8-2004

The Effect of a 6-Week Strength and Balance Training Program on Navicular Drop and Proprioception in Excessive Pronated Foot

Ryoko Suzuki
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Ryoko Suzuki entitled "The Effect of a 6-Week Strength and Balance Training Program on Navicular Drop and Proprioception in Excessive Pronated Foot." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

Wendell Liemohn, Major Professor

We have read this thesis and recommend its acceptance:

Songning Zhang, Edward Dooley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Ryoko Suzuki entitled “The effect of a 6-week strength and balance training program on navicular drop and proprioception in excessive pronated foot.” I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

Wendell Liemohn

Wendell Liemohn, Major Professor

We have read this thesis
and recommended its acceptance:

Songning Zhang

Edward T. Howley

Accepted for the Council:

Vice Chancellor and Dean of Graduate Studies

The effect of a 6-week strength and balance training program on navicular drop and proprioception in excessive pronated foot

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ryoko Suzuki
August 2004

Dedication

This thesis is dedicated with boundless love to my father, Yukichi, who always supports and encourages me to pursue higher education; my mother, Akemi, who is my constant source of strength and has raised me who I am today; my sister, who is my best friend; Jennifer & Ron, who made my dream come true; and Matt ("My Happy Camper"), who gives me great gift of love.

Acknowledgements

I would like to thank my major advisor, Dr. Wendell Liemohn, for his guidance and patience in helping me complete my Master of Science in Exercise Science. Thank you to my other committee member, Dr. Songning Zhang, for his feedback and advice. I would also like to thank John krusenklaus, P.T., O.C.S., for giving me a deep understanding and importance of biomechanics, and challenging me to become a better clinician to help people. Lastly, I would like to thank my subjects who dedicated their time to participate in this study.

Abstract

The purpose of this study was to determine the effect of a 6-week strength and balance training program on navicular drop and proprioception in subjects with excessive pronated feet. Eleven subjects who exhibited excessive pronated feet from student population participated in this study. Navicular drop test was used to assess the subtalar joint motion. The Biodex Stability System was used to determine balance using three indices; (1) overall stability index (OSI), (2) the anterior-posterior stability index (APSI), and (3) the medial-lateral stability index (MLSI). In a randomized order, the subjects were tested balancing on each foot at the two different stability levels, namely Level 8 (more stable/less difficult) and Level 2 (less stable/more difficult). The subjects performed the following two exercises: (1) one-leg standing with flat foot for one minute and (2) one-leg standing with heel raise for one minute (6 sec up and 6 sec down). Each exercise was repeated three times on each foot. After the 6-week training period, navicular drop test and balance testing were conducted to determine if there were any changes in navicular drop and balance control. To determine treatment effect (time) and foot-side effect, means of variables (navicular drop height, OSI, APSI, and MLSI) were evaluated utilizing a repeated analysis of variance measures (ANOVA). Further analyses were made using paired t-tests. A 6-week strength and balance training program resulted in a significant improvement on the height of the medial longitudinal arch measured by the navicular drop height during one-leg standing. A significant treatment effect was also seen on balance ability during one-leg standing on the MLSI index of the BSS for the easier (more stable) balance task. This study suggests that a 6-week program of simple one-leg standing and unilateral heel-raise exercises can positively affect navicular drop height and balance ability in subjects with excessive pronated feet.

Table of Contents

List of Tables

List of Figures

Chapter I

Introduction

During the loading phase of the gait cycle, the foot is designed to be flexible in order to adapt to uneven terrain and work as a shock absorber as it becomes pronated. At the end of loading phase, the foot becomes supinated and works as a rigid lever for propulsion. However, excessive and prolonged pronation imbalance of the foot has been considered to be linked to structural deformities and soft tissue pathology,[1-4] hallux abducto valgus,[5] knee pain,[6, 7] and shin splints;[8] it may also increase the risk of the injury to the Anterior Cruciate Ligament.[9, 10] The development of an excessive pronation usually results from a specific chain of events.[11] Various factors, such as rearfoot or forefoot deformities and tibial torsion, can cause excessive pronation of the feet and these factors can affect patients gradually or rapidly.[12]

The subtalar joint (STJ) consists of the articulation between the talus and the calcaneus; this joint influences foot and ankle function due to its anatomical position. Since changes in STJ position are transferred through the talus to the navicular at the midtarsal joint, measuring the distance of the navicular tuberosity from the floor ("navicular drop") is often used to assess the STJ motion and position.[4] Normal amounts of navicular drop are about 10 mm and greater than 15 mm is considered to be abnormal.[4]

Foot orthotics and motion control shoes have been used to correct misalignment of lower extremities; their purpose is to enhance foot stability and reduce compensation mechanisms in the lower extremities.[13] However, the long term effect of orthotic treatment has not be established.[14] Orthotic treatment can also involve high-cost and multiple clinic visits. Moreover, some patients never feel comfortable wearing them. Additionally, with orthotics patients tend to only passively get involved in their rehabilitation rather than an active involvement.

A strong tibialis posterior helps to control dynamically or eccentrically pronation and produce concentrically supination.[15] Also, a firm plantar aponeurosis, a neutrally placed non-constricted Achilles tendon, and adequate spring and deltoid ligaments have been suggested as essential factors for maintaining a neutral position.[11] The intrinsic muscles of foot originate at the medial tubercle of the calcaneus, cross the metatarsal-phalangeal joint, and insert at the middle-phalanx of the digits.[16] Contraction of these intrinsic muscles also raises the medial longitudinal arch.

The study done by Robbins and Hanna[16] supports the contention that plantar sensory feedback may activate the intrinsic foot musculature, which induces intrinsic foot shock absorption. Many articular nerve fivers terminate in mechanoreceptors in the joint capsule, ligaments, muscle, and skin; these mechanoreceptors detect joint pressure and tension from both dynamic movement and static position.[17] Position and movement sense are provided by these afferent nerve fibers; the afferent nerve fibers also play a role in a complex reflex system that controls posture and coordination. Balance and coordination training have resulted in an improvement in postural sway in individuals with functionally unstable ankles.[18-21] Proprioception training should theoretically enhance the neuromuscular response and dynamic support mechanisms. No research was found that examined the influence of strength and balance training on the medial longitudinal arch.

Problem Statement

The purpose of this study is to determine the effect of a 6-week strength and balance training program on navicular drop height and proprioception in subjects with excessive pronated feet.

Hypotheses

The following hypotheses were tested:

1) There is a significant decrease in navicular drop before and after a 6-week strength and balance training program.
2) There is a significant improvement in balance before and after a 6-week strength and balance training program.

Delimitations

The study was conducted with the following delimitations:

1) Eleven active and healthy subjects were selected as subjects from the University of Tennessee. They had no significant injuries of the lower extremities during the time of study.
2) Four test conditions were employed per subject including one-leg dynamic balance test with two different difficulty levels with each leg.

Limitations

The study was limited by the following factors:

1) Subjects were limited to the student population at the University of Tennessee.

2) Inherent errors from the balance-testing platform. Even though errors in the platform testing may be present, they were considered acceptable within the specifications of the manufactures.

Assumptions

The following assumptions were made for this study:

1) Biomechanical instruments used were sufficiently accurate for the purposes in this research.
2) All subjects were injury free in the lower extremities during the study.

Chapter II

Literature Review

Robbins and Hanna[16] examined changes in force-deflection characteristics and the adaptive pattern of the medial longitudinal arch of the foot associated with increased barefoot weight-bearing activity on 17 recreational runners. They hypothesized that foot adaptation associated with barefoot activity would occur to provide impact absorption and protection against running-related injuries since many authors[22-24] described that activation of intrinsic musculature of the foot rises and shortens the medial longitudinal arch (the distance measured from the medial tubercle of the calcaneus to the most distal point of the first metatarsal head), which allows the foot not only to act as a lever for propulsion but also to reduce dynamic impact. In the study of Robbin and Hanna, more than 1-hr of increased barefoot activity per day was required for all experimental subjects. A change greater than 1 mm was considered significant.

A summary of Robbin and Hanna's findings will now be discussed. Significant shortening of the medial longitudinal arch (> 1 mm) on X-rays during relaxed weight-bearing with applied normal load (15 and 55 kg for men, 15 and 45 kg for women) was shown after 4 months of increased barefoot running and walking (greater than 1-hr per day). The mean changes for the experimental group was a 4.7 mm shortening of the medial longitudinal arch. For the control group, there was a 4.9 mm lengthening of the arch. An activation of normally inactive intrinsic foot muscles of a shod population might have occurred with increased barefoot weight-bearing activity and caused shortening of the medial arch. Changes of skeletal muscular conditioning usually take over 2-3 months. The authors suggested that barefoot activity might increase sensory feedback largely from the glabrous epithelium of the foot and it might induce these adaptations. However, this adaptation was only limited in the laboratory setting while standing on the platform, not during walking, running, or jumping.

Subtalar Joint Neutral Measurement

The subtalar joint (STJ) consists of the articulation between the talus and the calcaneus with the axis of rotation of 42 degrees from the horizontal plane and 16 degrees from the sagittal plane; this joint influences foot and ankle function due to its anatomical position.[25] It is necessary for clinicians to measure the neutral position and movement of the STJ in an objective and reliable manner when they are treating lower extremity dysfunction because the foot and ankle position and their mobility have significant influence on overuse lower extremity injuries.[3, 4] In neutral position of the STJ, the medial and lateral edge of the talus to the calcaneus are congruous.[2] The STJ is a triplanar joint and has more complex kinematics during weight-bearing activities, which involve the leg and talus rotating over a more stable calcaneus; the calcaneus moves relative to the fixed talus in pronation and supination during non-weight-bearing activities.[25] Since changes in STJ position are transferred through the talus to the navicular at the midtarsal joint, measuring the distance of the navicular tuberosity from the floor ("navicular drop") is often used to assess the STJ motion and position.[4]

Closed kinetic chain measurements (weight-bearing position) of the STJ have been suggested to be more reliable method than traditional open kinetic chain measurement (using a universal goniometer with the patient prone).[26-28] Sell et al.[26] compared two different closed kinetic chain measurements and reported intertester and intratester reliability ranged from .68 to .91 and from .73 to .96 for calcaneal position and navicular height, respectively. Cook et al.[29] compared three methods (palpation of the subtalar joint, observation of skin lines over the sinus tarsi, and observation of malleolar curvatures) that measure the STJ neutral. Data were collected from 138 subjects, and the statistical analysis revealed over 95% probability that all three techniques correlate. Torburn et al.[28] did not find a significant difference between eversion during single-leg stance and maximum eversion during fast walking.

Foot Kinematics during the Gait Cycle

The medial longitudinal arch is made of the calcaneus, talus, navicular, cuneiforms, and three medial metatarsals; it acts as the primary load-bear and shock-absorber during weight-bearing activities.[25] During the stance phase, the medial longitudinal arch of the foot lowers slightly as the loading of body weight progressively increases.[30] During the first 30-35% of the gait cycle, the STJ pronates, which increases flexibility of the midfoot in order to absorb the stress from weight bearing and protect the foot.[31] As the subtalar joint becomes supinated by late stance, the arch rises and the midfoot becomes relatively rigid to prepare for propulsion.

Cornwall and McPoil[31] investigated movement of the rearfoot, midfoot, and forefoot by measuring the angular displacement of the calcaneus, navicular, and first metatarsal relative to the tibia of 153 healthy subjects during self-speed walking along the walkway. The 6D-RESEACH®[1] electromagnetic motion analysis system (3-D motion analysis) was used to measure kinematic data. They found very similar patterns of movement for the calcaneus and navicular bones relative to the tibia in frontal (inversion/eversion) planes. The authors supported the idea of the tarsal mechanism that subtalar and talocalcaneonavicular joints would have consistent, predictable, and interdependent motion during the gait cycle.

Anatomy and Function of the Tibialis Posterior

Both intrinsic and extrinsic muscles of the ankle and foot control static motion, provide dynamic thrust, and act as a shock absorber to the lower extremities.[25] The tibialis posterior primarily originates on the interosseous membrane, lateral portion of posterior surface of tibia and passes through the medial-posterior axis of the subtalar joint. Due to its extensive attachments on the tuberosity of navicular bone, three cuneiforms, cuboid, and bases of second, third, and fourth metatarsal bones, the tibialis posterior supports the medial longitudinal arch and acts as the primary supinator of the foot with the flexor hallucis longus and flexor digitorum longus. The tibialis posterior also decelerates the pronating rearfoot and controls the lowering of the medial longitudinal arch. The tibialis posterior has the longest period of its activation during the stance phase of the gait cycle (just before foot-flat to heel-off) compared to the other supinator muscles.[32]

Proprioception

Proprioception is defined as the awareness of posture, movement, and changes in equilibrium as well as the knowledge of position, weight, and resistance to objects in relation to the body.[33] Proprioception, a component of balance with visual and vestibular systems, is the cumulative neural input delivered from the mechanoreceptors in joint capsules, ligaments, muscle tendons, and skin to the central nervous system (CNS).[34] The sensory receptors consists of mechanoreceptors and nociceptors in muscles, joint, periarticular structures, and skin; they are four major types of joint receptors, the muscle spindles, the Golgi tendon organs, and cutaneous receptors.[35] Four major joint receptors are type I (Ruffini), type II (Golgi-Mazzoni or paciniform), type III (Golgi type), and type IV (free nerve endings). They are located in the joint capsules and ligaments and many articular nerve fibers terminate in these mechanoreceptors.

A decrease in joint proprioception is one of the contributing factors to functional ankle instability, in addition to anatomical or mechanical instability and muscle weakness.[17, 36-41] The absence of mechanical stability may cause symptoms of functional instability.[41-43] Functional ankle instability affects the ability to maintain balance[43, 44] and correct foot motion;[38] both are very crucial in preventing ankle injury and maintaining normal gait cycle. An improper foot position just prior to and at heel strike appears to be a cause of inversion ankle sprain.[40, 45-47]

Freeman et al.[17] proposed that a decrease in coordination can be caused by articular deafferentation due to afferent joint mechanoreceptor damage in injury (proprioceptive deficits), and the results of their research suggested that these damaged afferent joint receptors can be reeducated by strengthening muscles with coordination exercise (e.g., balancing on tilting boards). Drocherty st al. also found increase in active joint-reposition sense after a 6-week strength-training program (progressive resistive exercise using elastic tubing, three times a week for 10 minutes each day).[48]

Gauffin et al. reported that a decrease in static postural sway and an improved pattern of postural control.[19] Their subjects trained by one-leg standing on an ankle disk (a section of a sphere, LIC, Solna, Sweden) while the other leg was raised and flexed at the knee and the arms were crossed over the chest; one training session lasted for 10 min, five times a week for 8-weeks. Gauffin et al. found improvement of postural control in both the injured leg and the uninjured (untrained) leg; because of this, they suggested that postural sway could be controlled by central motor processing rather than peripheral proprioception.

Tropp et al.[49] also trained their subjects using an ankle desk. Their 10 subjects had a previous history of ankle injury and demonstrated functional instability of one or both ankles. Both legs were trained by one-leg standing on an ankle desk with the section of a sphere as the undersurface at a time for 15 minutes for 6-weeks. Their results showed improvement in static postural sway measured by stabilometry and decrease in subjective "giving way" sensation.

Bernier et al.[18] studied the effects of a 6-week coordination and balance-training program on proprioception of subjects with functional ankle instability. The Balance System (Chattanooga Group Inc., Hixson, TN) was used to assess postural sway during 20 sec one-leg standing under both static and dynamic conditions with and without visual cues. The KinCom II (Chattanooga Group Inc., Hixson, TN) isokinetic dynamometer was utilized in assessing active and passive joint position sense in a nonweight-bearing position. The 6-weeks balance training protocol (three times per week for 10 min each day) was designed from the most simple (one-leg balancing on fixed surface with eyes open) to the most complex sessions (functional hopping). The posttest scores for joint position sense were found to be significantly improved over the pretest scores for both the control and the experimental group, but there was no difference between groups. However, there was a significant training improvement (a significant difference between groups) on the modified equilibrium scores of balance in both the anterior/posterior and medial/lateral direction was found for two different conditions; their eyes were closed on a stable platform and eyes open on the inversion/eversion tilting platform.

Similar results were also found in non-impaired subjects (N = 28) by Hoffman and Payne.[50] Stabilometry recordings were measured with a Kistler (Kistler Instrumentation Corp., Amherst, NY) force platform. Stabilometry sampling was taken at 50Hz for 26 seconds while the subjects stood on their dominant limb. The middle 20 seconds of data were used for final analysis to calculate sway variability value for the X parameter (medial-lateral direction) and the Y parameter (anterior-posterior direction). The experimental group (N = 14) trained the dominant leg three times per week for 10 weeks on the Biomechanical Ankle Platform System™ (BAPS) (Spectrum Therapy Products, Jasper. MI). The authors concluded that the 10-week training period had a significant effect on proprioception as measured by postural sway in both the anterior/posterior and medial/lateral directions. The training improvement from the eyes closed condition suggested that "somatosensory" input could be improved in the functionally unstable ankle. They stressed that proprioceptive training was important for injury prevention.

Rozzi et al.[21] studied the effects of a 4-week balance training with the Biodex Stability System (BSS) (Biodex, Inc, Shirly, NY). Three trials were taken with two different levels of test difficulty on the BSS. Level 6 (more stable/an easier task) and Level 2 (less stable/ a more difficult task) were chosen in this study. Each trial lasted for 20 sec and subjects attempted to keep the platform stable during single-leg stance. Their subjects were both healthy participants (N=13) and subjects with a functionally unstable ankle (N = 13). They participated in 3-days-per-week single-leg balance training program on the BSS for 4-weeks.

As would be expected, Rozzi et al. found poorer balance ability in their subjects with functionally unstable ankles.[21] They also found a significant improvement in balance ability in both the experimental group (unstable ankle) and the non-impaired group as well as no significant difference between the posttraining scores of the two groups. In addition, their results showed a training effect on the untrained limb: this was also supported by Gauffin et al.[19] Rozzi et al. concluded that four weeks of training was a sufficient period to promote reflex muscular activation patterns and that centrally mediated neuromuscular control mechanism was possibly stimulated by this balance training.

Biodex Stability System (BSS)

The BSS (Biodex, Inc, Shirly, NY) reported in the prior study utilizes a computerized moveable balance platform that provides up to 20° of surface tilt in a 360° range; this enables the assessment of proprioceptive neuromuscular control by quantifying the ability to maintain dynamic bilateral or unilateral postural stability on an unstable surface.[51] This system is also designed to stimulate joint mechanoreceptors and to promote reflex muscular activation. A microprocessor-based actuator provides varying degrees of difficulty of the balance tasks; these range from easy (Level 8) to more difficult (Level 1) challenges as the subject tries to maintain balance for periods ranging from 10 sec to 10 min. Proprioceptive neuromuscular mechanisms affect both dynamic joint and unilateral postural stability as well as play an important roll in initiating muscular responses in the maintenance of stability. A variance from center is quantified to measure the ability to control the tilted platform angle; larger variance indicates poor neuromuscular control, which is associated with greater amounts of body movement. Specific neuromuscular activation patterns can be detected with the quantification of anterior/posterior and medial/lateral platform tilt.[51] The dependent measurement obtained from the BSS to determine the objective effects of the balance training include three indices:

- **Overall Stability Index (OSI):** The OSI represents the variance of platform displacement in degrees from level in all motions during a test. A high number is indicative excessive movement during a test.
- **Anterior/Posterior Stability Index (APSI):** The APSI represents the variance of platform displacement in degrees from level for motion in the sagittal plane.
- **Medial/Lateral Stability Index (MLSI):** The MLSI represents the variance of platform displacement in degrees from level for motion in the frontal plane.

The Stability Indices (SI) were calculated by summing the squares of all variations from the level position and dividing this value by the total number of the samples. A lower SI indicates a better balance score since it reflects less movement from the level position while a high SI is indicative of less stability. SIs for the anterior/posterior (AP) and medial/lateral (ML) directions are also calculated to determine motions in sagittal and frontal planes, respectively.

Hinman[52] measured the test-retest reliability of the balance measures provided by the BSS under two different levels of test condition (Level 3 and 6) and under three different visual conditions: eyes open, looking straight ahead; eyes open, receiving visual feedback; and eyes closed. The more challenging condition (Level 3) with eyes open, looking straight ahead was found to have the highest intraclass correlation coefficient (ICC = .89) with narrowest confidence intervals (CI = .89 - .92). The second highest ICC was .87 of the less challenging Level 6 with eyes open, looking straight ahead (CI = .78 - .92), which was followed by Level 6 with eyes closed (ICC = .83, CI = .72 - .90). Level 6 with visual feedback had the lowest ICC (.49) and the lowest CI (.25 - .67). In the challenging test condition, the variability of the SI values was the highest among the subjects.

Their findings that the higher test-retest reliability was produced with the most difficult test conditions did not agree with the results reported by Pincivero et al.[53] The latter investigators found that the easier test condition (Level 8) with dominant, single-leg stance had the highest ICC (.95) compared to the lowest ICC (.60) at Level 2 (more difficult) either with dominant limb or nondominant limb. Pincivero et al. recommended performing two practice trials prior to data collection to negate learning effects.[53]

Arnold et al.[54] reported that 95% of the variance in performance on the OSI could be counted for by performance on the APSI. This may be explained by subsequent research done in this lab that found MLSI's low reliability (intratester ICC's of .43) compared to .82 for OSI and .80 for APSI.[55] This higher error rate of MLSI could diminish the effect of MLSI on OSI. Another explanation was suggested because of greater amplitude of tilt in the sagittal plane (APSI) than the frontal place (MLSI); therefore, the APSI has more influence on the OSI score than the MLSI. Using MLSI and APSI separately has been suggested rather than combining them in the OSI.[54]

Chapter III

Research Methods

Experimental Methods

The purpose of this study was to determine the effect of a 6-week strength and balance training program on navicular drop and proprioception in subjects with excessive pronated feet. The protocol for the experiment during pre and post testing consisted of navicular drop measurements and two different balance test conditions. Subjects were screened to ensure that they had more than 10 mm navicular drop height[12] and met six standards that are delineated under Subject section. After two measures of navicular drop were taken for each foot, each subjects performed three trials of balance testing on each leg at the two different levels of difficulty, for a total of 12 trials. After a 6-week strength and balance training program, the same measurements were conducted during the posttesting.

Subjects

Eleven subjects (Age: 25.27 ± 4.6 yr, Body mass: 74.38 ± 10.22 kg, Height: 169.24 ± 4.63 cm) were recruited from student population (5 male and 6 female) at the University of Tennessee who exhibited excessive pronated feet. Prior to testing, a survey of medical history (Appendix A) was completed in order to exclude persons who did not meet the six standards: (1) not currently receiving any treatment for their lower extremities, (2) having no neurological or vestibular disorders, (3) currently taking no medication which may affect overall stability, (4) having no previous serious orthopedic injuries to lower extremity (e.g. Grade II or

III ankle sprains, fractures, and surgery/casting for 4 - 6 weeks), (5) not being diabetics, and (6) not having Raynaud's Syndrome. The navicular drop test was used as an inclusion criterion, namely that a navicular drop of greater than 10 mm would be considered as an indication of excessive pronated foot.[12] The experimental protocol was explained to the subjects. All subjects read and signed an Informed Consent Form (Appendix B) approved by the Institutional Review Board at the University of Tennessee.

Experimental Protocol

Pretesting Protocols

Navicular Drop Measurement: After the subjects were informed about the purpose of this study and had the testing protocol described to them, the navicular drop for each foot was measured twice. Navicular drop is the difference between the navicular height (distance between the floor and the navicular tuberosity) in STJ neutral and relaxed weight bearing.[4] The navicular tuberosity was palpated and labeled with a marker pen. While the subjects were seated on a chair, the STJ was placed in the neutral position by the principal investigator and the height of navicular tuberosity was measured with a digital caliper (Figure F-1). The principal investigator is familiar with the technique of positioning the STJ neutral via palpation of the head of the talus which is described by Brody.[4] For relaxed one-leg standing, the subjects were instructed to stand in relaxed, balanced position with the knee of the tested leg bent slightly and the navicular tuberosity was digitized again. The subjects who had a difficult time in balancing in that position were allowed to use their fingertips to maintain the balanced position. Unilateral stance was used in this study as a simulation of the midstance phase of the gait cycle. The principal investigator made all measurements. Two trials were averaged to provide a measure of navicular drop. This testing was conducted in the Biomechanics/Sports Medicine Lab.

Balance Test: The balance test was administered in the Men's Athletic Training Room of the Neyland-Thompson Sports Complex at the University of Tennessee. The Biodex Stability System (BSS) (Biodex, Inc, Shirly, NY) (Figure F-2) utilizes a computerized balance platform to evaluate proprioception by assessing dynamic measures of balance and records the subject's ability to control platform variance from a balanced position.[21, 54] In this investigation the BSS was used to determine balance using three indices (Figure F-3), namely (1) overall stability index (OSI), (2) the anterior-posterior stability index (APSI), and (3) the medial-lateral stability index (MLSI).

The subjects had navicular drop in excess of 10 mm were asked to participate in the balance testing and in the training program. According to the BSS testing protocol (Figure F-4), the subjects were positioned on the BSS balance platform (Figure F-5) with barefoot, and performed two practice sessions immediately followed by the first single leg dynamic balance test. The subjects were instructed to keep the unsupported leg off the platform and from contacting the test leg with both arms crossed on their chest. The subjects were also required to focus on a black dot located on the front wall at eye level to eliminate feedback from the screen of the BBS (Figure F-6).

In a randomized order, the subjects were tested balancing on each foot at the two different stability levels, namely Level 8 (more stable/less difficult) and Level 2 (less stable/more difficult). Each test lasted for 20 seconds and was repeated three times. Subjects were given a one-minute rest between tests. Each mean of OSI, APSI, and MLSI was calculated from the three trials for each of the four test conditions: (1) right leg at Level 8, (2) left leg at Level 8, (3) right leg at Level 2, and (4) left leg at Level 2. The mean value was used for further analysis in the study. The pretest and instruction took approximately 1 hour and 30 minutes.

Training Protocols

After all pretest measurements were made, the 11 subjects were taught the correct way to perform the following two exercises: (1) one-leg standing with flat foot for one minute and (2) one-leg standing with heel raise for one minute (6 sec up and 6 sec down). Each exercise was repeated three times on each foot; the subjects had their arms across their chest during this process. During one-leg standing with flat foot, the subject was encouraged to shorten the distance of the medial longitudinal arch to emphasize the activation of intrinsic foot muscles. With their understanding of exercise procedure, the subjects trained on their own for 12 minutes, three times per week for six weeks. All testing and training were conducted in barefoot condition; the subjects were responsible to keep a training log.

Posttesting Protocols

After the 6-week training period, the same testing procedures cited previously in Pretesting Protocols were conducted to determine if there were any changes in navicular drop and balance control. The posttest lasted about 40 minutes and was conducted in the Men's Athletic Training Room of the Neyland-Thompson Sports Complex.

Statistics

To determine treatment effect (time) and foot-side effect, means of variables (navicular drop height, OSI, APSI, and MLSI) were evaluated utilizing a repeated analysis of variance measures (ANOVA). Further analyses were made using paired t-tests. The significance level was set at $\alpha < 0.05$; statistical analysis was conducted by using SPSS statistical program (version 12.0).

Chapter IV

Results

The purpose of this study was to determine the effect of a 6-week strength and balance training program on navicular drop height and on proprioception in subjects with excessive pronated feet. Both male and female subjects with excessive pronated feet were recruited for this study. Navicular drop was measured as the distance between the floor and the navicular tuberosity with the subtalar in (a) neutral and (b) in relaxed weight bearing using the modified procedure described by Brody.[4] Eleven of the 12 subjects who volunteered for this study met the criterion of having excessive pronated feet delineated by Mueller et al. (i.e., 10 mm or more navicular drop).[11] These 11 subjects were then participated in this study.

ANOVA analyses

Foot-side effect

The results of the ANOVA from the observations of 11 subjects indicated no significant difference in foot side (i.e. right or left) on navicular drop height or on balance improvement when pre-and posttraining measurements/SI scores of both feet were compared.

Treatment effect

The results of the ANOVA from the observations of 11 subjects indicated no significant effect of time (treatment effect) on navicular drop height or on SI scores. This indicates no significant difference between pretraining and posttraining on navicular drop height or on balance improvement. However, there was a marginal difference in navicular height ($F_{1, 10} = 3.95$, $P = 0.08$), OSI at Level 8 ($F_{1, 10} = 3.54$, $P = 0.09$), and MLSI at Level 8 ($F_{1, 10} = 4.24$, $P = 0.07$) between pretraining and posttraining.

Paired t-tests

Since there was no difference between feet on navicular height and balance, all right and left measures were considered as individual data sets when the treatment effect was further analyzed with a total of 22 observation. A similar procedure was followed by Tropp et al.[49] The results of further analysis from these paired t-tests (22 observations) were:

Navicular Drop

Means and standard deviations for navicular drop height are presented in Table 1. There was a significant decrease in navicular drop height between pretraining and posttraining ($t_{21} = 2.76$, $P = 0.01$).

Table 1. Navicular Drop Height

	Pretraining	Posttraining
Navicular Drop Height (N = 11, Right foot)	15.28 ± 4.40	12.29 ± 2.97
Navicular Drop Height (N = 11, Left foot)	16.30 ± 6.15	12.26 ± 4.49
Navicular Drop Height (N = 22, Right & Left feet)	15.79 ± 5.23	12.28 ± 3.72*

*Indicates significant mean difference ($P \leq .05$) when compared with pretraining value

Balance Data: Level 2 *(More difficult/ Less stable surface)*

Test means and standard deviations for the 22 data sets from testing at stability Level 2 are presented in Table 2. The mean posttraining scores of OSI, APSI, and MLSI were not significantly lower than the mean pretraining scores of OSI, APSI, and MLIS, respectively.

Balance Data: Level 8 *(Less difficult/ More stable surface)*

Test means and standard deviations for the 22 data sets from testing at stability Level 8 are presented in Table 3. Results of the paired t-test for data obtained during testing at stability Level 8 revealed a significant difference in MLSI (t_{21} = 2.13, P = 0.05); this indicates a significant improvement in balance ability in frontal plane. The mean posttraining OSI score (2.32 ± 0.98) was also slightly lower than the mean pretraining OSI score (2.85 ± 0.91); however, this difference was not statistically significant (t_{21} = 1.82, P = 0.08).

Table 2. Mean and Standard deviation of OSI, APSI, and MLSI at Level 2 (N=22, Right & Left feet)

	Pretraining	Posttraining
OSI	3.54 ± 1.20	3.44 ± 0.97
APSI	2.60 ± 1.14	2.53 ± 0.95
MLSI	2.35 ± 0.87	2.30 ± 0.93

Table 3. Mean and Standard deviation of OSI, APSI, and MLSI at Level 8 (N=22, Right & Left feet)

	Pretraining	Posttraining
OSI	2.85 ± 0.91	2.32 ± 0.98†
APSI	2.14 ± 0.85	1.81 ± 0.92
MLSI	1.82 ± 0.87	1.46 ± 0.74*

†Indicates significant mean difference ($P \leq .10$) when compared with pretraining value

*Indicates significant mean difference ($P \leq .05$) when compared with pretraining value

Chapter V

Discussion

The purpose of this study was to determine the effect of a 6-week strength and balance training program on navicular drop height and proprioception in subjects with excessive pronated feet. Navicular drop height was determined following a modified version of a procedure used by Brody.[4] Proprioception was quantified utilizing three indices of the BSS. One of the major findings of this study was that a 6-week strength and balance training program resulted in a significant improvement on the height of the medial longitudinal arch measured by the navicular drop height during one-leg standing; this posture is similar to the midstance in the gait cycle.[28] A significant treatment effect was also seen on balance ability during one-leg standing on the MLSI index of the BSS for the easier (more stable) balance task.

Many articular afferent nerve fibers terminate on mechanoreceptors in the ligaments and joint capsules; these mechanoreceptors of the foot and ankle with other receptors are believed to control the gastrocnemius contractions instantaneously and quantitatively on unstable surfaces.[17] Additionally, the fusimotor gamma motoneurons, which receive messages from articular mechanoreceptor afferents along with segmentally related cutaneous afferents, innervate extrafusal muscle fibers; and influence the activity of muscle spindles. Thus, they can also adjust the muscle tone in posture and movement.[56] Therefore, a proprioceptive defect could be expected to result if mechanoreceptors are damaged when injuries occur to ligaments and joint capsules in the foot and ankle. Freeman[43] suggested that less stability in single-leg standing may be due to an altered proprioceptive response, which could cause impaired motor control in the lower extremities. In the present study, it is possible that a re-education of the afferent joint receptors occurs as the subjects participated in the strength and balance training activity.

Finding improvement in single-leg balance stability in the present study appears to be consistent with other previous balance training programs for subjects with or without a functionally unstable ankle.[18, 19, 21, 49, 50] Tropp et al.[49] found a significant improvement of stabilometric results and subjective "giving away" sensation after a 6-week program of ankle disk coordination training. This decrease in postural sway occurred both standing on the more and the less stable foot. Troop et al. suggested that this improvement might be due to a central tuning of a coordination program, a reeducation of an impaired position sense, or improved muscular strength. Since both right and left legs of the subjects were trained individually in the present study, centrally mediated neuromuscular control mechanisms to maintain balance could not be assessed.[19]

In my personal conversations with the subjects, I discovered that all of subjects found that the training exercises became easier every week and that they also felt improvement in their strength and balance ability. These subjective reports on training effect in this study are supported by the finding of Rozzi et al.[21] who used the ankle joint functional assessment tool questionnaire (AJFAT) and made a static balance assessment with the BSS to evaluate the effectiveness of a 4-week balance training program. Rozzi et al. reported that the posttraining AJFAT scores of subjects with unstable ankles (25.78 ± 3.80) and subjects with nonimpared ankles (29.15 ± 5.27) were significantly greater than their pretraining scores (17.11 ± 3.44 and 22.92 ± 5.22, respectively). Their results indicate an overall improvement in perceived ankle joint functional stability by quantifying their subjective effects. Although the reliability and validity of the AJFAT has not been established yet, once it has, this kind of questionnaire could be a valuable assessment tool in documenting subjective changes resulting from the training.

Arnold and Schmitz[54] suggested that the OSI and the APSI are closely related to each other while there is a relatively small contribution from the MLSI to the OSI. In the present study, only the MLSI at Level 8 was shown to be significantly different from pretraining to posttraining; there were no significant differences in OSI and APSI scores. These indices should be used separately if both anterior-posterior and medial-lateral motions are of interest to researchers.

Conclusions

The unilateral heel-raise exercise imposes similar muscle function to that required in everyday walking. This study suggests that a 6-week program of simple one-leg standing and unilateral heel-raise exercises can positively affect navicular drop height and balance ability in subjects with excessive pronated feet. The results of this study also supports the finding of Robbins and Hanna[16] that activation of intrinsic musculature can raise the medial longitudinal arch.

Limitations

This study had limitations. In this study a static measurement of navicular drop was utilized; it would be the desirable to measure dynamic function of the foot. For example, a 3-D video analysis may be a better device to determine not only the amount of navicular drop, but also the timing of the excessive navicular drop. Although surface markers on the skin may not accurately replicate the movement of bone underneath the skin, several studies have suggested that the motion of the posterior aspect of the calcaneus and the tibia in the frontal plane can be used to determine STJ movement.[1, 57] A 3-D video analysis could also be used to study the influence on the posterior calcaneal position and the tibia motion in the frontal plane.

Mueller et al.[12] found that rearfoot position contributed more to navicular drop than the forefoot position (r = 0.42 and r = 0.29, respectively). Different factors and kinematic chains of the lower extremities can significantly contribute to excessive navicular drop. These factors include soft tissue and joint capsule flexibility, tibial varum, tibial torsion, and hip rotation deformities; the latter were not assessed in the present study.

There was no control group in the present study. It was assumed that if a control group (non-training group) was used, there would be no changes in navicular drop height and balance without training. Further studies should investigate if single leg standing and heel raises improve the navicular height of people who do not have excessive pronated feet.

Clinical Implications

It is very important for clinicians to have a deep understanding of the biomechanics and neuromuscular involvement of the foot and ankle. By having this understanding, clinicians can use two approaches together to modify compensation patterns in the foot. Strength and balance training can effectively provide support for lower extremity rehabilitation. Foot orthotics can be used with active treatments that emphasize strength and balance.

References

References

1. McPoil TG, Bracato RS. Foot and ankle: biomechanical evaluation and treatment. In: Group J, ed. Orthopedic and Physical Therapy. Vol. 2. St. Louis: CV Mosby, 1990:313.
2. Root ML, Orien WP, Weed JH. Normal and abnormal function of the foot. Clinical Biomechanics. Vol. 2. Los Angeles: Clinical Biomechanics, 1977.
3. Ator R, Cunn K, McPoil T, Knecht H. Effect of adhesive strapping on medial longitudinal arch support before and after exercise. Journal of Orthopaedic and Sports Physical Therapy 1991; 14:18-23.
4. Brody D. Techniques in the evaluation and treatment of the injured runner. Orthopedic Clinics of North America 1982; 13:541-558.
5. Stevenson M. Study of the correlation between neutral calcaneal stance position and resting calcaneal stance position in the development of hallux abducto valgus. Australian Podiatrist 1990; 24:18.
6. Bennett P. A randomized clinical assessment of foot pronation and its relationship to patello-femoral syndrome. Australian Podiatrist 1988; 22:6-9.
7. Coplan J. Rotationl motion of the knee: a comparison of normal and pronating subjects. Journal of Orthopaedic and Sports Physical Therapy 1989; 10:366.
8. Lilletvedt J, Kreighbaum E, Phillips R. Analysis of selected alignment of the lower extremity related to the shin splint syndrome. Journal of the American Podiatry Association 1979; 69:211-217.
9. Beckett M, Massie D, Bowers K, Stoll D. Incidence of hyperpronation in the ACL injured knee: A clinical perspective. Journal of Athletic Training 1992; 27:58-62.
10. Woodford-Rogers B, Cyphert L, Denegar C. Risk factors for anterior cruciate ligament injury in high school and college athletes. Journal of Athletic Training 1994; 29:343-346.
11. Bowman G. New concepts in orthotic management of the adult hyperpronated foot: preliminary findings. Journal of Prosthetics and Orthotics 1997; 9:77-81.
12. Mueller M, Host J, Norton B. Navicular drop as a composite measure of excessive pronation. Journal of the American Podiatric Medical Association 1993; 83:198-202.
13. Novick A, Kelley D. Position and movement changes of the foot with orthotic intervention during the loading response of gait. Journal of Orthopaedic and Sports Physical Therapy 1990; 11:301-312.
14. Gross M, Byers J, Krafft J, Lackey E, Melton K. Impact of custom semirigid foot orthotics on pain and disability for individuals with plantar fascitis. Journal of Orthopaedic and Sports Physical Therapy 2002; 32:149-157.

15. Norkin CC, Levamgier PK. Ankle-foot complex; Gait. Joint structure & function: a comprehensive analysis. Philadelphia, PA: F. A. Davis Company, 1992:379-418, 448-495.
16. Robbins S, Hanna A. Running-related injury prevention through barefoot adaptations. Medicine and Science in Sports and Exercise 1987; 19:148-156.
17. Freeman M, Dean M, Hanham J. Etiology and prevention of functional instability of the foot. Journal of Bone and Joint Surgery 1965; 47:678-685.
18. Bernier J, Perrin D. Effect of coordination training on proprioception of the functionally unstable ankle. Journal of Orthopaedic and Sports Physical Therapy 1998; 27:264-275.
19. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. International Journal of Sports Medicine 1988; 9:141-144.
20. Mattacola C, Lioyd J. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: a single-case design. Journal of Athletic Training 1997; 32:127-135.
21. Rozzi S, Lephart S, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. Journal of Orthopaedic and Sports Physical Therapy 1999; 29:478-486.
22. Brody D. Running injuries. Clin. Synp 1980; 32:4.
23. James S, Bates B, Osternig L. Injuries to runners. American Journal of Sports Medicine 1978; 6:40-49.
24. Mann R. Biomechanics of running. Symposium of the Foot and Leg In Running Sports, P.R. Mack (Ed.). NY: C.V. Mosby, 1982:1-29.
25. Neumann D. Ankle and Foot. Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation. St. Louis, MO: Mosby, Inc., 2002.
26. Sell K, Verity T, Worrell T, Pease B, Wigglesworth J. Two measurement techniques for assessing subtalar joint position: a reliability study. Journal of Orthopaedic and Sports Physical Therapy 1994; 19:162-167.
27. Smith-Oricchio K, Harris B. Interrater reliability of subtalar neutral, calcaneal inversion and eversion. Journal of Orthopaedic and Sports Physical Therapy 1990; 12:10-15.
28. Torburn L, Perry J, Gronley J. Assessment of rearfoot motion: passive positioning, one-legged standing, gait. Foot and Ankle International 1998; 19:688-693.
29. Cook A, Gorman I, Morris J. Evaluation of the neutral position of the subtalar joint. Journal of the American Podiatric Medical Association 1988; 78:449-451.
30. Cashmere T, Smith R, Hunt A. Medial longitudinal arch of the foot: stationary versus walking measures. Foot and Ankle International 1999; 20:112-118.
31. Cornwall M, McPoil T. Three-dimensional movement of the foot during the stance phase of walking. Journal of the American Podiatric Medical Association 1999; 89:56-66.

32. Sutherland D. Electromyographic study of the plantarflexors of the normal walking on the level. Journal of Bone and Joint Surgery 1966; 48A:66-71.
33. Davies C. Taber's Cylopedic Medical Dictionary (16th Ed). Philadelphia: F.A. Davis Company, 1989.
34. Rowinski. Afferent neurobiology of the joint. In: Gould J, ed. Orthopaedic and Sports Physical Therapy. St. Louis. MO: CV Mosby Company, 1990:49-63.
35. Grigg P. Peripheral neural mechanisms in proprioception. Journal of Sport Rehabilitation 1994; 3:2-17.
36. Cornwall M, Murrell P. Postural sway following inversion sprain of the ankle. Journal of the American Podiatric Medical Association 1991; 81:243-247.
37. Garn S, Newton R. Kinesthetic awareness in subjects with multiple ankle sprains. Physical Therapy 1988; 68:1667-1671.
38. Glencross D, Thornton E. Position sense following joint injury. American Journal of Sports Medicine 1981; 21:23-27.
39. Lentell G, Katzman L, Walters M. Relationship between muscle function and ankle stability. Journal of Orthopaedic and Sports Physical Therapy 1990; 11:605-611.
40. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. American Journal of Sports Medicine 1985; 13:259-262.
41. Tropp H. Pronator muscle weakness in functional instability of the ankle joint. International Journal of Sports Medicine 1986; 7:291-294.
42. Evans G, Hardcastle P, Frenyo A. Acute rupture of the lateral ligaments of the ankle. Journal of Bone and Joint Surgery 1084; 66B:209-212.
43. Freeman M. Instability of the foot after injuries to the lateral ligament of the ankle. Journal of Bone and Joint Surgery 1965; 47B:669-677.
44. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. Medicine and Science in Sports and Exercise 1984; 16:64-66.
45. Sammarco J. Biomechanics of the ankle. I, Surface velocity and instantaneous center if rotation in the sagital plane. American Journal of Sports Medicine 1977; 5:231-234.
46. Glick J, Gordon R, Nishimoto D. Prevention and treatment of ankle injuries. American Journal of Sports Medicine 1976; 4:136-141.
47. Stormont D, Morrey B, Anm K, Cass J. Relationship between articular restraint and primary and secondary static restraints. American Journal of Sports Medicine 1985; 13:295-300.
48. Docherty C, Moore J, Arnold B. Effects of strength training on strength development and joint position sense in functional unstable ankles. Journal of Athletic Training 1998; 33:310-114.
49. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recordings of single limb stance. American Journal of Sports Medicine 1984; 12:185-188.

50. Hoffman M, Payne G. Effects of proprioceptive ankle disk training on healthy subjects. Journal of Orthopaedic and Sports Physical Therapy 1995; 21:90-93.
51. Balance System Operation & Service Manual. Shirley, NY: Biodex Medical Systems, 1995.
52. Hinman M. Factors affecting reliability of the Biodex Balance System: a summary of four studies. Journal of Sport Rehabilitation 2000; 9:240-252.
53. Pincievero D, Lephart S, Henry T. Learning effects and reliability of the Biodex Stability System. Journal of Athletic Training 1995; 30:S35.
54. Arnold B, Schinits R. Examination of balance measures produced by the Biodex Stability System. Journal of Athletic Training 1998; 33:323-327.
55. Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. Journal of Sport Rehabilitation 1998; 7:95-101.
56. Freeman M, Wyke B. Articular reflexes at the ankle joint: an electromyographic study of normal and abnormal influences of ankle-joint mechanoreceptors upon reflex activity in the leg muscles. British Journal of Surgery 1967; 54:990-1001.
57. Elveru R, Rothstein J, Lamb R, Riddle D. Methods for taking subtalar joint measurements: a clinical report. Physical Therapy 1988; 68:678-682.

Appendices

Appendix A

Medical History Questionnaire Sheet

MEDICAL HISTORY QUESTIONNAIRE

Subject#:_____

Subject name:____________________ Date:________ AGE:_____

#	Have you ever had or do you have:	Response (Y/N)	Comments (specific information, dates, brief explanation as needed)
1	Currently receiving any treatment for lower extremities?		
2	Any neurological or vestibular disorders?		
3	Any recent injury, illness or infection disease?		
4	Chronic or recurring illness/conditions?		
5	Ever been hospitalized?		
6	Frequent headaches?		
7	Head injuries/concussions?		Date of most recent: Total # in past year:
8	Even been knocked unconscious?		Date of most recent: Total # of times:
9	Glasses or contact lenses?		
10	Frequent ear infections?		
11	Even passed out during or after exercise?		
12	Incidents of Dizziness during or after exercise?		
13	Seizures?		
14	Chest pain during or after exercise?		
15	High blood pressure?		
16	Ever been diagnosed with a heart murmur?		
17	Injury to neck?		
18	Injury to back/spine?		
19	Injury to chest/ribs?		
20	Injury to wrist/hands, elbow(s), or shoulder(s)?		
21	Injury to hip(s)/pelvis?		
22	Injury to knee(s)?		

23	Injury to ankle(s)?		
24	Shin Splints?		
25	Stress fractures?		
26	Fractured/broken bone?		
27	Any surgeries?		
28	Casting lower extremity for 4-6 weeks?		
29	Any pins, plates or screws from previous surgery?		
30	Foot orthotics or motion control shoes?		
31	Any braces/special protective equipment?		
32	Injury to eye(s)?		
33	Injury to nose?		
34	Take any medication?		
35	Any unhealed injury?		
36	Diabetes?		
37	Asthma?		
38	Raynaud's Syndrome		

ADDITIONAL COMMENTS: (Reference with the Item #)

Participant's signature: ________________________________ Date__________

Appendix B

Informed Consent Form

INFORMED CONSENT FORM

TITLE OF THE STUDY: The effect of a 6-week strength and balance training program on navicular drop and proprioception in excessive pronated foot

Principal Investigator: Ryoko Suzuki, B.S., A.T.C., C.S.C.S.
Faculty Advisor: Dr. Wendell Liemohn
Address: Department of Health, Safety and Exercise Science
University of Tennessee, Knoxville
Knoxville, TN 37996
Phone: (865)974-6674

PURPOSE
You are invited to participate in a research study. The purpose of this study is to determine if a six-week strength and balance training program improves your balance ability and the major arch height of your foot.

PROCEDURES

PRETEST

The pretest will last approximately one half hour, and this session will be held in the two different places:

Biomechanics Lab:
1. You will be given this informed consent form, and will be asked to read it; if you have any questions do not hesitate to ask me.
2. You will be asked to fill out a medical history questionnaire, and your height and weight will be determined.
3. Navicular Height. The height of your navicular bone (a small bone in the foot) will be determined for the right and the left foot.

- Navicular height is the distance between the floor and the navicular tuberosity (the most prominent bone under the inner side of your ankle). This height for each foot will be measured in neutral position and relaxed standing positions. The two measures will be repeated twice.
- If the difference in navicular heights between the two positions (neutral & relaxed standing) meets inclusion criteria (e.g., 10 mm), you will be qualified to participate in this study and then will be tested on your balance performance. If navicular height difference does not meet inclusion criteria, there is no point in your participating in this study. However, I appreciate your cooperation and I would be happy to teach you the balance exercises.

Men's Athletic Training Room:
4. Balance. You will be taught the correct way to perform a single-leg balance testing on a balance measuring device. You will be allowed to have two practice sessions to get familiar with this device and the testing protocol.

- During the balance testing, you will be asked to stand on a single leg on the platform with both arms across your chest. Your unsupported leg should be held in a comfortable position in air without contacting the testing leg or the platform. This testing position will be used for all practice and data collection trials. You will be asked to focus your eyes on a spot on the front wall during the testing. The equipment used to measure balance permits setting for an easy (Level 8) or a more difficult (Level 2) test.
- In random order, your balance will be measured as follows:
  - Right leg at Level 8
  - Left leg at Level 8
  - Right leg at Level 2
  - Left leg at Level 2

Each test lasts for 20 seconds and is repeated 3 times. You will be asked to take one-minute between tests. You will be asked to be barefoot during all measurements and testing.

TRAINING

After all pretest measurements are taken, you will be taught the correct way to perform two different exercises:

(1) one-leg standing with flat foot for one minute
(2) one-leg standing on heel-raises for one minute.

Each exercise will be repeated three times a day for each leg in barefoot condition. You will be asked to do these exercises, three times per week for six weeks. You will be responsible for logging your own training when you do so; the procedure will take approximately 12 minutes.

POSTTEST

After the six-week training program, you will be asked to come back for the posttest; it will last about 20 minutes. During this session, your navicular heights and balance will be measured using the same procedure used in the pretest. If you remain in the area during summer, you will be asked to continue your training for another two weeks and return for a second posttest.

BENEFITS OF PARTICIPATION

You may improve your strength and ability to balance, alleviate lower extremity symptoms which may currently exist, and receive possible correction in your abnormal flat foot. This research may also provide allied health professionals a cost-effective way to enhance stability and prevent the lower extremity injuries in their patients.

RISKS OF PARTICIPATION

The potential risks that you may have after the testing are very minimal in this study. You will be screened using a medical history form to meet the criteria and avoid any contraindications to yourself, such as any recent trauma to feet, ankles, knees, and lower back. You may experience mild discomfort in your lower legs after the training. This is very normal muscle reaction after regular workout, and typically disappears within a day or two. Moreover, you will be taught the correct way to perform stretching before and after the training in order to minimize discomfort. Protective handrails on the balance device will prevent you from falling down. You should not participate in this study if you feel that it would be detrimental to your overall health.

EMERGENCY MEDICAL TREATMENT

The principal investigator, who will be present at each session, is a certified athletic trainer. Standard first aid procedures would be administered as necessary. In the event of physical injury is suffered as a result of participation in this study, the University of Tennessee does not automatically provide reimbursement for medical care or other compensation.

CONTACT INFORMATION

If you have questions or concerns at any time about the study or the procedures, you may contact the principle investigator at (865)974-6674. If you have questions about your rights as a participant, you may contact the University of Tennessee Institutional Review Board at (865)974-3466.

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

CONFIDENTIALITY

The information in the study records will be kept confidential. Data from this study will be stored securely in the office of Dr. Wendell Liemohn in the Department of Health, Safety, and Exercise Science at the University of Tennessee, Knoxville, for three years and will be destroyed. The information will be made available only to the principal investigator and her faculty advisor unless you specifically give permission in writing to do otherwise. No reference will be made in oral or written reports, which could link you to the study. Confidentiality of collected data will be protected by assigning you a number, and your name will not be included in any discussion or publication.

AUTHORIZATION

By signing this informed consent form, I have read and understood the above information. I have received a copy of this form for my personal records. I have been given the opportunity to ask questions that I may have. I acknowledge that I cannot hold any injury or incident that may occur from this research. I agree to participate in this study.

Participant's name ______________________________

Participant's signature ______________________________ Date____________

Investigator's signature ______________________________ Date____________

Appendix C

Subject Information Sheet

Subject Information

Assigned #:_______ Age:_________ Gender: *male/ female*
Date:__________________

Body Height	(inch)	(cm)
Weight	(lb)	(kg)

Navicular Drop Test (mm)

Right Leg

	Subtalar Joint Neutral	Relaxed	Navicular Drop
1			
2			
Mean			

Left Leg

	Subtalar Joint Neutral	Relaxed	Navicular Drop
1			
2			
Mean			

Balance Test

Right Leg/Level 2: FOOT ANGLE (degrees): HEEL POSITION( )

	OSI	A/P SI	M/L SI
1			
2			
3			
Mean			

Left Leg/Level 2: FOOT ANGLE (degrees): HEEL POSITION( )

	OSI	A/P SI	M/L SI
1			
2			
3			
Mean			

Right Leg/Level 8: FOOT ANGLE (degrees): HEEL POSITION( )

	OSI	A/P SI	M/L SI
1			
2			
3			
Mean			

Left Leg/Level 8: FOOT ANGLE (degrees): HEEL POSITION( )

	OSI	A/P SI	M/L SI
1			
2			
3			
Mean			

Appendix D

Navicular Drop Height Tables

Table D-1. Pretraining Navicular Drop Height Data (mm)

Subjects	R ND 1	R ND 2	R ND	L ND 1	L ND 2	L ND
1	13.19	12.93	13.06	14.21	13.58	13.90
2	15.82	15.77	15.80	10.20	11.41	10.81
3	16.97	15.39	16.18	19.99	21.21	20.60
4	10.12	11.66	10.89	10.58	11.38	10.98
5	14.05	10.43	12.24	21.52	21.88	21.70
6	11.88	11.31	11.60	13.69	13.47	13.58
7	12.81	11.01	11.91	9.42	10.01	9.72
8	15.01	15.15	15.08	14.72	11.29	13.01
9	14.47	15.35	14.91	13.57	13.48	13.53
10	24.71	25.29	25.00	27.78	29.75	28.77
11	21.71	21.13	21.42	22.72	22.72	22.72
Mean			15.28			16.30
Std Dev			4.38			6.15

Table D-2. Posttraining Navicular Drop Height Data (mm)

Subjects	R ND 1	R ND 2	R ND	L ND 1	L ND 2	L ND
1	13.13	13.32	13.23	14.47	14.94	14.71
2	9.14	9.58	9.36	11.04	10.62	10.83
3	18.23	16.83	17.53	21.66	19.14	20.40
4	11.56	9.84	10.70	10.87	10.33	10.60
5	15.59	16.21	15.90	20.20	19.16	19.68
6	7.81	8.55	8.18	7.20	8.92	8.06
7	10.31	9.93	10.12	8.56	6.55	7.56
8	13.58	13.16	13.37	10.20	11.20	10.70
9	14.72	14.11	14.42	13.66	13.36	13.51
10	9.68	9.18	9.43	7.24	7.15	7.20
11	12.56	13.42	12.99	11.60	11.75	11.68
Mean			12.29			12.26
Std Dev			2.97			4.50

Appendix E

Balance Stability Tables

Table E-1. Balance Data at Pretraining Level 2 (Right foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	5.30	2.40	1.20	2.97	4.80	1.40	0.90	2.37	2.60	2.10	0.90	1.87
2	4.80	6.10	3.10	4.67	3.70	5.30	1.90	3.63	3.30	3.10	2.70	3.03
3	4.70	3.70	3.70	4.03	3.80	1.40	1.00	2.07	2.90	3.60	3.40	3.30
4	1.40	3.70	4.90	3.33	0.00	2.40	2.40	1.60	1.40	2.90	4.60	2.97
5	1.40	2.10	2.70	2.07	0.80	1.80	2.10	1.57	1.30	1.30	1.90	1.50
6	4.60	6.10	2.20	4.30	3.90	5.80	1.90	3.87	2.70	1.90	1.40	2.00
7	4.90	5.80	2.30	4.33	3.40	2.60	0.90	2.30	3.80	5.30	2.20	3.77
8	4.70	5.10	3.40	4.40	2.90	.90	2.20	2.00	3.80	5.10	2.90	3.93
9	4.10	7.30	5.20	5.53	3.40	6.90	3.80	4.70	2.40	2.70	3.70	2.93
10	5.60	3.60	2.80	4.00	5.10	2.90	2.10	3.37	2.70	2.20	2.10	2.33
11	2.20	3.10	2.90	2.73	1.80	1.90	2.40	2.03	1.30	2.60	1.90	1.93
Mean				3.85				2.68				2.69
Std Dev				0.99				1.04				0.81

Table E-2. Balance Data at Pretraining Level 2 (Left foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	3.70	3.80	5.20	4.23	3.70	3.80	5.10	4.20	1.20	0.90	1.10	1.07
2	3.60	4.10	3.20	3.63	3.30	1.40	1.60	2.10	1.80	3.80	2.90	2.83
3	1.70	1.40	2.70	1.93	.90	.70	2.40	1.33	1.40	1.40	1.40	1.40
4	1.70	2.20	2.60	2.17	1.40	1.30	1.80	1.50	1.30	1.90	2.10	1.77
5	2.20	2.70	4.60	3.17	2.10	2.40	3.70	2.73	1.20	1.20	3.10	1.83
6	3.10	5.20	5.70	4.67	2.40	4.70	5.30	4.13	1.90	2.30	2.40	2.20
7	1.80	1.70	3.10	2.20	1.30	0.80	2.20	1.43	1.40	1.60	2.30	1.77
8	8.70	6.10	3.70	6.17	7.40	3.80	2.90	4.70	4.80	4.90	2.60	4.10
9	1.70	2.40	1.20	1.77	1.20	1.60	0.80	1.20	1.40	2.10	1.10	1.53
10	4.10	1.80	2.30	2.73	3.70	1.10	0.90	1.90	1.70	1.60	2.20	1.83
11	2.30	2.40	3.60	2.77	1.90	2.10	3.20	2.40	1.40	1.60	2.10	1.70
Mean				3.22				2.51				2.00
Std Dev				1.35				1.27				0.83

Table E-3. Balance Data at Pretraining Level 8 (Right foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	3.90	3.70	4.20	3.93	3.90	3.70	4.20	3.93	0.70	0.80	0.80	0.77
2	3.10	2.60	3.30	3.00	2.60	1.80	2.20	2.20	1.90	2.10	2.70	2.23
3	4.70	3.70	3.70	4.03	3.80	1.40	1.00	2.07	2.90	3.60	3.40	3.30
4	1.40	1.90	2.40	1.90	1.20	1.70	2.10	1.67	0.90	1.40	1.60	1.30
5	3.30	3.40	3.10	3.27	3.10	1.60	1.20	1.97	1.70	3.20	2.90	2.60
6	1.70	1.90	1.70	1.77	1.70	1.60	1.40	1.57	1.10	1.40	1.10	1.20
7	2.70	2.10	2.40	2.40	2.10	1.60	2.10	1.93	1.90	1.60	1.60	1.70
8	2.60	3.10	3.30	3.00	1.20	1.70	1.40	1.43	2.40	2.70	3.10	2.73
9	2.30	2.80	2.10	2.40	1.40	1.40	1.20	1.33	1.90	2.40	1.80	2.03
10	3.10	3.20	4.10	3.47	1.60	1.60	1.60	1.60	2.80	2.90	3.80	3.17
11	1.80	1.70	1.40	1.63	1.40	1.40	1.10	1.30	1.30	1.20	1.20	1.23
Mean				2.80				1.91				2.02
Std Dev				0.84				0.74				0.86

Table E-4. Balance Data at Pretraining Level 8 (Left foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	3.40	4.10	3.90	3.80	3.40	4.10	3.90	3.80	0.80	1.10	0.90	0.93
2	2.90	2.80	4.40	3.37	2.30	2.60	4.40	3.10	1.90	1.20	0.90	1.33
3	1.70	1.40	2.70	1.93	0.90	0.70	2.40	1.33	1.40	1.40	1.40	1.40
4	5.10	4.70	4.40	4.73	2.70	2.40	2.40	2.50	4.30	4.20	3.90	4.13
5	1.80	1.70	2.10	1.87	1.30	1.20	.90	1.13	1.30	1.40	1.90	1.53
6	1.40	1.40	1.20	1.33	1.40	1.20	1.10	1.23	0.70	0.90	0.90	0.83
7	2.30	2.90	2.40	2.53	2.20	2.70	2.20	2.37	1.20	1.40	1.20	1.27
8	3.80	1.90	4.90	3.53	3.80	1.10	4.70	3.20	.70	1.80	1.90	1.47
9	3.90	2.30	2.60	2.93	3.80	1.20	1.80	2.27	1.60	2.20	1.90	1.90
10	4.10	4.20	2.60	3.63	3.90	3.90	2.20	3.33	1.30	1.70	1.60	1.53
11	1.40	2.70	2.70	2.27	1.20	2.60	1.30	1.70	0.90	1.20	2.40	1.50
Mean				2.90				2.37				1.62
Std Dev				1.02				0.93				0.88

Table E-5. Balance Data at Posttraining Level 2 (Right foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	1.20	1.90	2.30	1.80	1.10	1.90	1.20	1.40	0.80	0.90	2.20	1.30
2	2.70	1.80	3.30	2.60	1.10	1.20	2.20	1.50	2.70	1.60	2.60	2.30
3	5.10	6.20	5.80	5.70	4.10	4.40	3.20	3.90	3.20	4.70	5.10	4.33
4	3.70	3.10	3.60	3.47	1.10	0.70	0.70	0.83	3.70	3.10	3.60	3.47
5	6.80	2.70	4.30	4.60	6.70	.80	3.60	3.70	1.80	2.70	2.80	2.43
6	3.20	3.70	4.30	3.73	3.10	3.60	4.20	3.63	1.20	1.10	0.90	1.07
7	3.40	2.20	2.80	2.80	2.40	1.40	2.60	2.13	2.70	1.70	1.30	1.90
8	2.60	3.20	3.70	3.17	1.90	1.90	2.60	2.13	2.10	2.80	2.90	2.60
9	4.90	4.90	3.60	4.47	2.10	3.60	2.20	2.63	4.70	3.80	2.90	3.80
10	3.80	3.60	4.40	3.93	2.40	3.10	4.10	3.20	3.20	2.10	2.20	2.50
11	5.40	2.10	4.60	4.03	4.70	1.60	2.80	3.03	2.90	1.70	3.90	2.83
Mean				3.66				2.56				2.59
Std Dev				1.07				1.03				1.00

Table E-6. Balance Data at Posttraining Level 2 (Left foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	1.20	2.40	2.60	2.07	0.70	2.30	2.60	1.87	1.10	0.70	0.80	0.87
2	5.10	2.90	3.30	3.77	2.90	2.30	1.90	2.37	4.20	1.90	2.80	2.97
3	2.80	6.20	2.40	3.80	2.30	4.80	2.10	3.07	1.70	4.10	1.70	2.50
4	2.60	2.70	2.70	2.67	1.40	1.40	1.40	1.40	2.40	2.40	2.40	2.40
5	3.60	2.70	2.40	2.90	1.70	.90	2.20	1.60	3.30	2.70	1.40	2.47
6	4.80	4.70	4.60	4.70	4.80	4.60	4.40	4.60	0.80	0.70	1.10	0.87
7	3.20	2.90	2.60	2.90	2.60	2.40	1.90	2.30	2.10	1.70	1.80	1.87
8	2.40	1.90	1.80	2.03	2.10	1.70	1.40	1.73	1.40	1.40	1.40	1.40
9	3.30	2.40	3.30	3.00	3.10	2.10	3.20	2.80	1.60	1.60	1.10	1.43
10	2.90	3.90	2.80	3.20	2.60	3.40	1.80	2.60	1.70	2.20	2.40	2.10
11	4.20	4.40	4.60	4.40	2.80	2.70	3.90	3.13	3.30	3.70	2.70	3.23
Mean				3.22				2.50				2.01
Std Dev				0.87				0.91				0.80

Table E-7. Balance Data at Posttraining Level 8 (Right foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	3.20	2.30	2.70	2.73	3.20	2.30	2.60	2.70	0.00	0.70	0.90	0.53
2	3.10	2.60	2.90	2.87	1.70	0.70	0.80	1.07	2.70	2.60	2.90	2.73
3	1.20	2.70	3.20	2.37	.90	2.10	2.40	1.80	0.70	1.90	2.30	1.63
4	1.20	1.20	0.70	1.03	0.90	0.90	0.00	0.60	0.90	0.90	0.70	0.83
5	3.20	2.70	2.30	2.73	2.90	1.80	1.40	2.03	1.30	2.20	2.10	1.87
6	1.40	0.90	0.70	1.00	1.40	0.90	0.70	1.00	0.40	0.70	0.40	0.50
7	4.60	4.60	5.30	4.83	3.60	3.20	3.70	3.50	2.90	3.40	4.10	3.47
8	1.30	2.70	1.40	1.80	1.20	1.80	0.70	1.23	0.70	2.20	1.40	1.43
9	2.20	2.60	2.10	2.30	1.90	2.30	1.70	1.97	1.30	1.20	1.40	1.30
10	2.70	2.30	3.10	2.70	1.70	1.40	1.70	1.60	2.40	1.90	2.70	2.33
11	1.60	1.60	1.30	1.50	1.60	1.40	1.20	1.40	0.70	0.90	0.80	0.80
Mean				2.35				1.72				1.59
Std Dev				1.07				0.83				0.95

Table E-8. Balance Data at Posttraining Level 8 (Left foot)

Subjects	OSI 1	OSI 2	OSI 3	OSI	APSI 1	APSI 2	APSI 3	APSI	MLSI 1	MLSI 2	MLSI 3	MLSI
1	1.90	0.90	1.30	1.37	1.30	0.70	1.30	1.10	1.70	0.70	0.40	0.93
2	1.30	1.90	1.30	1.50	0.70	1.80	1.20	1.23	1.10	0.90	0.70	0.90
3	4.60	4.90	2.60	4.03	4.40	4.70	2.40	3.83	1.60	1.70	1.20	1.50
4	1.80	2.20	2.40	2.13	0.40	1.10	1.20	0.90	1.80	2.10	2.30	2.07
5	2.10	1.80	1.40	1.77	1.90	1.70	1.30	1.63	1.20	1.10	0.90	1.07
6	3.40	2.40	3.10	2.97	3.20	2.40	2.90	2.83	1.30	0.80	1.20	1.10
7	2.30	1.60	1.90	1.93	2.10	1.20	1.70	1.67	1.40	1.30	1.20	1.30
8	3.20	4.70	2.90	3.60	3.10	4.60	2.80	3.50	1.40	1.30	1.40	1.37
9	1.20	2.70	1.70	1.87	0.40	2.60	.90	1.30	1.20	1.10	1.60	1.30
10	1.60	1.20	0.90	1.23	1.40	0.80	0.40	0.87	0.90	0.90	0.80	0.87
11	2.90	2.80	2.90	2.87	2.60	1.90	1.70	2.07	1.70	2.30	2.60	2.20
Mean				2.30				1.90				1.33
Std Dev				0.94				1.04				0.45

Appendix F

Figures

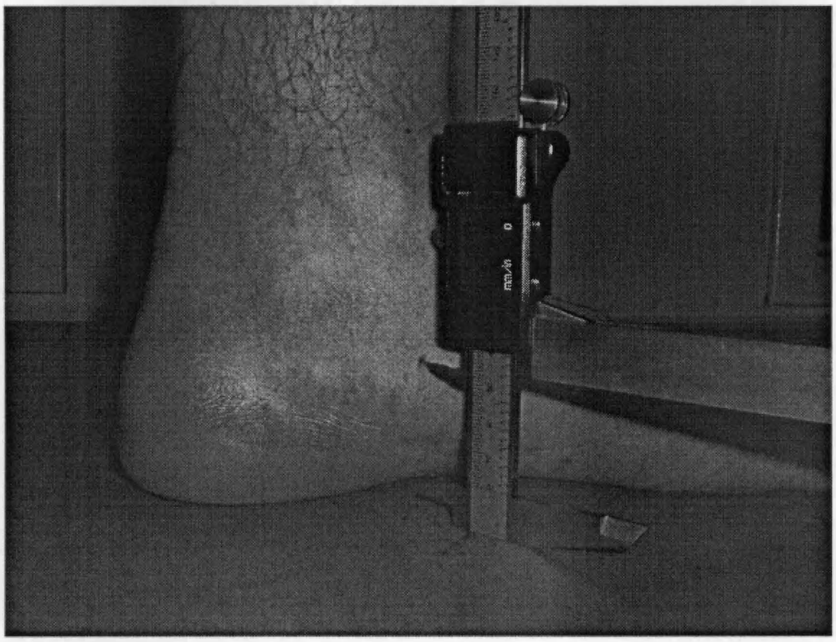

Figure F-1. Digital Caliper

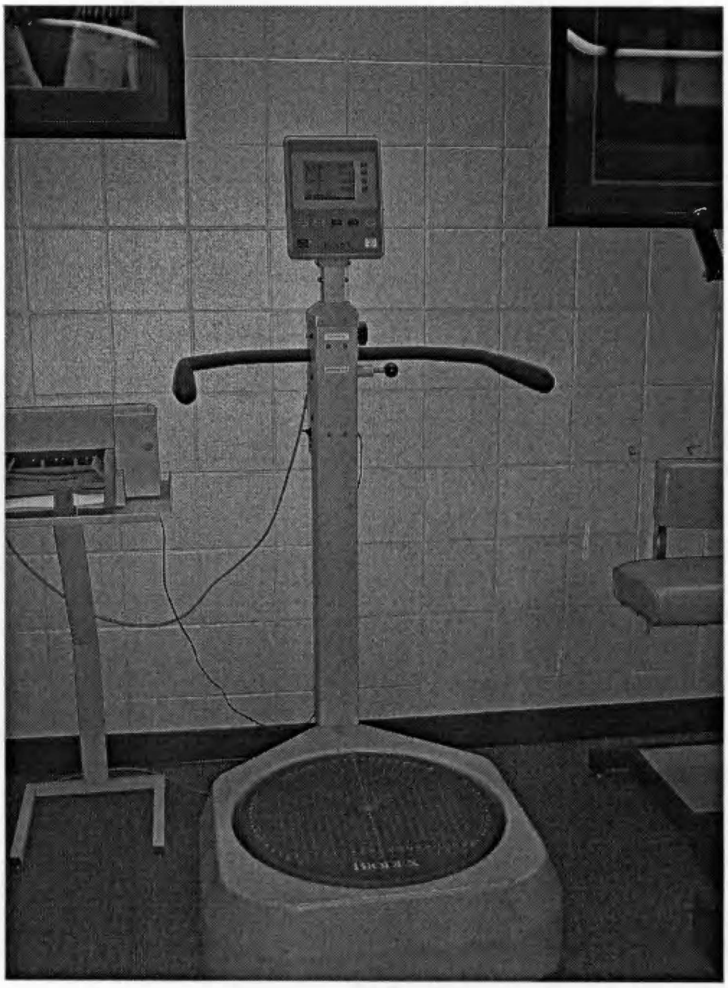

Figure F-2. Biodex Balance System

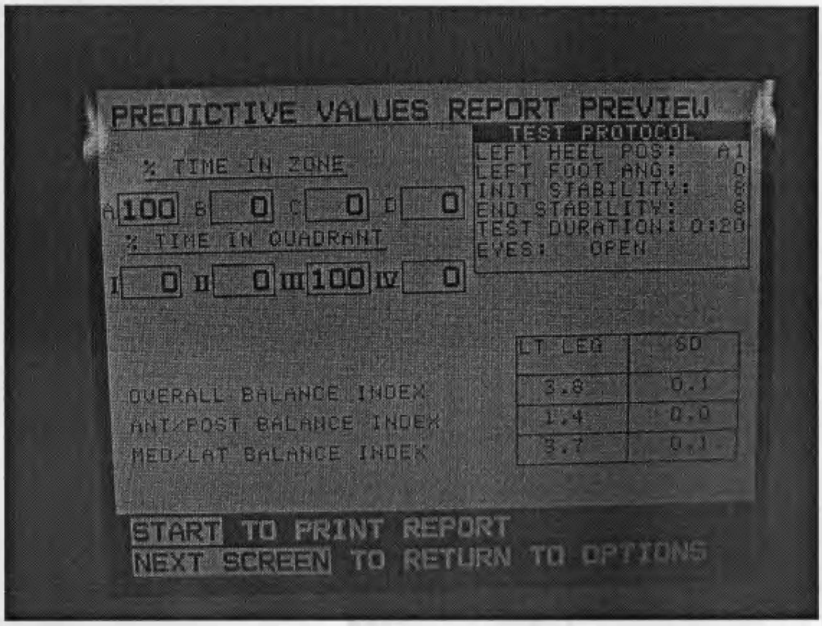

Figure F-3. Biodex Balance System Report Summary

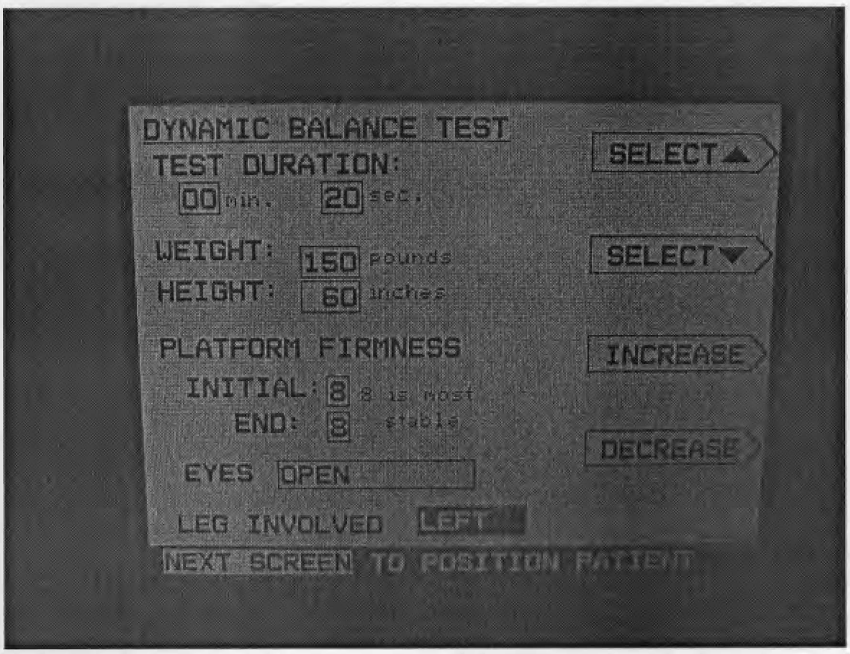

Figure F-4. Biodex Balance System Software

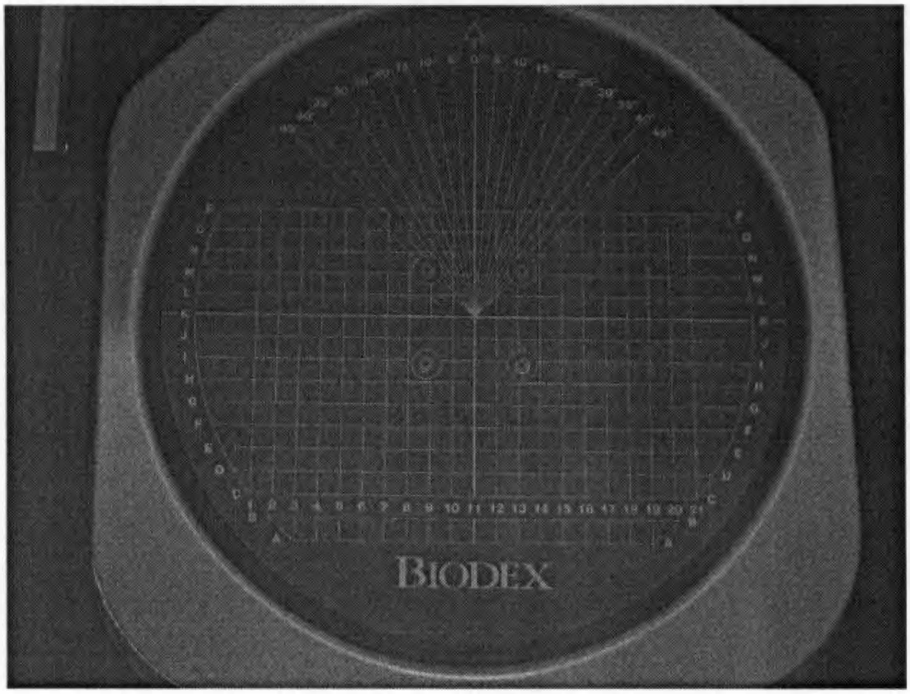

Figure F-5. Biodex Balance System Platform

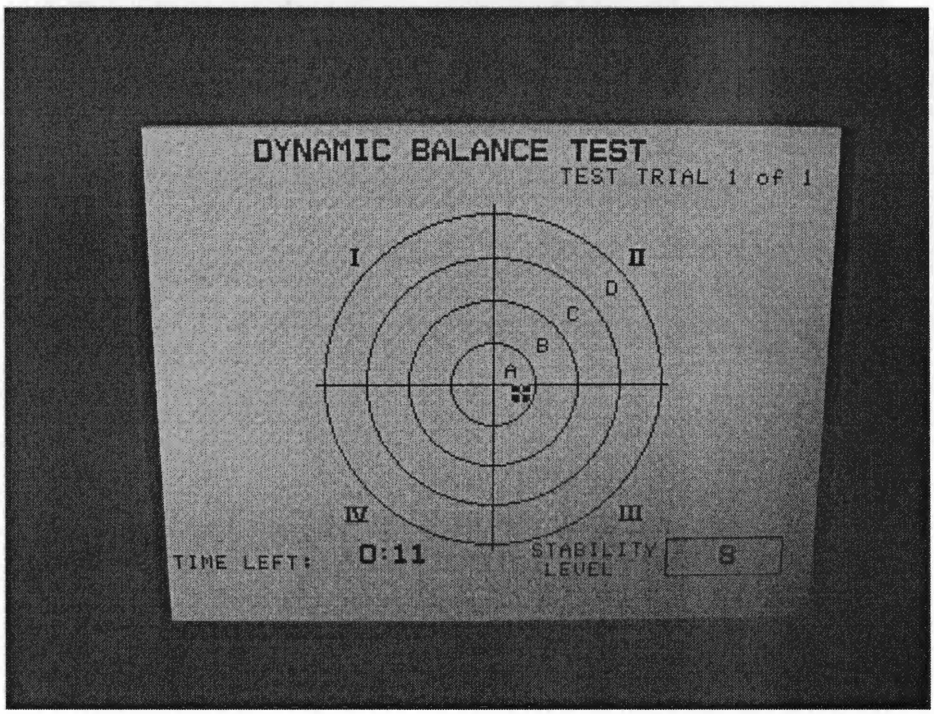

Figure F-6. Biodex Balance System Visual Feedback

Appendix G

Individual Subject Information

Table G-1. Individual Subject Information

Subjects	Age (years)	Body Mass (kg)	Height (cm)
1	25	36.28	157.36
2	24	69.39	172.59
3	23	72.56	162.44
4	30	65.76	162.44
5	21	61.22	164.97
6	35	58.96	159.90
7	19	66.67	175.13
8	27	64.85	171.32
9	29	61.22	177.66
10	23	74.38	190.36
11	22	68.03	167.51
Mean	25.27	63.57	169.24
Std. Deviation	4.63	10.22	9.54

Vita

Ryoko Suzuki was born in Aizuwakamatsu-shi, Fukushima-ken, Japan on May 3, 1977. After graduating from Aizu Girls High School in March, 1996, she attended Springfield College in Springfield, MA, and received a Bachelor of Arts degree in Athletic Training and a minor in Psychology in May, 2001. She received Multi-Year Ambassadorial Scholarship from Rotary Foundation, and in August of 2001, she began her graduate studies in Exercise Science with a concentration in Sports Medicine and biomechanics at the University of Tennessee, Knoxville. She works as an athletic trainer at Tennessee Sports Medicine Group and teaches Yoga and Pilates at Acupuncture & Yoga Center in Knoxville, TN. Upon completion of her thesis, she received the Master of Science in Exercise Science in August of 2004.