to the best of my ability.

Risks and Discomforts

There are no known or expected risks from participating in this study. While performing the star excursion balance test, it is likely that I will not lose my balance because I will be performing the test with my eyes open. However, I will be instructed to touch down with my reaching leg if I feel I am losing my balance. The principal investigator will also be standing next to me if I am unable to touch down with my reaching leg. Should any injury occur, I understand that Brinn Spencer, ATC will provide first aid and make any necessary medical referral at my expense. I understand that some muscles soreness may occur from the Star Excursion Balance Test, but I will be assisted and instructed in leg stretching techniques before the test to minimize muscles soreness. Stretching will consist of hamstring, quadriceps, calf and ankle stretching. I will also be allowed a warm up period before muscle strength testing begins to minimize soreness.

Alternative

I understand that I do not have to participate in this study.

Benenfits

I understand that this study may not directly benefit to me, but the knowledge gained through this study may be of benefit to others.

Financial Considerations

I understand that I will receive no monetary compensation for completing this study.

THE EFFECTS OF PROPHYLACTIC BRACING OVER THE COURSE OF AN ENTIRE VOLLEYBALL SEASON ON DYNAMIC POSTURAL CONTROL

Contact Persons

For more information about this research, I can contact Brinn Spencer, ATC at (607) 435-4851 or at bspencer@waynesburg.edu or her faculty advisor, Michelle A. Sandrey, PhD, ATC at (304) 293-3295 Ext. 5220 or at msandrey@mail.wvu.edu. For information regarding my rights as a research subject, I may contact the Executive Secretary of the Review Board at (304) 293-7073.

Confidentiality

I understand that any information about me obtained as a result of my participation in this research will be kept as confidential as legally possible. Identifying information on the informed consent form and demographic/injury history questionnaire will be kept confidential by assigning a code number to each informed consent form and demographic/injury history questionnaire.

I understand that my research records and test results, just like hospital records, may be subpoenaed by court order. In any publications that result from this research, neither my name nor any information from which I might be identified will be published without my consent.

Voluntary Participation

Participation in this study is voluntary. I understand that I am free to withdraw my consent to participate in this study at any time and that such refusal to participate will not affect my future care as a student athlete at Waybesburg College, my class standing or grades or my status on the Waynesburg College volleyball team. Refusal to participate or withdrawal will involve no penalty to me including evaluation and treatment of injuries. I have been given the opportunity to ask questions about the research, and I have received answers concerning areas I did not understand. In the event new information becomes available that may affect my willingness to continue to participate in this study, this information will be given to me so I may make an informed decision about my participation.

Upon signing this form I will receive a copy.

I willingly consent to participate in this research.

____

Signature of Subject   Date/Time

____

Signature of Principal Investigator   Date/Time

Table C2. HIPPA Form

Authorization to Use or Disclose Protected Health Information (PHI)

West Virginia University

I hereby voluntarily authorize the use or disclosure of my individually identifiable health information as described below.

Patient Name:	______________________	ID Number:	____________________
Date of Birth:	______________________	IRB Protocol #:	____________________

Persons/organizations providing the protected health information (e.g. hospitals):

Persons/organizations receiving the information (e.g. investigators, clinical coordinators, sponsor, FDA):

The following information will be used:

The information is being disclosed for the following purposes (Start with the Title of the study and include additional information e.g. screening and recruiting subjects; analyzing research data, or other specified purposes):

I may revoke this authorization at any time by notifying the Principal Investigator in writing at:

(Name and address of PI)

If I do revoke my authorization, any information previously disclosed cannot be withdrawn. Once information about me is disclosed in accordance with this authorization, the recipient may redisclose it and the information may no longer be protected by federal privacy regulations.

Page 1 of 2

Authorization to Use or Disclose Protected Health Information (Contd.)

I may refuse to sign this authorization form. My clinical treatment may not be affected by whether or not I sign this form. I may not be allowed to participate in the research if I do not sign the form.

This authorization will expire on the date that the research study ends. (Other options for expiration include an actual date of expiration, occurrence of a particular event, or "none" if the authorization will have no expiration date.)

Expiration date: ________________

I will be given a copy of this authorization form.

____ ________________

Signature of subject or subject's legal representative Date
(Form MUST be completed before signing)

____

Printed name of subject's legal representative
Relationship to the subject Initials

- ☐ Parent ______________
- ☐ Medical power of attorney/representative ______________
- ☐ Legal guardian ______________
- ☐ Health care surrogate ______________

Table C3. Demographic Questionnaire and Inclusion Questionnaire

---

Demographic/Injury Questionnaire

Demographics

Name___________________

Age________

Year in school (Circle) Fr So Jr Sr Graduate Student

Height_______ Weight_______

Dominant leg (Circle) R L

Inclusion Questionnaire

1. Have you had a lower extremity injury in the past six months that has required the intervention of a doctor or allied health professional? Yes/No If yes, please explain:

____

2. Have you had a head injury in the past six months? Yes/No If yes, please explain:

____

3. Are you currently taking any prescription medication that may effect balance? Yes/No If yes, please explain:____

4. Have you had any inner ear or balance disorders in the past six months that have required the intervention of a doctor or allied health care professional? Yes/No If yes, please explain:

____

5. Have you had any surgical procedure on the lower extremity in the past six months? Yes/No If yes, please explain: ____

____

6. Have you had any visual disorders in the past six months? Yes/No If yes, please explain: ____

____

7. Have you had any neurological disorders in the past six months? Yes/No If yes, please explain: ____

____

8. Do you currently wear any ankle supports or braces? Yes/No If yes, please explain:

____

9. Do you have a history of chronic ankle sprains? Yes/No If yes, please explain:

____

10. Are you currently in a training program for balance? Yes/No If yes, please explain:

____

Table C4. Data Collection Form

Code #_______
Time (circle) Pre-test Mid-test Post-test

Subject's Leg length: R_______ L________

Star Excrusion Balance Test: Pre-test

	Anterior	A/M	Medial	P/M	Posterior	P/L	Lateral	A/L
Trial 1								
Trial 2								
Trial 3								
Average								

Mid-test

	Anterior	A/M	Medial	P/M	Posterior	P/L	Lateral	A/L
Trial 1								
Trial 2								
Trial 3								
Average								

Post-test

	Anterior	A/M	Medial	P/M	Posterior	P/L	Lateral	A/L
Trial 1								
Trial 2								
Trial 3								
Average								

Ankle Ligament Laxity:

Anterior Drawer: 0 1 2 3

Talar Tilt: 0 1 2 3

Medial Subtalar Glide: 0 1 2 3

Ankle Inversion Strength 0 1 2 3 4 5

Ankle Eversion Strength 0 1 2 3 4 5

Table C5. Directions for Brace Application (Active Ankle Systems Inc.)

Step1. Adjust the large fastening strap by sliding it up for high top shoes, or down for low top shoes.

Step 2. Place the active ankle inside the shoe with the logo positioned so that it will be on the outside of your ankle.

Step 3. If your shoe has a removable insole or orthotic, place the Active Ankle under it.

Step 4. Place your foot inside the shoe. Make sure to adjust the pivot points to be in line with your ankle bones.

Step 5. Place the small strap in the back comfortably and without tension around the back of your ankle and secure it as low as possible to the Velcro on the inside.

Step 6. Secure the large fastening strap firmly around the ankle.

Table C6. Directions for the Star Excursion Balance Test

1. Subjects will be instructed to remove their shoes and socks and stand with the foot of their dominant leg in the center of the star. The will be asked to perform a single leg stance and maintain their balance while reaching maximally with their non-dominant leg along a given excursion.

2. Subjects will be instructed to lightly touch the star with the most distal aspect of the reach leg.

3. Subjects will be instructed to return to a bilateral leg stance afterwards, while maintaining balance.

4. Subjects will be asked to perform a practice session and perform each of the eight excursions six times with a 15 second rest period between each excursion.

5. The subject will then have a one minute rest period between the practice session and the actual trials.

6. The trials will begin with a 15 second rest period between each of the eight excursions.

7. Trials will be discarded and repeated if the reach leg is used for substantial support, if the stance leg comes off of the star and if the subject fails to maintain their balance.

8. The scores will then be averaged for one score of the subject's dynamic postural control.

Table C7. Procedure for Ligament Laxity Testing

1. Subjects will be asked to sit on an examination table with their ankles over the edge of the table.

2. For the anterior drawer test, the examiner gently pulled anteriorly on the calcaneus to attempt to distract the calcaneus from the talus and assess lateral ligament laxity.

3. For the medial subtalar glide test, the examiner gently pulls medially on the calcaneus attempting to distract the calcaneus from the talus and assess medial ligament laxity.

4. For the talar tilt test, the examiner gently inverts the subjects' ankle attempting to stretch and assess the lateral ligaments.

Table C8. Procedure for Arch Index Testing

1. Subjects was asked to sit on an examination table with the bottom of their foot exposed.

2. The bottom of their foot was rolled with washable ink.

3. They were then asked to step down with their full weight on a piece of white paper.

4. The subject's foot was wiped off.

Table C9. Procedure for Ankle Strength Testing

1. Subjects will be asked to sit on an examination table with their ankles over the edge.

2. For inversion testing, subjects will be asked to maximally invert their ankle and hold it there while the examiner applies force in the opposite direction.

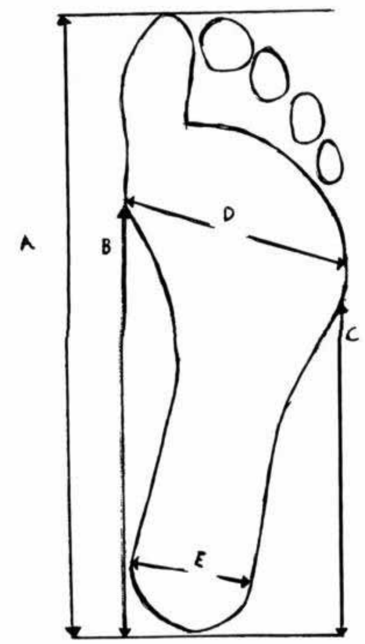
3. For eversion testing, subjects will be asked to maximally evert their ankle and hold it there while the examiner applies force in the opposite direction.

4. They will then be given a score for both inversion and eversion on a scale from 0 to 5, with 0 representing very weak and 5 representing very strong.

Figure C1. The Active Ankle Brace

Figure C2. The Star Excursion Balance Test [3]

Figure C3. Arch Index Measurements



Key: A = Foot length, B = First metatarsal length, C = Fifth metatarsal length, D = Ball width, E = Heel width, F = Midfoot arch.

APPENDIX D

ADDITIONAL RESULTS

Table D1. Descriptive Statistics for Reach Direction

Direction	Pre-test	Mid-test	Post-test
Anterior	88.072±8.509	83.018±6.952	81.551±6.953
Anteromedial	88.198±6.419	84.715±4.774	81.551±5.952
Medial	89.496±6.269	85.658±6.088	85.909±5.603
Posteromedial	89.090±7.119	84.857±8.131	87.160±7.833
Posterior	83.537±9.377	84.543±10.648	83.685±11.835
Posterolateral	78.619+9.284	76.496±12.385	76.680±10.727
Lateral	68.735±7.554	67.676±9.881	67.176±10.402
Anterolateral	78.511±6.362	75.985±7.544	74.856±8.278

Table D2. Within Subjects ANOVA 2 x 8 Factorial

	F Value	P Value	ES	ß
Condition	6.561	.026*	.374	.646
Direction	25.433	.001*	.973	1.00
Condition x Direction	.272	.940	.276	.079

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D3. Pairwise Comparisons for Pre-test Measures

Direction	t value	Significance (2-tailed_
Anterior	2.404	.035*
Anteromedial	1.496	.163
Medial	1.495	.163
Posteromedial	1.142	.278
Posterior	1.016	.332
Posterolateral	2.703	.021*
Lateral	2.487	.030*
Anterolateral	3.605	.004*

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D4. Within Subjects ANOVA 3 x 8 Factorial

	F Value	P Value	ES	β
Time	3.232	.059	.227	.556
Direction	31.079	.000*	.739	1.000
Time x Direction	1.924	.028*	.149	.927

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D5. Results of Pre-test/Mid-test Pairwise Comparisons

	t Value	Significance (2 Tailed)
Pre Anterior/ Mid Anterior	3.379	.006*
Pre Anteromedial/Mid Anteromedial	2.228	.048*
Pre Medial/ Mid Medial	2.248	.046*
Pre Posteromedial/ Mid posteromedial	1.976	.074
Pre Posterior/ Mid Posterior	-.433	.673
Pre Posterolateral/ Mid Posterolateral	1.075	.305
Pre Lateral/Mid Lateral	.539	.601
Pre Anterolateral/ Mid Anterolateral	1.789	.101

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D6. Results of Mid-Test/Post-Test Pairwise Comparisons

	t Value	Significance (2 Tailed)
Mid Anterior/ Post Anterior	1.488	.165
Mid Anteromedial/ Post anteromedial	-.199	.846
Mid Medial/ Post Medial	-.165	.872
Mid Posteromedial/ Post Posteromedial	-1.337	.208
Mid Posterior/ Post Posterior	.533	.605
Mid Posterolateral/ Post Posterolateral	-.098	.923
Mid Lateral/ Post Lateral	.412	.688
Mid Anterolateral/ Post Anterolateral	1.063	.310

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D7. Results of Pre-Test/Post-Test Pairwise Comparisons

	t Value	Significance (2 Tailed)
Pre Anterior/ Post Anterior	4.215	.001*
Pre Anteromedial/ Post anteromedial	2.054	.064
Pre Medial/ Post Medial	2.271	.044*
Pre Posteromedial/ Post Posteromedial	.924	.375
Pre Posterior/ Post Posterior	-.060	.953
Pre Posterolateral/ Post Posterolateral	.987	.345
Pre Lateral/ Post Lateral	.871	.402
Pre Anterolateral/ Post Anterolateral	3.416	.006*

Key: Significance at .05 level.* P = significance, ES = effect size, ß = power

Table D8. Correlations of Pre-test Data and SEBT Performance

	AD	TT	MSTG	INV	EV	AI
Pre Ant	.106	.240	.078	-.375	.505	.184
Pre AM	.286	.474	.239	-.322	.307	.145
Pre Med	-.050	.276	-.038	-.374	.474	.218
Pre PM	.038	.263	-.115	-.312	.535	.182
Pre Post	-.117	-.011	.064	-.324	.451	-.158
Pre PL	-.031	.242	.404	-.363	.333	-.062
Pre Lat	.609	.048	.485	.470	-.321	.393
Pre AL	.165	.382	.557	-.419	.249	-.025
Mid Ant	-.026	.142	.179	-.212	.460	.159
Mid AM	.023	.199	.203	-.483	.331	.049
Mid Med	.540	-.138	-.065	-.144	-.260	.507
Mid PM	-.013	-.006	-.143	.010	.568	.105
Mid Post	-.195	-.122	-.064	-.122	.455	.083
Mid PL	-.148	-.002	.087	-.259	.471	-.026
Mid Lat	.502	.017	.360	.218	-.215	.440
Mid AL	-.078	.146	.116	-.265	.429	.031
Post Ant	-.061	.244	.009	-.308	.489	-.028
Post AM	-.078	.303	.223	-.658	.058	-.055
Post Med	-.234	.268	.185	-.678	-.003	-.010
Post PM	-.299	.019	-.058	-.457	.144	-.064
Post Post	-.179	-.110	-.180	-.314	.375	-.220
Post PL	-.216	.200	-.097	-.327	.458	.071
Post Lat	.750	.038	.339	.303	-.409	.469
Post AL	-.137	.162	.357	-.467	.167	-.017

Ant Drawer	-.137	1.00	.564	.258	.258	.200
Talar Tilt	.564	1.00	.243	.081	.188	.492
MSTG	.357	.258	.243	1.00	-.111	-.258
Inversion	-.467	.258	.081	-.111	1.00	.258
Eversion	.167	.200	.188	-.258	.258	1.00
Arch index	-.017	.058	.492	-.075	.376	.291

Table D9. Correlations of Pre-test measures

	AD	TT	MSTG	Inv Strength	Ev Strength	Arch Index
AD	1.00	.564	.258	.258	.200	.058
TT	.564	1.00	.243	.081	.188	.492
MSTG	.258	.243	1.00	-.111	-.258	-.075
Inv Strength	.258	.081	-.111	1.00	.258	.376
Ev Strength	2.00	.188	-.258	.258	1.00	.291
Arch Index	.058	.492	-.075	.376	.291	1.00

Table D10. Descriptive Statistics for Pre-test Demographics

	Mean	Standard Deviation
Anterior Drawer	.167	.389
Talar Tilt	.750	.621
Medial Subtalar Glide	.250	.452
Inversion Strength	4.75	.452
Eversion Strength	4.83	.389
Arch Index	1.14	.669

Table D11. Raw Data

Code	Age	Year	Height	Weight	Dom.Leg
WK4OH	22.00	4.00	70.00	155.00	1.00
RG1S	18.00	1.00	65.00	136.00	1.00
GL1S	17.00	1.00	68.00	150.00	1.00
SA1	18.00	1.00	65.00	140.00	2.00
ML2OH	18.00	2.00	72.00	180.00	1.00
ZJ1	18.00	1.00	66.00	130.00	1.00
KA2DS	19.00	2.00	60.00	150.00	1.00
MB4	21.00	4.00	71.00	190.00	1.00
HK3OH	20.00	3.00	68.00	135.00	1.00
DS2	19.00	2.00	68.00	142.00	1.00
MA1MH	18.00	1.00	71.00	158.00	1.00
LL1	17.00	1.00	67.00	130.00	1.00

PreANT	PreAM	PreMedial	PrePM	PrePost	PrePL	PreLat	PreAL
91.68	98.59	94.62	94.12	78.94	72.56	65.71	78.94
90.59	85.52	88.74	86.90	71.72	69.43	68.06	76.33
92.31	89.99	89.99	87.66	86.27	82.99	73.68	81.59
79.08	85.49	92.74	94.03	90.18	76.08	67.10	69.23
87.49	87.00	89.84	90.33	85.59	80.40	80.40	83.23
107.07	96.85	99.27	98.80	98.31	88.09	65.69	83.71
85.30	82.70	92.21	98.29	96.10	90.49	66.23	71.01
85.52	91.03	91.03	89.21	81.85	84.14	72.19	81.85
83.58	83.10	84.03	83.10	74.65	69.01	61.52	76.54
72.23	76.92	75.23	72.67	67.10	59.85	52.56	68.38
93.70	95.51	93.24	88.76	88.30	86.95	78.38	88.76

Data for the Braced Condition

Ant	AM	Med	PM	Post	PL	Lat	AL
87.26	84.32	82.35	80.41	61.76	53.94	58.82	72.56
73.10	76.80	77.71	78.62	76.80	63.45	53.79	66.68
83.92	88.59	89.99	89.06	89.06	81.11	75.52	77.87
76.08	76.51	84.21	86.77	81.21	72.56	66.67	67.10
88.43	91.74	95.04	95.52	82.75	63.41	83.23	83.69
92.47	92.96	93.43	99.27	105.61	83.71	68.15	83.71
80.96	90.49	91.79	94.39	84.86	90.50	59.32	69.27
68.10	75.42	71.28	67.59	64.83	69.43	60.25	67.59
82.65	83.58	84.06	84.99	73.72	68.56	45.07	72.31
79.49	74.36	80.77	76.08	66.26	55.56	44.03	68.82
92.81	93.24	91.00	91.00	90.54	86.05	71.62	79.30

MidANT	AM	Med	PM	Post	PL	Lat	AL
81.38	83.35	83.82	81.38	74.52	61.76	63.24	73.06
81.38	83.70	77.71	79.56	81.85	69.43	63.45	73.57
85.31	85.79	90.91	85.79	90.46	82.52	75.08	82.07
73.96	77.36	81.21	79.08	73.51	69.67	64.97	64.54
86.07	89.36	88.43	85.59	80.40	83.23	78.01	84.17
94.89	93.93	97.81	96.85	106.10	95.39	73.99	86.13
83.12	84.42	90.91	100.88	100.00	94.81	76.62	73.17
75.42	82.32	78.62	71.72	73.57	66.68	61.59	67.59
77.94	79.35	84.99	82.17	82.65	64.79	47.89	72.31
76.92	80.35	79.49	78.21	74.79	61.54	55.13	70.51
95.95	90.11	90.11	89.19	91.00	84.70	79.30	88.30

PostANT	PostAM	PostMed	PostPM	PostPost	PostPL	PostLat	PostAL
81.38	85.79	86.29	84.82	77.94	75.00	64.24	71.09
76.33	79.56	80.47	77.71	68.06	68.52	60.69	73.10
90.46	86.27	84.39	87.19	92.31	86.27	70.77	78.32
71.38	74.79	77.79	76.51	70.10	68.82	59.85	61.13
87.94	88.43	92.20	91.26	88.91	84.65	81.82	84.17
91.50	94.42	92.47	99.77	107.07	92.96	77.87	84.20
83.12	89.61	90.91	100.44	98.70	90.49	69.69	65.82
75.86	91.50	91.97	88.28	73.57	69.90	63.01	75.42
78.87	82.17	83.58	87.80	85.92	66.20	53.52	72.79
72.67	76.92	79.92	81.21	74.79	62.41	50.44	68.38
89.19	87.84	91.00	91.46	86.49	86.49	82.43	90.11

AnteriorDrawer	Talar Tilt	MedSubGlide	Inv Strength	Ev Strength	Arch Index
1.00	2.00	.00	5.00	5.00	2.00
.00	1.00	.00	5.00	5.00	3.00
.00	1.00	.00	5.00	5.00	1.00
.00	.00	.00	5.00	5.00	1.00
.00	1.00	.00	4.00	5.00	1.00
.00	.00	.00	4.00	5.00	1.00
.00	1.00	.00	5.00	5.00	2.00
.00	1.00	1.00	4.00	4.00	1.00
.00	.00	.00	5.00	5.00	1.00
.00	.00	.00	5.00	4.00	1.00
.00	1.00	1.00	5.00	5.00	2.00

APPENDIX E

RECOMMENDATIONS FOR FUTURE RESEARCH

1. Since the sample size in this study was small, similar studies could be done with volleyball teams with larger rosters, or with other athletic teams such as basketball or soccer, which also typically have larger rosters. Another benefit to conducting similar research with soccer or basketball teams is that the movements in those sports are explosive and dynamic in nature.

2. Further research could utilize the brace for pre-testing, mid-testing and post-testing, to examine dynamic postural control with the brace on throughout the entire season.

3. The use of a hand held dynamometer or an isokinetic machine would make ankle strength testing more objective. Similarly, the use of a Telos ankle arthrometer to measure ligament laxity rather than manual stress tests would also yield more objective laxity measurements.

4. Conduct a between subjects study using two athletic teams.

5. Conduct a study that examines dynamic postural control differences between dominant and non-dominant legs.

6. Examine a relationship between dynamic postural control and joint position sense with brace use.

7. Conduct a study that takes into account turf vs. natural grass and their effects on dynamic postural control with bracing.

8. Conduct a study to determine peroneal latency with prolonged brace use.

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