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Lyn H. Nakagawa for the degree of Master of Science in Human Performance presented on August 28, 2002.
Title: Performance in Static, Dynamic, and Clinical Tests of Postural Control in Individuals with Functional Ankle Instability

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Abstract approved ___________________________
Mark A. Hoffman

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Performance in Static, Dynamic, and Clinical Tests of Postural Control in Individuals with Functional Ankle Instability

by
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Lyn H. Nakagawa, Author

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Key words: ankle instability, balance, center of pressure

ABSTRACT

Objective: To evaluate postural control in individuals with functional ankle instability with static, dynamic, and clinical balance tests. Also, to examine the relationships between the performances in each of these tests. ***Design:*** Postural control was evaluated with a single leg balance test, a balance test involving movement, and the star excursion balance test. ***Setting:*** A university Sports Medicine and Disabilities Laboratory. ***Participants:*** A volunteer sample of 19 subjects with functional ankle instability and 19 uninjured control subjects. ***Main Outcome Measures:*** Center of pressure sway path length was calculated for the static and dynamic balance tests. Total reach distance was measured for the star excursion balance test. ***Results:*** Subjects with functional ankle instability demonstrated a significantly greater center of pressure sway path length in both the static and dynamic balance tests. ***Conclusions:*** Functional ankle instability may be associated with reduced postural control as demonstrated by decreased performance in static and dynamic balance tests.

Ankle injuries, mainly lateral ankle sprains, account for 25% of all injuries in running and jumping sports.[1,2] In addition to being the most common experienced injury, reinjury rates of ankle sprains as high as 80% have been estimated.[3,4] Authors hypothesize that, at least in part, the high rate of reinjury results from functional ankle instability.[5,6] Freeman et al.[6] introduced the concept of functional instability and described it as a tendency or feeling of "giving way" after an ankle sprain and the injury results in articular de-afferentation. Theoretically, de-afferentation interferes with proper functioning of articular mechanoreceptors in providing information regarding joint position and movement.[6] A proprioceptive deficit in functional instability may manifest itself as decreased postural control, joint position sense, kinesthesia, peroneal muscle reaction time, common peroneal nerve function, strength, and range of motion at the ankle.[7,8]

In contrast to functional ankle instability, mechanical instability refers to joint motion beyond physiological limits.[9] Most agree that functional ankle instability does not necessarily result from mechanical instability, as measured by joint laxity, because many individuals without joint laxity report feelings of "giving way" of the ankle and still suffer from repeated injuries.[5,6,8,9] Instead, the proprioceptive deficit associated with de-afferentation from the initial ankle trauma is believed to cause the reported "giving way" in functionally unstable ankles.

Proprioception refers to the information obtained from receptors regarding joint and limb position or movement in space.[6] According to Sherrington[10], the proprioceptive system receives information from peripheral receptors located in joints, muscles, and tendons. When integrated and processed by the central nervous system, the proprioceptive information contributes to movement and reflexes that help stabilize the joint with appropriate muscular activity.[11] Assessment of joint proprioception is divided into kinesthesia testing and joint position sense evaluation.[12] Measuring threshold to detection of passive movement assesses kinesthesia, while measuring reposition of active or passive positioning assesses joint position sense.[13] In functionally unstable ankles, equivocal results have been demonstrated in accuracy of joint positioning. Significantly greater joint repositioning errors have been demonstrated in some functionally unstable ankles[14-17] while others have demonstrated no significant differences.[18]

Neuromuscular control is defined as the "unconscious efferent response to an afferent signal concerning dynamic joint stability."[13] These responses depend on proprioceptive and afferent information obtained in the periphery. Neuromuscular control is often assessed by evaluating the expected and predictable response to an unexpected stimulus.[19] In research regarding ankle stability and postural control, response times for the defense mechanisms of the peroneals, the first muscles to contract in response of sudden inversion, have been measured and evaluated.[19-22] With functional ankle instability, delayed responses by the peroneals have been demonstrated.[22,23] Increased latencies of the peroneal response may predispose functionally unstable ankles to reinjury because of the inability to appropriately respond to an inversion stress.[16,22]

Proprioceptive deficits associated with functional ankle instability result from partial de-afferenation due to the initial injury to the lateral ligaments of the ankle or the joint capsule with an inversion ankle sprain.[6] It has been hypothesized that the initial traction injury of these structures alters the functioning of the mechanoreceptors and their role in somatosensation for reflex actions.[6] This effect has been termed as "joint de-afferentation" and results in altered afferent information from joint mechanoreceptors, causing a decrease in stability due to altered reflex actions.[11] Thus, increased risk and prevalence of repetitive injury and reported feelings of instability is common with functional ankle instability because of the decreased joint movement sense and position sense, and the delayed reflexive responses from previous ankle injuries.[5,16,22]

Proprioceptive and neuromuscular control deficits associated with functional ankle instability manifests as deficits in postural control. Postural control is defined as the act of maintaining, achieving, or restoring a state of balance during any posture or activity.[24] Maintenance of postural control requires acquisition of the afferent information from somatosensory, visual, and vestibular inputs; integration and processing of the afferent information by the central nervous system for the selection and organization of proper motor responses, and execution of the motor commands by the musculoskeletal system.[13] Since postural control requires the interaction of adequate afferent information from inputs, the integration of this information, and the appropriate responses, it may be used to assess both the proprioceptive and neuromuscular function in joints.[25] Thus, assessment of postural control with balance testing, during closed chained functional tasks, provides information on the overall function of the joints and their proprioceptive and neuromuscular control abilities.

Lateral ankle sprains often result in a condition of reoccurring injuries and a continued feeling of "giving way" known as functional ankle instability. Proprioceptive deficits, resulting in reduced postural control and balance abilities have been demonstrated by increased postural sway with a single-leg stance.[5,6,9,13,14,26-33] However, few studies have examined the effect of functional ankle instability on performance in dynamic functional postural control tasks. Previous studies have not attempted to combine these types of tests and evaluate the performance in static, dynamic, and functional tests of postural control. Therefore, the purpose of this study was to evaluate the performance in static, dynamic, and clinical tests of postural control and balance in individuals with functional ankle instability. Also, the relationships between the performances in each of these balance tests were examined. It was hypothesized that individuals with functional ankle instability would display decreased performance on the static, dynamic, and clinical balance tests. If postural control is impaired with functional ankle instability, then these deficits are possible contributing factors to the continual reported feeling of instability and "giving way" in the ankle.

METHOD

Prior to data collection, the study was reviewed by and received approval from the Oregon State University Institutional Review Board (Appendix A). Prior to participation in this study, informed consent from all subjects was obtained in accordance with institutional guidelines regarding the protection of human subjects (Appendix B).

Subjects were recruited from intercollegiate athletics and recreational athletic facilities at Oregon State University. Prior to inclusion in the study, all perspective subjects for this functional ankle instability group were screened with a questionnaire to evaluate ankle injury history (Appendix C). Inclusion criteria as a subject with functional ankle instability included: an inversion ankle injury that required a period of protected weight bearing and/or immobilization, a history at least 2 ankle sprains to the same ankle within the past 5 years, and reported feeling of instability or "giving way." Individuals with either no history or ankle sprain or no injury within the past 10 years were included in the study as control subjects. Any perspective subject who had an ankle fracture, ankle reconstructive surgery, or possessed a balance related disorder, was excluded from the study.

All subjects reported to the Sports Medicine Lab for 2 sessions which were approximately 30 minutes each. In the first session, the subject's injury history was assessed using a questionnaire (Appendix C). Based on the results of the ankle history questionnaire, each subject's ankle was categorized as either a functionally unstable ankle or a control non-injured ankle. Also, during this first session the mechanical stability of both ankles for all subjects was examined by a certified athletic trainer. The anterior drawer and inversion talar tilt was used to evaluate the integrity of the anterior talofibular and calcaneofibular ligaments. Information regarding the mechanical stability of the subjects' ankles was used only for descriptive purposes and was not included in the analysis. Lastly, during this first session, subjects performed practice trials for the clinical balance test. In the second session, all subjects, regardless of ankle classification, performed all three balance tests on both the right and left ankle. The three balance tests to evaluate postural control included a static, dynamic, and clinical balance test. The order of testing was counterbalanced to minimize learning and testing effects.

Static and dynamic postural control tests were performed using the NeuroCom Smart Balance Master® (NeuroCom, Inc., Clackamas, OR). This device consists of an 18" x 60" long force plate that uses information from four force transducers to monitor and calculate movement of the center of gravity (Appendix D). Each force transducer samples at a rate of 100 Hz and measures the vertical force exerted. Movement in both antero-posterior and medio-lateral directions is combined to calculate an overall assessment of postural sway.

The static postural control test was performed on the NeuroCom Smart Balance Master® using the Unilateral Stance testing protocol. This test requires the subject to maintain a single leg stance for 10 seconds in an eyes open condition. Subjects were instructed to balance on one foot while keeping their hands on their hips. Subjects were allowed to stand in a comfortable single leg stance with either a straight or bent knee stance (Appendix E). Subjects were also instructed to look straight ahead, and the testing period was started when the subject lifted their contralateral foot off the ground. Subjects performed the unilateral stance, barefoot, on the long force plate. All subjects performed three consecutive trials on their left ankle, followed by three trials on their right ankle.

The dynamic postural test required subjects to step laterally onto a foam pad where they held and maintained a single leg stance for approximately 4 seconds. Subjects stood on a wooden block of a similar height as the foam pad, barefoot with their feet together. The testing period was initiated and whenever the subject was ready, he/she performed a lateral step onto the foam pad where a single leg balance stance was held until the testing period was complete (Appendix F). During the lateral step, the subjects were instructed to look straight ahead and no limitations were placed on arm movement. The lateral step width was standardized to 50% of the subject's height. Subjects performed this test barefoot, and stepped laterally in both directions, allowing both ankles to be tested. Three consecutive trials were performed on the left ankle followed by three trials on the right ankle. If the subject put their non-test foot down or stepped off the foam pad to regain their balance, the trial was marked as a fall and disregard. Consecutive trials were performed until three successful trials on each ankle was completed.

The star excursion balance test (SEBT) was used as the clinical test to measure postural control and balance. This test is used by clinicians to assess dynamic balance and postural control. It requires the individual to maintain balance on a single leg while reaching out with the other leg.[34] Moderate to high reliability estimates have been reported when analyzing intraclass correlations in each of the directions.[34,35] All subjects performed at least six practice trials in each direction as significant learning effects have been demonstrated with the SEBT.[35] The SEBT layout consisted of four lines: two forming vertical and horizontal lines and two at 45° with respect to the vertical and horizontal lines. A rectangle box large enough to fit both of the subject's feet was used as the starting position (Appendix G). Subjects stood with both feet in the box. Subjects were instructed to reach out to one of the four diagonal directions (right-anterior, left-anterior, right-posterior, and left posterior) with one foot while maintaining balance on the other foot. Their reaching leg was not allowed to touch the ground at any time during the reach. The maximal reach distance attained by the subject was marked using colored dot stickers. A successful trial required the subject to return to and stand in the center box with both feet. Multiple layout grids were used to prevent the subjects from having their previous marked distances as targets to reach for. In total, three trials in each direction were completed. All subjects performed the SEBT on both ankles.

For the static and dynamic tests performed on the NeuroCom Smart Balance Master®, postural control was assessed by evaluating the movement of the center of pressure (COP). The movement of the COP was quantified by the sway path length (SPL) or the total excursion of the COP. Such analysis of the movement of the COP position provides information regarding postural control.[36] The position of the COP was identified from the surface force characteristics. The position of the center of vertical force for each axis was determined using the following:

$$\text{X Axis Center of Vertical Force} = \frac{(RR + RF) - (LR + LF)}{RR + RF + LR + LF} \times 8.25 \text{ in}$$

$$\text{Y Axis Center of Vertical Force} = \frac{(LF + RF) - (LR + RR)}{LL + RF + LR + RR} \times 29.25 \text{ in}$$

Using Microsoft Excel (Microsoft® Excel 2002) to analyze the data, the COP for each sample was identified. The COPSPL (measured in centimeters) was then calculated as the sum of the distances between each consecutive COP location and represents the total excursion of the center of pressure during each trial.

For the static postural control test in the Unilateral Stance protocol, the entire 10 second trial was analyzed. Therefore, in the static postural control test, the SPL represented the total excursion (in centimeters) for the entire trial. For the dynamic postural control test (lateral step onto the foam pad), the three seconds following contact with the foam pad were analyzed. Contact with the foam pad was defined by analyzing the graph of the vertical force recorded by each force transducer across time. Two critical points were identified by determining where the outputs of the left front and rear transducers and the right front and rear transducers cross in this graph. These represent when the subject's center of gravity shifted from the back to the front of the long force plate. To ensure that the subject made contact with and was balanced on the foam, the later of the two critical points was used as the point signifying the beginning of the single leg balance component in the dynamic postural control test. From this point, the next three seconds were analyzed and the SPL represented the total excursion of the COP in the three seconds for that trial.

Performance on the SEBT was evaluated by measuring the distances (in centimeters to the nearest tenth) reached with the contralateral leg while maintaining a single leg stance. When the maximal reach distance was determined, the distance was marked along the taped axes. Reach distances were standardized to the subjects height. The average distance reached in each of the four directions was determined and these averages were totaled to create one overall score representing the subject's performance on the clinical SEBT.

All data was analyzed using Microsoft Excel spreadsheets (Microsoft® Excel 2002). COPSPL was the dependent measure for the static and dynamic postural control tests. For the clinical postural control test (star excursion balance test), total distance reached was the dependent measure analyzed. To ensure that there was no leg dominance effect, independent, two-tailed t-tests were performed comparing the left and right leg performances of each test for the control group. To evaluate the effect of functional ankle instability on postural control, independent, two-tailed t-tests were performed on each dependent variable from the three postural control tests to compare the functional instability group to the control group. Differences were accepted as significant at an alpha level of 0.05 (α=0.05).

To evaluate the relationship between performances in the static, dynamic, and clinical postural tests, Pearson product moment correlation coefficients were calculated. Correlations were used to evaluate the relationship between the static and dynamic postural tests, the static and clinical postural tests, and the dynamic and clinical postural tests.

RESULTS

Thirty-eight subjects (17 male, 21 female) were recruited from intercollegiate athletics and recreational athletic facilities at Oregon State University to participate in this study. Of these 38 subjects, 19 subjects were included in the functional ankle instability group because of their history of repetitive ankle injuries to either one or both of their ankles. The remaining 19 subjects comprised the unaffected ankle control group who reported no ankle problems or injuries within the past 10 years.

In the unaffected ankle control group (n=19), both ankles were tested in the static, dynamic, and clinical balance tests. To ensure that there was no leg dominance effect, t-tests were performed comparing the performance of the left to the right ankle. The average left and right leg COPSPL in the static, 10 second, unilateral stance task was 79.73 ±11.51 cm and 76.22±11.84 cm, respectively. In the dynamic balance test, the average left and right leg COPSPL for the 3 seconds following contact with the foam was 81.90±9.72 cm and 83.49±10.42 cm, respectively. The SEBT total score for the left and right leg was 1.78±0.11 and 1.82±0.15 times total body height, respectively. There were no significant differences between left and right legs in either the static (p=0.36), dynamic (p=0.63), or clinical (p=0.30) balance tests. Therefore, since there were no significant differences between the left and right foot in any of the balance tests, the limbs of the control subjects were matched to the affected ankle of the subjects in the functional ankle instability group. This limb matching was then used to compare the performance of the functional ankle instability subjects to the uninjured controls.

In the functional ankle instability group (n=19), 8 subjects reported bilateral instability, 3 subjects reported their left ankle as the affected ankle, and 8 subjects reported their right ankle as the affected ankle. In order to identify an affected ankle in subjects with bilateral instability, the ankle with the higher SPL in the static, single leg balance test was used. As a result, in the functional ankle instability group, the left ankle was the affected ankle for 8 subjects and the right ankle for 11 subjects. The 19 subjects in the control group were then limb matched to each of the functional ankle instability subjects.

To examine differences between the functional ankle instability group and control group, independent t-tests were performed on the outcome variables for the static, dynamic, and functional balance tests. In the static balance test, the average SPL for the functional ankle instability and control group was 84.82±12.92 cm and 77.07±9.60 cm, respectively. The functional ankle instability group had a significantly greater COPSPL (p=0.04, Figure 1) in the 10 second static balance task than the control group. In the dynamic balance test, the average COPSPL for the 3 seconds while balancing on the foam pad for the functional ankle instability and control group was 87.70±8.43 and 81.60±8.44 cm, respectively. There was a significant difference (p=0.03, Figure 2) between the two groups as the functional ankle instability group displayed a significantly greater SPL. In the clinical SEBT, the overall performance score for the functional ankle instability and control group was 1.71±0.18 and 1.80±0.15 times body weight respectively. There was no significant difference ($p=0.11$, Figure 3) between the two groups.

To assess the relationship in the performances in the three balance tests, Pearson product correlations were calculated between the scores for all subjects in each test. When comparing the static and dynamic balance tests, there was a very weak correlation ($r=0.10$, Figure 4) between the performances in the two tests. Also, there was a very weak correlation ($r=-0.05$, Figure 5) between the performances in the static and SEBT. Lastly, there a very weak correlation ($r=-0.12$, Figure 6) between the performances in the dynamic and SEBT for all subjects.

Figure 1: Comparison of COPSPL Means in the Static Postural Control Test for the Functional Ankle Instability and Control Group.

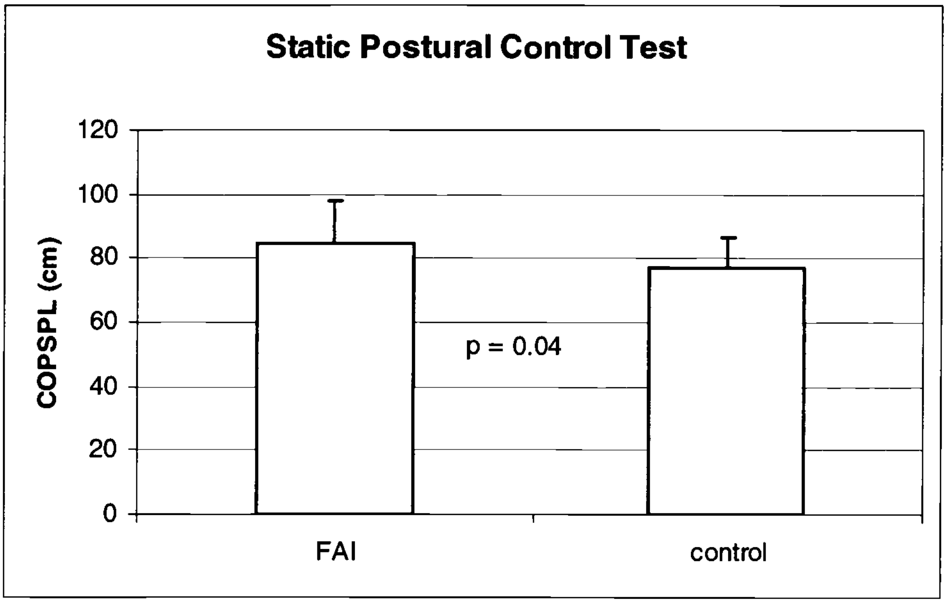


Figure 2: Comparison of COPSPL Means in the Dynamic Postural Control Test for the Functional Ankle Instability and Control Group.

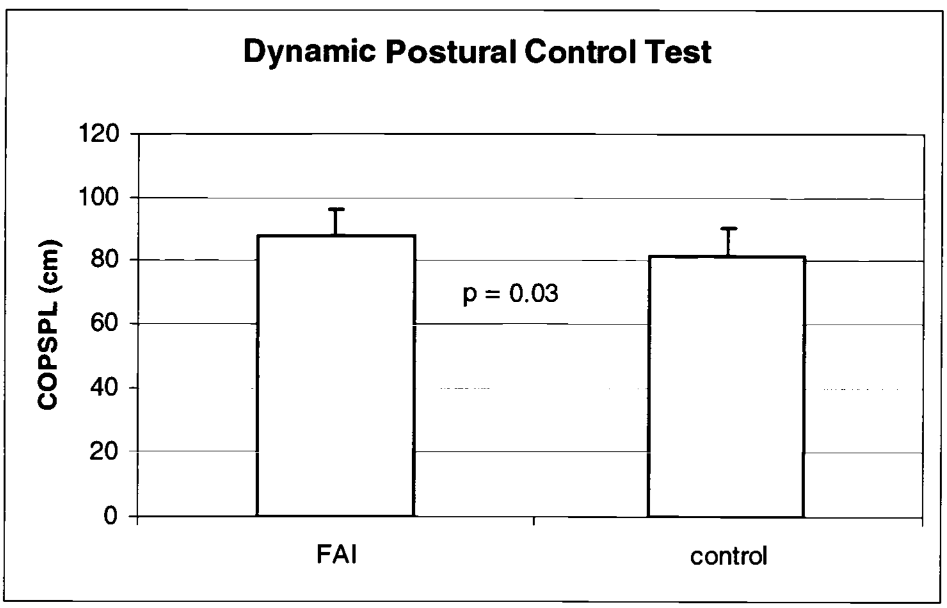


Figure 3: Comparison of COPSPL Means in the Clinical Postural Control Test for the Functional Ankle Instability and Control Group.

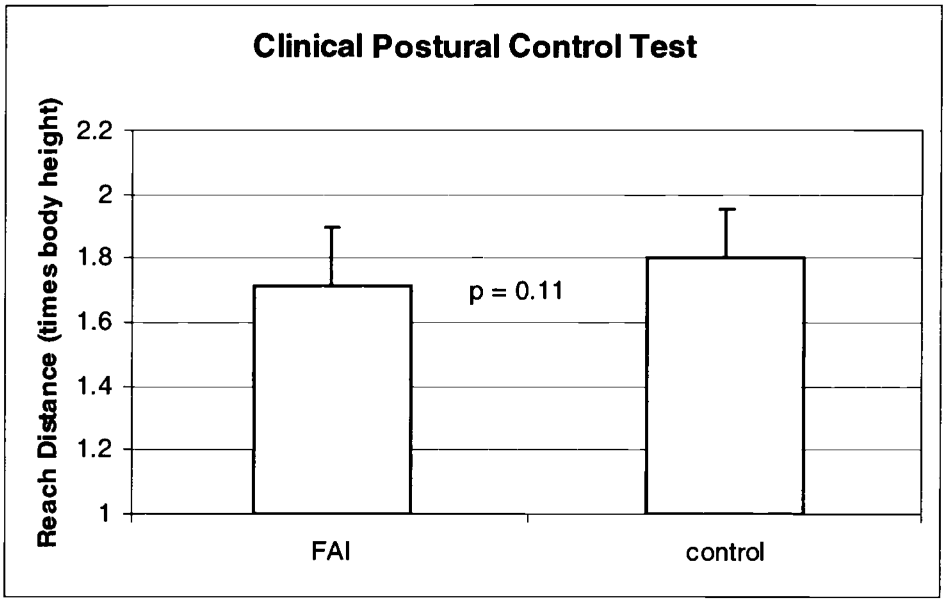


Figure 4: Relationship Between Performance in the Static and Dynamic Postural Control Test in All Subject

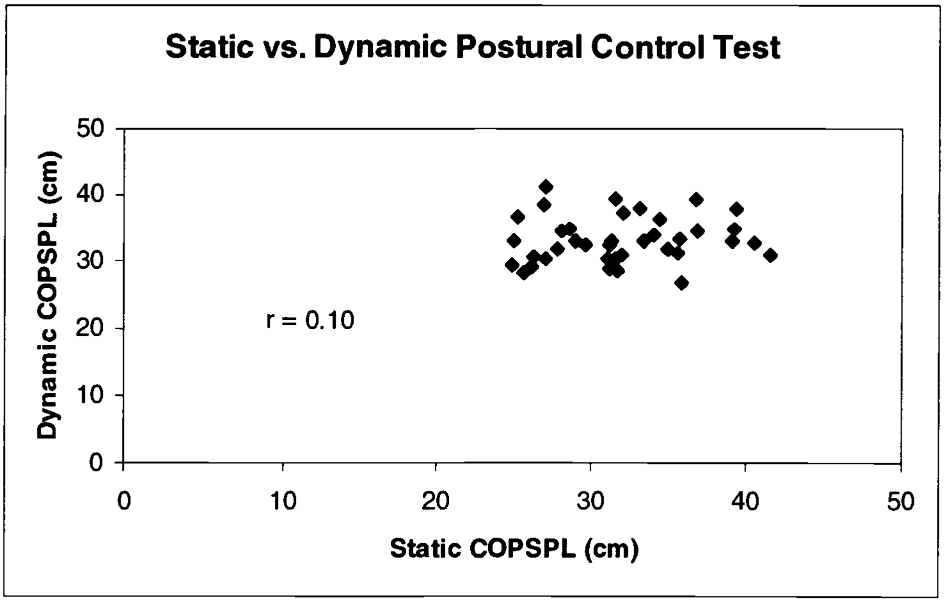


Figure 5: Relationship Between Performance in the Static and Clinical Postural Control Test in All Subjects

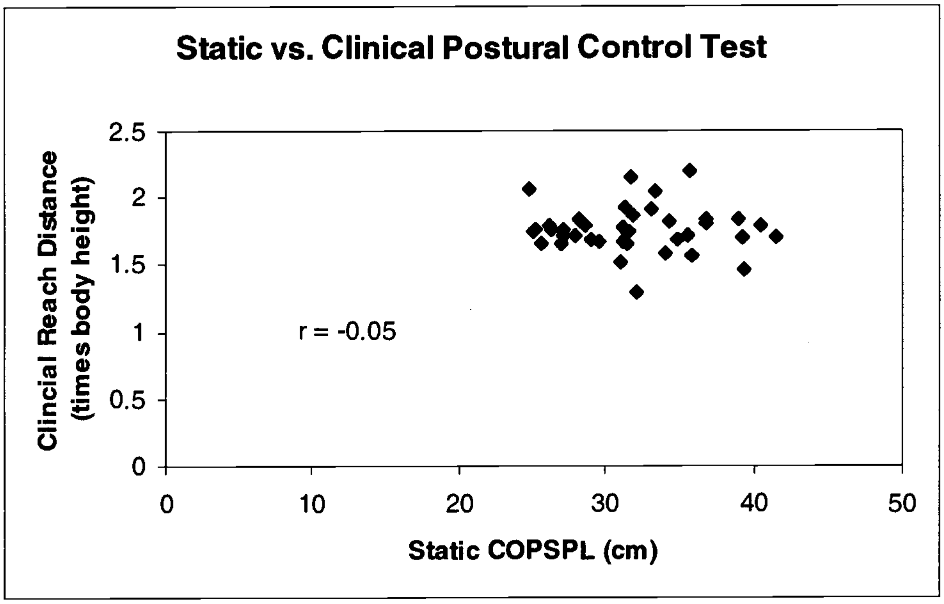
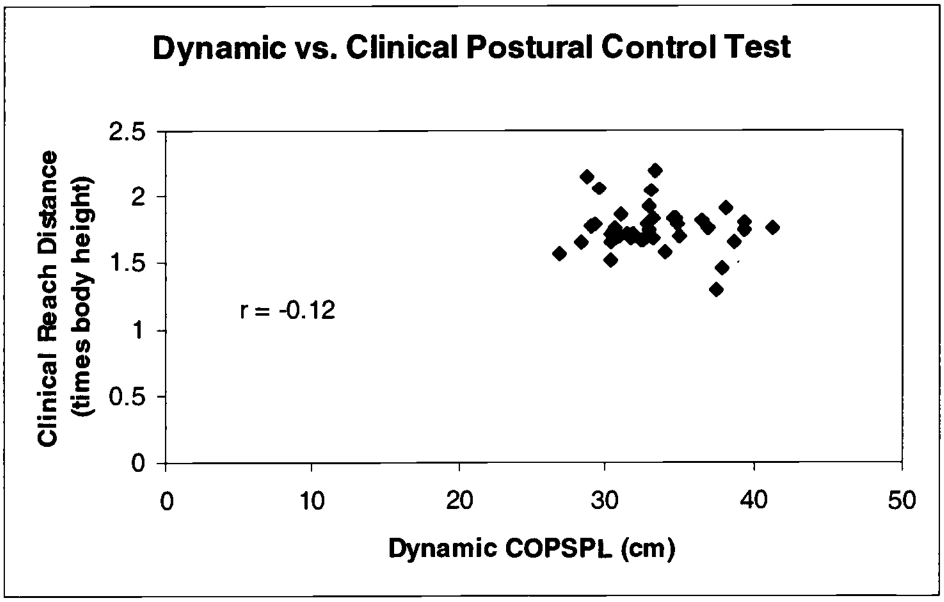


Figure 6: Relationship Between Performance in the Dynamic and Clinical Postural Control Test in All Subjects



DISCUSSION

Functional ankle instability often results in repeated ankle injuries and a continual feeling of "giving way."[5,6] The injuries and symptoms associated with functional ankle instability are attributed to articular de-afferentation, which interferes with the proprioceptive capabilities of the joint.[6] These proprioceptive deficits and feeling of "giving way" related to functional ankle instability manifests itself as deficits in postural control, joint position sense, kinesthesia, peroneal muscle reaction time, common peroneal nerve function, ankle joint strength, and range of motion.[7,8] In this study, postural control was evaluated as the performance in static, dynamic, and clinical tests of balance was assessed in individuals with functional ankle instability. Also, the relationships between performances in these tests were examined.

Postural control can be described as the ability to maintain, achieve, or restore a state of balance during any posture or activity.[24] Maintaining balance involves maintaining a specific posture as in quite sitting or standing.[24] In this study, the static balance test involved a single leg stance task and was used to assess this aspect of postural control. Achieving a state of balance, requires the ability to achieve balance during voluntary movement with different postures.[24] In this study, the dynamic balance test assessed the subject's ability to achieve a state of balance in a single leg stance after a voluntary, lateral side step onto a foam pad. The SEBT also assessed dynamic balance as it evaluated the subject's ability to achieve a state of balance following the movement of the contralateral limb. However, this test was used as a clinical measure that could possibly be used to assess balance. Therefore, this study attempted to examine performances by individuals with functional ankle instability in different postural control tests, in particular the ability to maintain (static balance) and achieve a state of balance (dynamic balance) in a single leg stance.

Compared to the uninjured controls, the functional ankle instability group demonstrated a significantly greater COPSPL during the static, single leg balance test. This increased movement of the center of pressure suggests decreased or impaired postural control.[36] These results are in accordance with other studies that have demonstrated decreased postural control and balance abilities with functional ankle instability.[6,9,14,26-33]

In studies that have assessed balance in individuals with functional ankle instability, different dependent variables were used to evaluate postural control.[6,9,14,26-33] Several studies used measures based on the ground reaction forces in the mediolateral and/or the anterior-posterior axis by evaluating the amplitude or variability of these forces.[26,29] Other researchers visually evaluated postural control during single leg balance tasks by counting foot touches and trunk movements or comparing one leg to the other.[6,14,28,32] However, most studies have used center of pressure measures to evaluate postural control.[9,27,30,33] Generally, these studies examined a confidence ellipse that describes a sway area encompassing the movement of the center of pressure during the balance task. In this study, the

COPSPL or total excursion of the COP, was used to assess postural control. This measure identifies the location of the COP at each sampled movement and appears to evaluate some movements in the foot and ankle of the subject. However, the results of this study with the static balance test are in accordance with most of the literature which demonstrates significant decreases in postural control as demonstrated by increased postural sway with functional ankle instability.

The dynamic balance test in this study evaluated the subject's ability to achieve a state of balance following the voluntary movement into the single leg stance position on the foam pad. The functional ankle instability group demonstrated a significantly greater COPSPL in the three seconds of balance than the uninjured control group. This greater COPSPL with functional ankle instability suggests increased movement and decreased postural control when challenged with the voluntary movement and balance task in this dynamic balance test.

In this dynamic balance test, the single leg stance period in which postural control was assessed was the three seconds following contact with the foam pad. Generally, when assessing balance during a static single leg stance, time periods ranging from ten to thirty seconds are used.[6,9,14,26-33] However, in this study, the single leg stance task following the lateral side step onto the foam was used to assess dynamic balance whereas single leg stance tasks with longer test periods are usually used to assess static balance. Therefore, only three seconds were used because this was the critical period where the subject was challenged to achieve a state of balance following movement, and a longer test period than this would simply be assessing static balance on an unstable surface.

Results from this study suggest that functional ankle instability is associated with reduced postural control as demonstrated by decreased abilities in static and dynamic balance tests. Therefore, it appears that both aspects of postural control, the ability to maintain and achieve a state of balance, may be affected by functional ankle instability. This finding is significant as it suggests the importance in considering both static and dynamic balance during the assessment and rehabilitation of ankle injuries and functional ankle instability.

The SEBT was used as a clinical test to assess postural control by evaluating the subject's ability to achieve balance while reaching out as far as possible with the contralateral leg in specified directions. As studies have established intratester and intertester reliability of the SEBT,[34,35] no studies have used this test to assess postural control deficits between injured and uninjured limbs.[35] Therefore, this study attempted to assess postural control in subjects with functional ankle instability using the SEBT.

The SEBT was evaluated using the composite score, which represented the total reach distance (standardized to height) in all four diagonal directions. There was no significant difference in the SEBT score between the functional ankle instability group and the control group. Hertel, Miller, and Denegar[35] suggest that the SEBT is an excellent method to assess dynamic balance as it requires adequate neuromuscular control of the joints in the stance leg in addition to the integration of sensory information from vestibular, visual, and somatosensory system. Since the SEBT requires adequate neuromuscular control as well as proper proprioceptive abilities of the joint, it appears to assess the overall functional capabilities of the joint. As a result, the absence of a deficit in the SEBT score with functional ankle instability may suggest that the proprioceptive deficits demonstrated with decreased postural control with functional ankle instability may not be significant enough to manifest as a difference in the overall functional performance of the joint. However, in this study, the functional ankle instability group demonstrated significant deficits in postural control during the static and dynamic balance tests. Therefore, it appears that deficits in functional performance in the functionally unstable ankle joint exist and that the SEBT may not be a test which is sensitive enough to detect these deficits.

As mentioned previously, postural control involves the ability to maintain, achieve, or restore a state of balance during any posture or activity.[24] As these aspects are identified as components of postural control, the relationship between the performances in each of these tasks was examined. To assess the relationship between static and dynamic balance, a Pearson product moment correlation was performed on the COPSPL from the static and dynamic tests. Results demonstrated that there was a very weak relationship between these aspects of postural control. This result may suggest that the static and dynamic tests assess different aspects of balance and postural control and the performances in each are not related to each other. This finding is in accordance with Hoffman and Koceja[37] who found that static sway measures including sway area, sway path length, sagittal sway standard deviation, and lateral sway standard deviation did not correlate with dynamic phase duration which assesses dynamic balance. The clinical SEBT was used to assess the overall function of the ankle. Also, the performance in this test compared to that in the static and dynamic postural control test was examined. However, there was only a very weak correlation between the SEBT overall score and the SPL from either the static and dynamic test. This analyses performed, assessing the relationship between performance in static, dynamic, and clinical tests are unique as no other study has attempted to correlate functional balance performance with forceplate measures.[35]

Since only very weak correlations exist between the performances in the static, dynamic, or clinical balance tests, it appears that each may assess a different component of postural control. Also, the absence of a significant correlation between the SEBT and forceplate measures suggests that since the SEBT assesses the overall proprioceptive and neuromuscular control abilities of the ankle joint, it may not be a sensitive enough test to identify postural control deficits. Therefore, balance tasks used to assess or rehabilitate functional ankle instability appear to be very specific and as a result, multiple tests should be used to assess the postural control. Also, functional ankle instability does not affect everyone's postural control in the same manner as individuals may possess decreased static balance abilities, dynamic balance abilities, or a combination of both.

Although this study demonstrated deficits in static and dynamic abilities associated with functional ankle instability, there are some limitations due to characteristics of the individuals in the functional ankle instability group. Eight subjects in this group were bilaterally functionally unstable and a decision had to be made in the choice of an "affected" ankle. Also, individuals who reported no symptoms of "giving way" were still included in the functional ankle instability group if they met the criteria of the number of previous ankle injuries. Other limitations of the study include the ability to interpret the results of the SEBT. Reach scores were standardized to the subject's height, however standardizing the reach distance to leg length may have been more appropriate to account for limb length differences between subjects.

This study was conducted to evaluate postural control in functional ankle instability using static, dynamic, and clinical postural control tests. Results suggest balance deficits associated with functional ankle instability as demonstrated by increased COPSPL during static and dynamic balance tasks. However, functional performance, as in the SEBT, did not appear to be affected. The absence of relationship between performances in each of these tests suggests that with functional ankle instability, only certain aspects of postural control may be affected. Therefore, in the assessment or rehabilitation of functional ankle instability, static and dynamic balance, as well as overall functionality of the joint must be assessed.

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APPENDICES

APPENDIX A- IRB APPROVAL

OREGON STATE
UNIVERSITY

Report of Review by the Institutional Review Board

March 26, 2002

TO: Mark Hoffman
EXSS

COPY: Laura Lincoln,
Research Office

RE: The Effect of Functional Ankle Instability on Static, Dynamic and Clinical Balance Tests

The referenced project was reviewed under the guidelines of Oregon State University's institutional review board (IRB) and the U.S. Department of Health and Human Services. The IRB has **approved** your application. The approval of this application expires upon the completion of the project or one year from the approval date, whichever is sooner. The informed consent form obtained from each subject should be retained in program/project's files for three years beyond the end date of the project.

Any proposed change to the protocol, the informed consent form, or testing instrument(s) that is not included in the approved application must be submitted using the MODIFICATION REQUEST FORM. Allow sufficient time for review and approval by the committee before any changes are implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB. Any happening not connected with routine expected outcomes that result in bodily injury and/or psychological, emotional, or physical harm or stress must be reported to the IRB within three days of the occurrence using the ADVERSE EVENT FORM. Please use the included forms as needed.

Anthony Wilcox ______________ Date: 3/26/02

Anthony Wilcox, Chair
Committee for the Protection of Human Subjects
Langton 214
anthony.wilcox@orst.edu; 737-6799

APPENDIX B- INFORMED CONSENT FORM

A. Title: The Effect of Functional Ankle Instability on Performance in Static, Dynamic, and Functional Tests of Postural Control

B. Investigators: Lyn H. Nakagawa, ATC
Mark A. Hoffman, Ph.D., ATC

C. Purpose: The purpose of this study was to evaluate the performance in static, dynamic, and functional tests of postural control and balance in individuals with functional ankle instability.

D. Procedures: I understand that as a participant in this study, the following things will happen:

1. ***Pre-Study Screening***
   a. If I have a history of 2 or more ankle injuries to the same ankle within the past 3 years, with no associated fracture, I will be asked to be a subject with functional ankle instability.
   b. If I have no history of any ankle injury, I will be asked to be a control subject in this study.
   c. If I have had orthopaedic surgery or undergoing a formal rehabilitation program for either ankle, or if I have a balance related disorder, I will not be asked to participate in this study.
   d. If I am not between the ages of 18 and 55 years old, I will not be asked to participate in this study.
2. ***What participants will do during the study***
   a. My participation will involve one testing session in the Sports Medicine Lab that will last approximately 1 hour. During this session, I will have my balance abilitities evaluated and tested in three different balance tasks. I will be required to perform a one-legged stance on a stable surface, a lateral sidestep onto a foam pad, and a task where I will balance on one foot and reach out with the opposite foot. I will perform all these balance tasks in a specified, designated order.

E. Risks and Benefits

3. ***Foreseeable risks or discomforts*:** The only risk to me as a subject in this study is the risk of falling during the postural control tests, but this risk does not exceed the risk of falling experienced by most individuals during participation in recreational physical activities. Also, I may experience some discomfort and strain during the balance tasks.
4. ***Benefits to be expected from the research*:** There is no direct benefit to me as a subject in the study. However, the information gained from this research will contribute to the overall body of knowledge and may help

understand postural control in functional ankle instability and possible identify specific tests that can be used to assess and differentiate those ankles with functional ankle instability.

F. **Confidentiality:** Any information obtained in this study that can be identified with me will be kept strictly confidential. A code number, rather than my name, will appear on materials that contain your laboratory data. Neither my name nor any information from which I might be identified will be used in any publications.

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

H. **Voluntary Participation Statement:** I understand that my participation in this study is completely voluntary. I understand that I may either refuse to participate of withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled.

I. **If You Have Questions:** I understand that any questions I have about the study or procedures should be directed to Lyn H. Nakagawa, 103 Gill Coliseum, Oregon State University, Corvallis, Oregon at (541) 737-7357. If I have any questions about my rights as a research subject or if I have sustained an injury as a result of participation in this study, I should contact the IRB Coordinator, OSU Research Office, (541) 737-3437.

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

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

APPENDIX C- SUBJECT QUESTIONNAIRE

Name ______________________________ Code Number ____________

Date__________________

Contact Information: Phone number _______________________

1. Have you had an inversion ankle injury that required a period of protected weight bearing and/or immobilization? Yes No

2. Since the initial injury, have you had repetitive injuries to this ankle? If yeas, approximately how many? __________ Yes No

3. Does this ankle feel to "give way," or feel chronically weaker and/or less functional at this time? Yes No

4. If you have a history of ankle problems, which is the involved ankle? Right Left Both

5. Do you exercise regularly at least 20 minutes, three times a week? Yes No

6. Have you ever had reconstructive ankle surgery? Yes No

7. With this injury, or any other injury, have you had any ankle and/foot fractures? Yes No

8. Are you currently undergoing a rehabilitation program for the ankle? Yes No

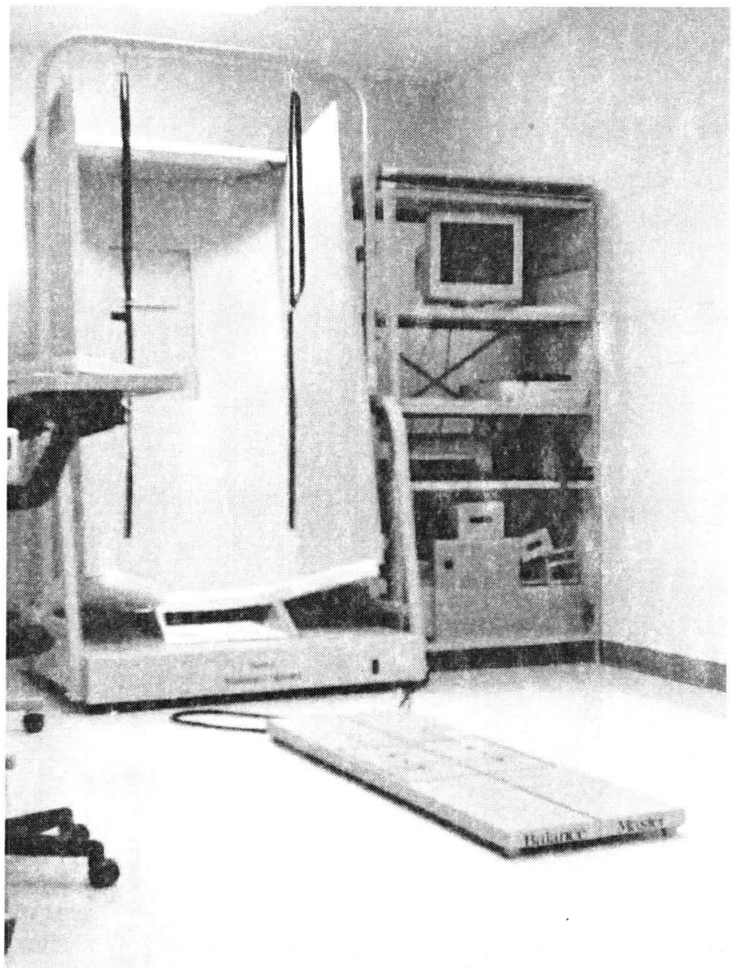
9. Do you have a balance related disorder which may affect your ability to perform these balance tasks. Yes No

Sex M F

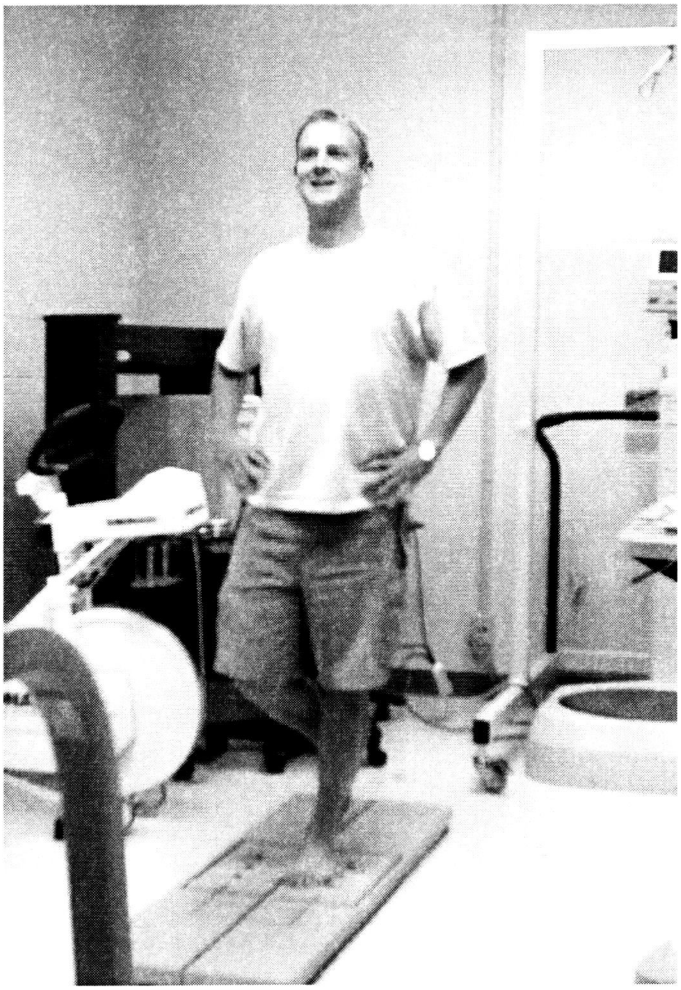
Height____________

Date of Birth_________________________

APPENDIX D- NEUROCOM® SYSTEM



APPENDIX E- STATIC POSTURAL CONTROL TEST

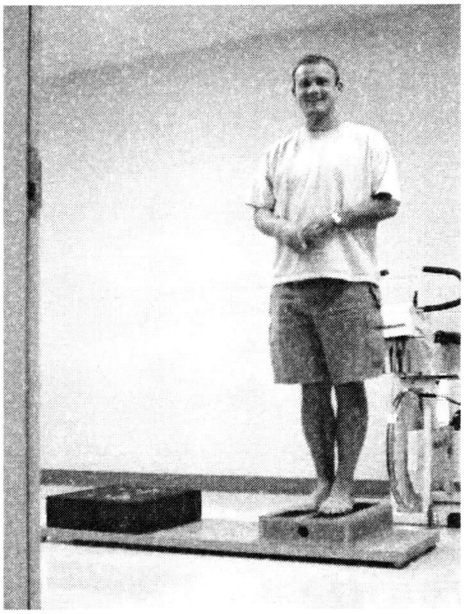


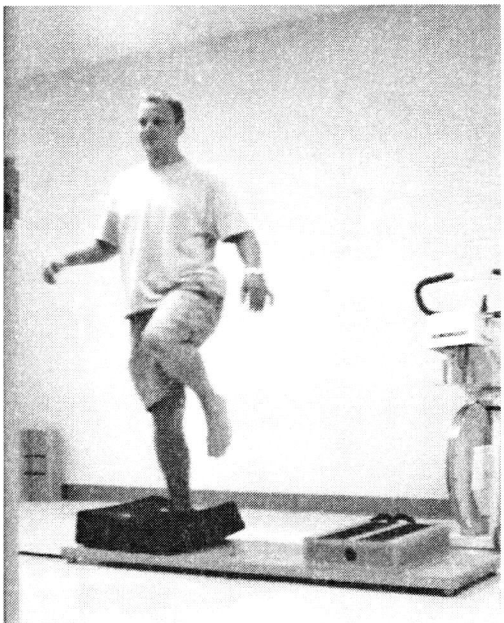
APPENDIX F- DYNAMIC POSTURAL CONTROL TEST

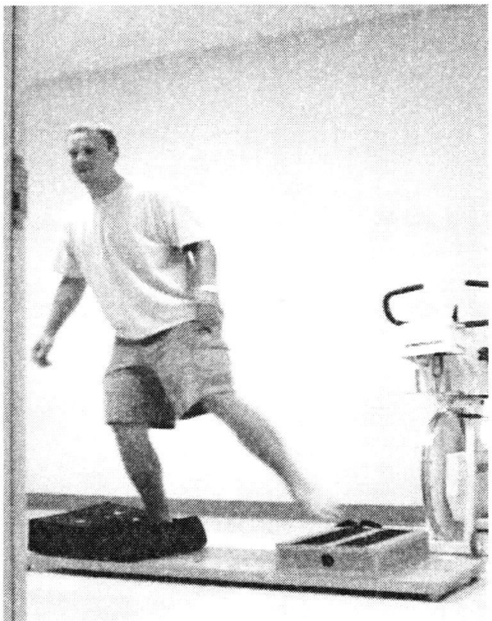
Top: Start position

Bottom Left: Movement phase of the test (lateral side step)

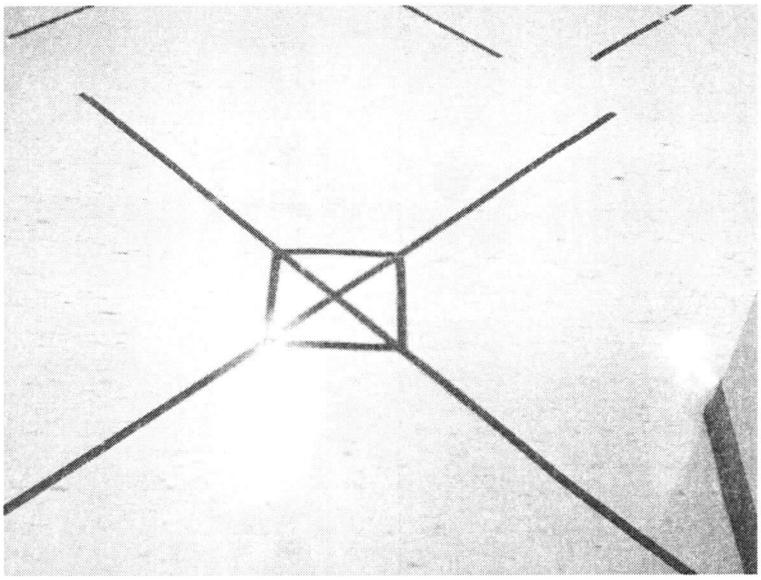
Bottom Right: Ending position (single leg blance)



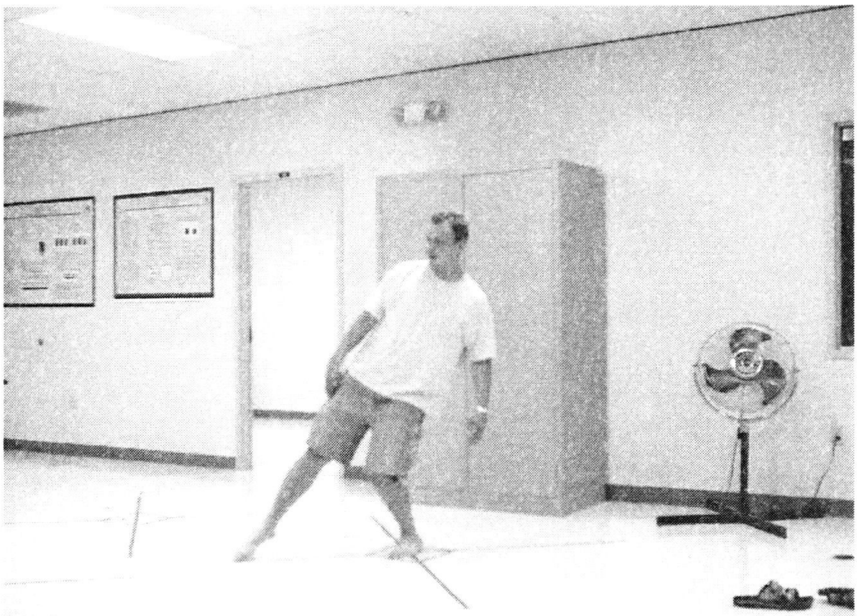




APPENDIX G- STAR EXCURSION BALANCE TEST



SEBT grid layout



Antero-medial reach- testing the left leg

APPENDIX H- SUBJECT DATA

		STATIC (COPSPL in cm)		*DYNAMIC (COPSPL in cm)*		*CLINICAL (times body height)*	
	status	*left*	*right*	*left*	*right*	*left*	*right*
1	FAI	**81.1**	74.537	**78.906**	97.432	**1.8729**	1.9548
2	FAI	71.703	**63.603**	86.563	**83.873**	1.7544	**1.7472**
3	FAI	**86.413**	72.514	**86.607**	87.153	**1.5879**	1.6834
4	FAI	**90.512**	81.172	**84.927**	90.021	**2.1936**	2.4613
5	FAI	98.505	**102.68**	85.197	**83.379**	1.8552	**1.7851**
6	control	**68.473**	58.203	**98.158**	106.1	**1.6615**	1.7188
7	FAI	86.76	**93.397**	91.17	**99.966**	1.785	**1.8023**
8	control	72.597	**71.498**	90.767	**88.327**	1.8042	**1.8331**
9	control	**79.203**	81.846	**73.598**	83.741	**1.7842**	1.7848
10	FAI	**105.41**	91.11	**78.713**	76.579	**1.6985**	1.5709
11	FAI	72.582	**81.544**	88.009	**95.181**	1.3683	**1.2987**
12	control	**84.223**	102.76	**96.751**	104.5	**1.9108**	1.9794
13	control	81.558	**63.133**	84.699	**75.019**	1.8558	**2.0629**
14	control	82.833	**90.967**	78.995	**68.155**	1.5889	**1.5685**
15	control	**93.465**	75.933	**87.896**	105.17	**1.8403**	1.8405
16	FAI	67.153	**78.927**	76.801	**77.107**	1.5455	**1.5137**
17	control	90.892	**79.558**	91.708	**83.876**	1.9205	**1.9255**
18	FAI	**75.177**	64.557	**82.781**	74.638	**1.6659**	1.677
19	control	77.995	**73.592**	79.944	**84.334**	1.6816	**1.6804**
20	FAI	69.479	**72.599**	74.644	**88.598**	1.8589	**1.7964**
21	control	**70.778**	58.892	**81.083**	73.74	**1.7154**	1.7385
22	FAI	100.15	**99.91**	69.457	**96.372**	1.7036	**1.4593**
23	FAI	76.683	**63.999**	80.347	**93.612**	1.7875	**1.76**
24	FAI	**88.71**	78.363	**80.739**	78.054	**1.6904**	1.7048
25	FAI	**80.121**	66.868	**100.16**	88.187	**1.7477**	1.6798
26	control	73.787	**66.777**	78.884	**77.948**	1.7559	**1.7571**
27	FAI	77.866	**99.648**	82.593	**88.954**	1.7281	**1.6985**
28	FAI	71.851	**99.096**	87.85	**84.396**	1.7832	**1.8396**
29	FAI	**80.103**	75.736	**77.106**	82.924	**1.6577**	1.6279
30	control	93.319	**84.79**	81.639	**84.13**	1.924	**2.0438**
31	FAI	81.186	**68.719**	104.19	**104.93**	1.7301	**1.7561**
32	control	105.96	**87.264**	68.166	**92.842**	1.7044	**1.8172**
33	control	**90.307**	90.663	**79.843**	74.651	**1.7112**	1.8382
34	control	**79.35**	74.24	**82.375**	84.104	**1.6659**	1.677
35	control	77.233	**80.576**	79.614	**72.989**	2.0136	**2.1513**
36	control	62.393	**66.6**	81.083	**74.244**	1.6816	**1.7848**
37	control	**68.719**	75.736	**77.106**	78.054	**1.722**	1.7824
38	control	61.634	**65.116**	66.435	**71.814**	1.8316	**1.6542**

** The values in bold represent the ankle used in the analysis.

APPENDIX I- REVIEW OF LITERATURE

INTRODUCTION

The purpose of this study was to evaluate the effect of functional ankle instability on the performance in static, dynamic, and functional tests of postural control and balance. In this review of literature, relevant information to this study is presented. First, balance and postural control is discussed, including definition of terms and current testing and evaluating methods. Contributions to balance and postural control from vestibular, visual, and somatosensory systems are then discussed. The somatosensory system is discussed in detail, outlining the role of mechanoreceptors and the proprioceptive system. Lastly, functional ankle instability is discussed and research regarding specific deficits observed with this condition is provided.

BALANCE AND POSTURAL CONTROL

Balance describes a state of an object when the resultant force acting upon it is zero.[1] In order to maintain balance, the human body attempts to maintain the position of the center of gravity over the base of support.[2] While balance describes a state or current status of an object, postural control depicts the ability to control the center of gravity in order to maintain balance.[1] Postural control can be described as the ability to maintain, achieve, or restore a state of balance during any posture or activity.[1] In this organization of postural control into three classes of activity, maintaining balance involves maintaining a specific posture as in quiet sitting or standing.[1] Achieving a state of balance, the second class of postural control, requires the ability to achieve balance during voluntary movement with different postures.[1] Lastly, restoring a state of balance involves recovering for an unexpected perturbance such as a slip, trip, or fall.[1]

Maintenance of postural control depends on the acquisition of afferent sensory information. The systems responsible for this information retrieval include the visual, vestibular, and somatosensory systems. Information from these systems regarding body motions and positions are necessary as this information is integrated and processed within the central nervous system, which results in the selection and coordination of appropriate motor responses, and execution of the motor commands by the musculoskeletal system.[2-4] Therefore, balance involves integration of various types of information and requires the coordination of the systems responsible for the gathering of the appropriate information.[4]

Since postural control requires the interaction of adequate afferent information from inputs, the integration of this information, and the appropriate responses, it assesses the proprioceptive and neuromuscular function in joints.[4] Thus, assessment of postural control with balance testing, during closed chained functional tasks, provides information on the overall function of the joints.

ROLE OF PROPRIOCEPTION AND NEUROMUSCULAR CONTROL

Somatosensory information, which contributes to the afferent information obtained from the periphery, includes proprioceptive information. The efferent response to this somatosensory information from the periphery requires appropriate neuromuscular control. The proprioceptive and neuromuscular control systems are discussed, including their role in maintaining balance and joint stability.

Proprioception

In addition to visual and vestibular sources, maintenance of balance depends on the acquisition of afferent sensory information from the somatosensory system. The somatosensory system gathers information regarding tactile senses (touch, pressure, and vibration) and proprioception (position, velocity, and tension).[4] Proprioception involves the acquisition of stimuli by peripheral receptors and the conversion of these stimuli into a neural signal that is transmitted along afferent pathways to the central nervous system for processing.[3] Peripheral receptors responsible for the acquisition of proprioceptive information are located in joints, muscles, and tendons.[3] Proprioceptive information gathered from peripheral receptors includes information regarding static position sense and kinesthesia for the respective joint.[3,4] Static position sense involves the general awareness of the joint ankle and position of the limb in space.[3,4] Kinesthesia entails the sense of movement, either passive or active, in the limb or joint.[3,4]

Proprioceptive information regarding both joint movement and position is an important and necessary contribution to the sensory information that is integrated by the central nervous system in order to initiate the appropriate responses to maintain balance and postural control.[3] Therefore, evaluation of functioning of the proprioceptive system provides information regarding afferent inputs that are conveyed to the central nervous system. Assessment of the proprioceptive system includes evaluation of joint position sense or kinesthesia.[5,6] With assessment of joint position sense, reposition errors of referenced joint angles are measured.[3,7-9] Measuring threshold to detection of passive movement assess kinesthesia.[3] With passive movement of the joint, only mechanoreceptors in the joint provide information regarding the movement in the joint.[5,6]

Neuromuscular Control

The proprioceptive system provides the central nervous systems with the necessary sensory information that is integrated and processed in order to initiate the appropriate responses.[3] This response to the proprioceptive information regarding joint position and movement comprises neuromuscular control.[3] Initiated by the central nervous system, these responses are transferred by the neuromuscular system to the periphery where the effects are observable.[3] These reflexive responses result in joint movement to maintain balance and postural control.[3]

Assessment of neuromuscular control often involves evaluating the expected and predictable response to an unexpected stimulus.[10] Research regarding ankle stability and responses employed to counteract an unexpected perturbance involves the measurement and evaluation of defense mechanisms, including responses by the peroneals counteract the imposed inversion stress.[10-16]

ANATOMY OF THE ANKLE

Lateral Ankle Joint Ligament Complex

Three main ligaments comprise the lateral ankle joint ligament complex that provides resistance against rotation and inversion stresses.[17-19] These ligaments include the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL), each which has its own functions.[17,18] The ATFL is a long, slender ligament which acts as the main stabilizer on the lateral aspect of the ankle.[18] Its orientation is parallel to the axis of movement such that in plantarflexion the ATFL acts as a true collateral ligament preventing inversion.[18] However, since mechanical or static stability of the ankle is reduced in plantarflexion as the narrowest part of the talus in the ankle mortise, the ATFL is most susceptible to injury.[17,18] Located between the joint capsule and peroneal tendon sheath, the CFL provides addition restraint against ankle inversion.[17,18] However, the CFL only provides stability in extreme inversion while remaining lax in all other joint positions.[18] The PTFL appears as a short, thick ligament which remains taut in ankle doriflexion.[18] Although the PTFL is very strong, it provides minimal support to the lateral ankle because when taut in dorsiflexion, most stability against inversion is provided by bony restraints from the articulation between the talus and ankle mortise.[17]

Mechanoreceptors in the Ankle

Somatosensory information, specifically proprioceptive information, regarding joint position and movement in the ankle originates from mechanoreceptors in the periphery. Mechanoreceptors are located in both articular structures (ligaments and joint capsule) and muscular structures (muscle fibers and tendons).[20] Each type of mechanoreceptor can be classified based on their physiological function and morphology. Basically, there are four different types of articular mechanoreceptors and two different types of muscular mechanoreceptors.[20]

Freeman and Wyke[21] first identified and classified the different type of articular mechanoreceptors based on their function and the type of information it received. A later modification and supplementation to this system resulted in a new classification system based on the morphology of the mechanoreceptors.[22] Type I receptors appear as thinly encapsulated globular corpuscles that are slow adapting and have a low threshold.[23,24] Also referred to as Ruffini endings, these mechanoreceptors have continuous firing rates, even with no joint motion.[20,23-25] Therefore, Ruffini endings convey a sense of static joint and limb position, the initiation of movement, and the velocity and amplitude of joint movement.[20,23,25] Generally, these Type I, Ruffini ending, mechanoreceptors are found in joint capsules and ligaments throughout the body.[20,24,25] Specifically in the ankle, they are found in all subtalar ligaments (anterior talofibular ligament, calcaneofibular ligament, posterior talofibular ligament, and deltoid ligament), but at a very low frequency.[23] Type II receptors are thickly encapsulated corpuscles that are rapidly adapting with low thresholds.[23,24] Also referred to as Pacinian corpuscles, these mechanoreceptors are believed to be inactive during static and constant speed joint movements, but are very sensitive to acceleration and deceleration.[20,25] In general, these are believed to be found in ligaments and deeper layers of the joint capsule.[20,24,25] In the ankle, these Type II receptors are the most commonly found mechanoreceptor in all the ligaments and appears to provide information about the initiation of joint motion or stress transmission.[23] Type III articular mechanoreceptors are thinly encapsulated fusiform corpuscles that are slow adapting and have high thresholds.[23,24] Also known as Golgi tendon organ-like endings, these receptors are generally found in ligaments and are inactive in nonmoving joints, thus they are believed to measure the extremes of the joints normal range of motion.[23-25] These mechanoreceptors are also very abundant in the ligaments of the ankle, especially the anterior talofibular ligament, posterior talofibular ligament, and deep tissues of the deltoid ligament.[23] Type IV receptors are unmyelinated free nerve endings that are high threshold pain receptors.[20,23,24] Found in ligaments and joint capsules, these receptors become active and signal pain when the associated tissue is put into extreme and abnormal range of motion, subjecting the structure to mechanical deformation.[24,25] In the human ankle however, no type IV receptors were found, suggesting that ligaments have no detection or sensation of pain.[23]

Like articular mechanoreceptors, muscular mechanoreceptors are classified based on their function, but more importantly on their location.[20] Golgi tendon organs, very similar to Type III receptors, are slow adapting and contribute to a reflex function.[20] They are found in muscle tendons and are activated when tension in the tendons increases, causing a reflexive relaxation through inhibition of the motor neurons innervating the muscles that where stretched while activating motor neurons of the antagonist muscles.[20] Muscle spindles are also slow adapting and have a reflexive function, commonly known as the stretch reflex.[20] These spindle receptors are found within the muscle as bundles of modified muscle fibers called intrafusal fibers and their main function is to signal changes in the length of the muscle in which they reside.[20,26] When activated, due to stretching of the muscle, these spindles facilitate a reflex contraction of the muscle fibers of the same muscle.[20,27]

Together, joint and muscle mechanoreceptors provide afferent input regarding limb and joint position.[20,26] Based on this afferent information received from the periphery, movement is initiated and later modified to maintain balance and postural control.[25,26]

ANKLE STABILITY- STATIC AND DYNAMIC RESTRAINTS

Ankle stability can be achieved by static or dynamic restraints. The bony configuration and articulation between the talus and ankle mortise, the lateral ankle ligaments (ATF, CF, and PTF), and the joint capsule provide static restraint.[10,17] Active muscles including the peroneus longus and brevis, the main evertors of the foot, offer dynamic restraint through reflexes and central medicated strategies by the spinal cord or cerebral cortex.[10] Although these passive and dynamic restraints attempt to resist inappropriate motions at the ankle, inversion ankle sprains are the most common ankle injury, and they result from an inversion rotation of the joint which involves a combination of plantarflexion and inversion.[10,28-30] In this plantarflexion, inversion joint position, passive restraint from bony stability is lost, thus stability must be maintained by other passive and dynamic stabilizers.[10,17]

ANKLE INJURIES AND FUNCTIONAL ANKLE INSTABILITY

As mentioned previously, lateral ankle sprains account for 25% of all injuries in running and jumping sports, with repeated injuries and reinjury rates reported as high as 80%.[28,31-33] Along with these repeated sprains, a continued reporting of instability or reduced function is also reported. Functional ankle instability describes this enduring condition of repeated injuries and reported unstable feeling.[34,35] Freeman[34] characterized functional ankle instability as the tendency or feeling of "giving way" after an ankle sprain due to proprioceptive and neuromuscular control deficits resulting from the damage to ligamentous structures in the initial ankle trauma. This physical damage causes articular deafferentation that causes the generation of impaired or inappropriate afferent neural impulses which results in the proprioceptive and neuromuscular deficits observed with functional ankle instability.[35] Functional ankle instability can exist in the absence of mechanical instability (as measured by joint laxity) as many individuals without ligament laxity still report feelings of "giving way" and suffer from repeated injuries.[29,34-36] Other deficits, rather than joint laxity, including balance deficits, joint position and movement sense deficits, delayed peroneal muscle reaction times, altered common peroneal nerve function, strength deficits, and decreased dorsiflexion range of motion, characterize functional ankle instability and contribute to the unstable feeling and altered function reported.[29,30] These deficits associated with functional ankle instability are discussed in the following sections.

Postural Control Deficits

Maintenance of postural control requires acquisition of the afferent information from somatosensory, visual, and vestibular inputs; integration and processing of the afferent information by the central nervous system for the selection and organization of proper motor responses; and execution of the motor commands by the musculoskeletal system.[3] As mentioned previously, functional ankle instability is believed to result in articular de-afferentation that alters the functioning of articular mechanoreceptors in providing information regarding joint position and movement.[35] Therefore, since postural control depends on afferent information from somatosensory systems, the altered proprioceptive functioning with functional ankle instability is believed to result in deficits in postural control.

Decreased or impaired postural control has been demonstrated in individuals with functional ankle instability.[3,16,34-44] These deficits in postural control can be assessed with various dependent variables to evaluate postural stability and balance. For example, several researchers visually evaluated postural control during single leg balance tasks by counting foot touches and trunk movements or comparing one leg to the other.[35,37,40,43] Generally, a modified Romberg test was used where the subject first stood on their uninjured foot with their eyes open and then with their eyes closed, followed by their injured foot.[35] In these tests, the researcher, the subject, or both, evaluated the performance by comparing the affected ankle to the contralateral unaffected ankle. Lentell, Katzman and Walters[43] demonstrated that 55% of subjects presented with visually notable side to side differences during the modified Romberg test. In addition, subjects generally reported better balance in their unaffected ankle compared to their affected sides.[35,37,43]

In order to objectively assess balance and postural control, other researchers have used stabilometry and force platform information to evaluate ground reaction forces. For example, several studies assessed the ground reaction forces in the mediolateral and/or the anterior-posterior axis and evaluated the amplitude or variability of these forces.[38,41] Goldie, Evans and Bach[38] demonstrated significantly greater standard deviations or variability of the mediolateral force signal, suggesting decreased postural control and steadiness in subjects with functional ankle instability. The most common assessment of postural control has been the use and evaluation of the movement of the center of pressure.[16,36,39,44] Generally, these studies have examined a confidence ellipse that describes a sway area that encompasses the movement of the center of pressure during the balance task. Perrin, Bene, Perrin, and Durupt[39] compared the displacement and the sway area of the center of pressure to assess postural control in basketball players with functional ankle instability. Subjects with functional ankle instability demonstrated significantly greater displacements and sway area with functional ankle instability, meaning increased movement of the center of pressure, implying decreased or impaired postural control.[39]

Joint Position Sense Deficits

Evaluation of joint position sense by measuring joint repositioning errors assesses proprioception by determining the functioning of the mechanoreceptors to provide information to the central nervous system regarding joint position. Some have suggested that joint position sense is an important aspect of proprioception as it provides information regarding the joint and limb position in reference to the body, which can be especially important in injury prevention.[5] In studies with functional ankle instability, reference angles used during testing include 10° of eversion and inversion angles ranging from 10° to 20°.[7-9] Selection of subtalar inversion seems to closely replicate the inversion stresses that occur with ankle sprains and specifically stress the injured ligaments.[9] Generally, the ability to sense joint position appears to be adversely affected with functional ankle instability.[7,9] However, conflicting findings were demonstrated by Gross.[8]

Konradsen and Magnusson[9] measured absolute inversion angle replication error of functionally unstable ankles compared to contralateral ankles and stable (uninjured) controls. Passive set, active replication design was used with reference angles of 10°, 15°, and 20°. Functionally unstable ankles demonstrated significantly greater error angles (2.5 ±0.2°) compared to contralateral stable ankles (2.0 ±0.3°) and normal ankles (1.7 ±0.2°). The authors suggested that while these error angles appear small, their physiological relevance exists in the fact that these errors in detection of joint position may provide inaccurate information, ignoring the risk of excessive inversion leading to injury.[9] Also, the inaccurate information may contribute to a delayed response by a defense mechanism to sufficiently counteract the external perturbation.[9]

Impaired Detection of Joint Movement

Detection of joint movement describes kinesthesia, and impaired ability to detect passive motion in the ankle with functional ankle instability has been demonstrated.[37,45-47] Studies evaluating the detection of passive joint sense have generally examined plantarflexion and dorsiflexion[37,45,47], while one study examined inversion joint movement.[46] The ability to detect these ranges of motion were examined with slow passive movement, ranging from 0.3°/sec to 2.5°/sec.

Studies examining joint movement sense have demonstrated kinesthesia deficits associated with functional ankle instability.[37,45-47]

The only study to examine kinesthesia by evaluating passive joint movement sense with inversion was performed by Lentell et al.[46]. When inverting the foot at 0.3° /sec, functionally unstable ankles demonstrated significantly greater excursion angles before joint movement was sensed (4.3 ±3.1°) compared to contralateral uninjured ankles (3.2 ± 1.8°). Also, functional unstable ankle excursion angles ranged from 1° up to 14°, compared to a range of 1° to 8° for the uninjured ankles. These larger excursion angles observed suggest greater range of motion is required before motion is detected by functionally unstable ankles. The authors suggested that this diminished awareness of passive movement may contribute to delays in reflex activity associated with defense mechanisms.

Proprioceptive deficits, both joint position sense and kinesthesia, contribute to inappropriate and insufficient afferent information regarding joint position and movement to the central nervous system, resulting in absent or inappropriate reflexive movement.[3,7] As a result, these proprioceptive deficits demonstrated in functional ankle instability could be detrimental in maintaining balance and postural control, as well as maintaining joint stability and prevention of injury.[3,7]

Delayed Peroneal Muscle Reaction Time

The functional of the peroneal muscles are most frequently studied as they are the primary evertors of the foot and are believed to be the defense mechanism in response to an inversion stress experienced during a lateral ankle sprain.[10] As a defense mechanism to maintain ankle stability, the peroneals require the ability to react and counteract an inversion torque.[10,48] This reaction by the peroneals to a sudden enexpected inversion force to the ankle, as in an inversion sprain mechanism, includes a reflexive response that is initiated by the information obtained by the periphery.[10,48] The response of the peroneals is initiated by activation of type II, Pacinian corpuscle receptors in the lateral ligaments from the inversion stress placed on the ligaments.[10,23,46] These receptors send information regarding joint position and movement to the spinal cord which integrates the information and initiates an appropriate reflexive reaction.[20,26,27] The response manifests as eversion of the ankle and foot in attempt to lessen the stress on the lateral ankle structures in order to prevent injury to these structures.[11]

The response by the peroneals to an inversion stress requires accurate information from the proprioceptive system (mechanoreceptors in the periphery) and adequate neuromuscular control to respond accordingly.[3,4,10] Proprioceptive deficits have been demonstrated with deficits in joint position sense and kinesthesia, however, the direct applicability of these deficits to the presence of functional instability could not be demonstrated. Therefore, many studies have attempted to examine the dynamic stability of the ankle and the response times of the peroneal muscles when the ankle exposed to a sudden inversion perturbation. Significant longer latency times, suggesting longer reaction times, by the peroneals have been demonstrated.[12,14,16,49,50] Results of these studies suggest that this delayed response by the peroneals contribute to the increased risk or reinjury as the defense mechanism of the peroneals to counteract the inversion stress is compromised.[10,12,16] Also, it has been suggested that this delay in reflex time, not the strength, of the peroneals is a more important indicator of functional ankle instability.[13,15] In contrast, others contend that no neuromuscular control deficits are associated with functional ankle instability as these studies have demonstrated unaffected peroneal activity and response times with functional instability and chronic ankle sprains.[11,13,15]

Konradsen and Ravn[16] first demonstrated an association between functional ankle instability and an increased peroneal reaction time when measuring muscle activity in response to trapdoor testing which subjects the lateral ankle to an unexpended inversion torque. Comparing 15 athletes with complaints of functional ankle instability symptoms and who used protective external orthosis during activity with 15 athletes with no complaints or history of ankle injury, functionally unstable ankles demonstrated a significantly greater peroneal reaction time in response to unexpected ankle inversion. In both the peroneus brevis and longus, the functionally unstable ankles exhibited an average increase in reaction time of approximately 15 msec. Researchers suggested that this increased reaction time results from damaged mechanoreceptors and afferent nerve fibers from the initial ankle trauma and causes the observed delayed responses. In addition, these delayed responses due to deficits in peroneal reaction time could contribute to the repetitive injuries or the reported feelings of giving way and instability.

Normal peroneal reaction times in response to a plantarflexion-inversion perturbation, suggesting normal neuromuscular control, were demonstrated by Ebig et al.[13] In this study, reaction times of both the peroneals and tibialis anterior of unstable and uninjured ankles were compared and no significant differences were demonstrated, suggesting the absence of neuromuscular control deficits. No significant differences were observed when comparing the peroneal reaction times of the unstable ankle (58.6 $\pm$ 11.0 msec) to the uninjured control (65.3 $\pm$ 17.0 msec), and the anterior tibialis reaction times (67.9 $\pm$ 14.0 msec and 71.6 $\pm$ 14.0 msec, respectively). Authors suggested that peripheral neural pathology which contributes to decreased neuromuscular control may not result from functional ankle instability. Therefore, while delayed reaction times of dynamic stabilizers of the ankle alone may not contribute to reported symptoms associated with functional ankle instability, it may, combined with other factors (muscle strength, mechanical instability, kinesthesia) it may result in altered motor functioning which causes the reported symptoms.

Altered Common Peroneal Nerve Function

According to Freeman[34] and Freeman et al.[35] functional ankle instability results from the damage to structures, including mechanoreceptors and nerve fibers, in the lateral ankle from traction associated with the inversion stress of an ankle sprain. Injury to the common peroneal nerve, demonstrated by slowed nerve conduction velocity and altered sensation, has been suggested as a complication that may contribute to functional instability.[51-53] Nitz et al.[52] demonstrated that with a moderate or severe lateral ankle sprain, 17% and 86% respectively, possessed slowed nerved conduction velocity. Also, 54% of these individuals, regardless of severity of ankle injury, reported an inability to distinguish between crude touch and a pin prick along the peroneal nerve distribution. Diminished sensation, specifically the ability to detect vibration, was demonstrated in individuals with severe lateral ankle sprains.[53] No studies have specifically examined nerve conduction velocity in individuals with functional ankle instability and reported symptoms of giving way or instability. However, some have suggested that since altered nerve function has been demonstrated following moderate to severe ankle sprains, up to six weeks, that these deficits may exist for longer periods of time and may alter the function of the ankle even after other symptoms have disappeared.[30,52] Therefore, this slowed nerve conduction velocity may predispose the ankle to further injury and repetitive ankle sprains, resulting in functional and chronic ankle instability.

Strength Deficits

Ankle strength and its role in functional ankle instability and the resulting reported "giving way" has been examined. All range of motions, including ankle dorsiflexion, plantarflexion, eversion, and inversion have been examined, but most research has focused on muscles that evert or pronate the ankle and foot complex as these muscles attempt to counteract the inversion torque.[10,11,48] Typically the strength of the peroneals is examined as these muscles are the prime movers during concentric eversion of the foot and ankle.[10,30,48] Equivocal results regarding ankle the presence of ankle evertor weakness in functional ankle instability have been presented as some studies have demonstrated significant deficits in eversion strength[7,42,54,55] while others demonstrated no differences when compared to healthy controls.[43,46,56,57] However, regardless of the conflicting results, the assessment of eversion strength has been questioned regarding the use of open kinetic chain isokinetic dynamometers and testing in concentric ranges of motion at speeds much slower than functional activities.

Tropp[42] first demonstrated pronator muscle weaknesses in ankles with functional ankle instability. With isokinetic dynamometer testing at 30° /s and 120° /s, ankles with functional instability demonstrated a significantly reduced strength (20.2 ±4.7 Nm and 16.2 ±3.9 Nm, respectively) compared to ankles without instability (23.0 ±5.8 Nm and 18.5 ±4.7 Nm, respectively) at both testing speeds. These significant strength deficits were suggested to result from functional ankle instability that contribute to the continued feeling of giving way and therefore should be emphasized in rehabilitation programs in order to minimize these deficits in the long term.

In contrast, Kaminski et al.[56] compared the concentric and eccentric ankle eversion strength at 0° /s, 30° /s, 60° /s, 90° /s, 120° /s, 150° /s and 180° /s of functionally unstable ankles to normal uninjured ankles and no significant differences in peak torque were observed. The researchers warn that rehabilitation programs and its effect on the performance in strength measurements must be considered. Also, multiplaner motions like plantarflexion-inversion, the mechanism for injury, have not been examined. Therefore, the absence of strength deficits in this open chain, eccentric and concentric contraction in purely eversion cannot directly be applied to an injury mechanism with much greater torque, speed of inversion, and multiplaner motion. However, the lack of difference in both eccentric and concentric eversion strength provide the researchers with confidence that other factors like that lack of neuromuscular control are more likely causes of chronic functional ankle instability.

While most studies measure peak torque to evaluate strength, several studies have emphasized the importance of strength ratios to standardize the values for each individual.[54,56] Wilkerson et al.[56] examined evertor and invertor peak toques, but also determined evertor/invertor peak torque rations. In addition to observing greater deficits in invertor peak torque, the evertor/invertor ratios better illustrated the differences in muscle strengths between functionally unstable and uninjured ankles. Hartsell and Spaulding[55] suggested that eccentric/concentric ratios should be measured as this ratio is an important concept in strength evaluation at any joint. As no previous studies measured the eccentric/concentric ratios of healthy or functionally unstable ankle, this study attempted to quantify these values. Results demonstrated that functionally unstable ankles were significantly weaker in concentric and eccentric eversion and inversions, but there were no significant differences in the eccentric/concentric strength ratios.

Therefore, Hartsell and Spaulding[55] recommend that both peak torque values and strength ratios should be evaluated to obtain a complete evaluation of strength performance of a joint.

Decreased Dorsiflexion Range of Motion

With repeated ankle sprains, increased tension resulting from decreased flexibility in the Achilles tendon, gastrocnemius, and soleus, can cause decreased ankle dorsiflexion range of motion.[30,41] Leanderson et al.[41] compared active dorsiflexion range of motion in professional basketball players with histories of bilateral functional ankle instability (mean of 3.6°) to healthy controls (mean of 17.9°) and observed a significant decrease in available range of motion. With a decreased ankle dorsiflexion range of motion, the ankle is held in a more plantarflexed position throughout the gait cycle which is an injury prone position as passive restraint from bony stability is lost and stability is maintained by other passive and dynamic stabilizers.[10,17,30] Therefore, the lack of dorsiflexion in the ankle may predispose individuals to recurrent lateral ankle sprains and functional instability.[30]

Functional Performance

Various proprioceptive and neuromuscular control deficits have been suggested as contributors to and causes of functional ankle instability. However, as no conclusive information has been provided, the exact symptoms or outcomes of functional ankle instability remains unclear. Also, as many continue to report the subjective "giving way" in their ankle, the effect of functional ankle instability on the overall performance and functioning during activity remains unclear.

Jerosch et al.[40] compared the performance of unstable ankles to healthy controls using a timed functional hop test. Specifically, the authors attempted to evaluate the function of the ankles on an uneven surface.[40] Subjects with functional ankle instability required a significantly greater amount of time than the uninjured subjects to complete the hop test. The authors concluded that although there are various aspects of proprioception, there is a decrease in proprioceptive function with the recurring ankle injuries associated with functional ankle instability.[40] Also, these proprioceptive deficits can then result in decreased function as when challenged with the hop test.[40]

CONCLUSION

Freeman[34] characterized functional ankle instability as the tendency or feeling of "giving way" after an ankle sprain due to proprioceptive and neuromuscular control deficits. Generation of impaired or inappropriate afferent neural impulses due to damage to ligamentous structures and articular deafferentation in the initial ankle trauma result in the proprioceptive and neuromuscular deficits observed with functional ankle instability.[35] Functional ankle instability can exist in the absence of mechanical instability (as measured by joint laxity) as many individuals without ligament laxity still report feelings of "giving way" and suffer from repeated injuries.[29,34-36] Other deficits, rather than joint laxity, including balance deficits, joint position and movement sense deficits, delayed peroneal muscle reaction times, altered common peroneal nerve function, strength deficits, and decreased dorsiflexion range of motion, characterize functional ankle instability and contribute to the unstable feeling and altered function reported.[29,30] Thus, it appears that functional ankle instability is a complex condition that results in observable proprioceptive and neuromuscular control deficits which perpetuate this condition as these deficits make the individual susceptible to reinjury.

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