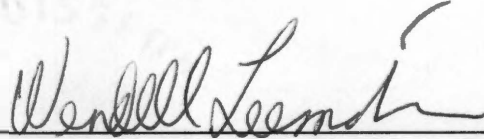


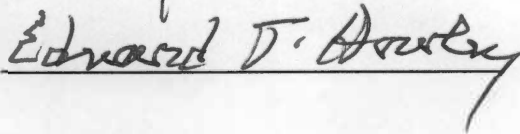
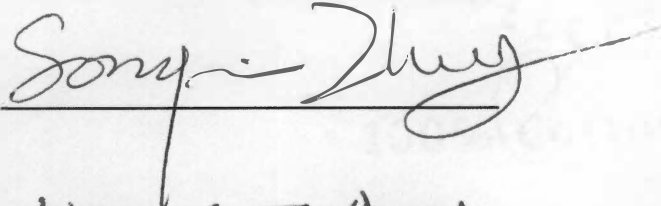
To the Graduate Council:

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.

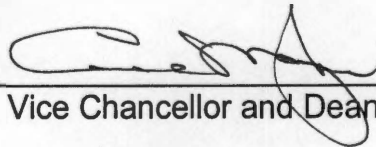


Wendell Liemohn, Major Professor

We have read this thesis
and recommended its acceptance:



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.

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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.

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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 been 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 Hanna¹⁶ supports the contention that plantar sensory feedback may activate the intrinsic foot musculature, which induces intrinsic foot shock absorption. Many articular nerve fibers 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 Hanna¹⁶ 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 authors²²⁻²⁴ 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 McPoil³¹ 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 et 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, Shirley, 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, Shirley, 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.

Hinman⁵² 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 plane (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 height¹² 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, Shirley, 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. Freeman⁴³ 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 nonimpaired 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 Schmitz⁵⁴ 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 Hanna¹⁶ 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 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.

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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			

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

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

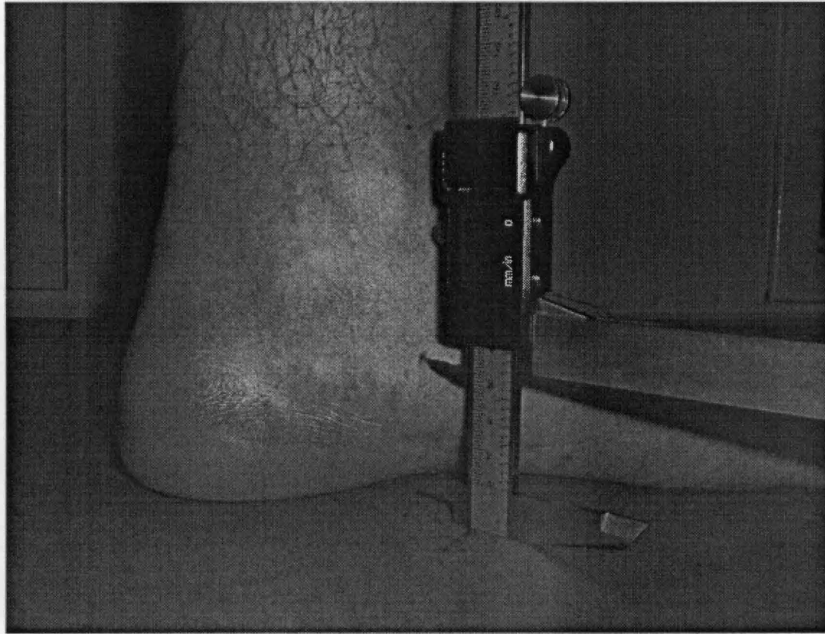


Figure F-1. Digital Caliper

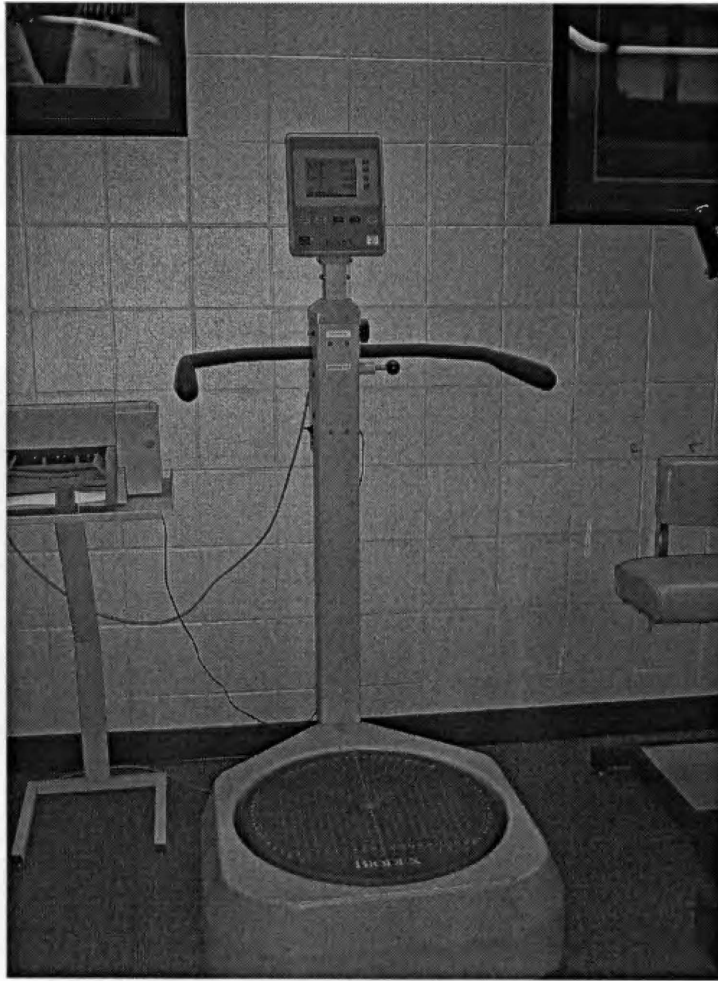


Figure F-2. Biodex Balance System

PREDICTIVE VALUES REPORT PREVIEW

% TIME IN ZONE:
 A B C D

% TIME IN QUADRANT:
 I II III IV

OVERALL BALANCE INDEX
 ANT/POST BALANCE INDEX
 MED/LAT BALANCE INDEX

TEST PROTOCOL
 LEFT HEEL POS: A1
 LEFT FOOT ANG: 0
 INIT STABILITY: 8
 END STABILITY: 8
 TEST DURATION: 0:20
 EYES: OPEN

LT LEG	SD
3.8	0.1
1.4	0.0
3.7	0.1

START TO PRINT REPORT
NEXT SCREEN TO RETURN TO OPTIONS

Figure F-3. Biodex Balance System Report Summary

DYNAMIC BALANCE TEST

TEST DURATION: min. sec. **SELECT ▲**

WEIGHT: pounds **SELECT ▼**

HEIGHT: inches

PLATFORM FIRMNESS **INCREASE**

INITIAL: 8 is most
 END: stable **DECREASE**

EYES

LEG INVOLVED

NEXT SCREEN TO POSITION PATIENT

Figure F-4. Biodex Balance System Software

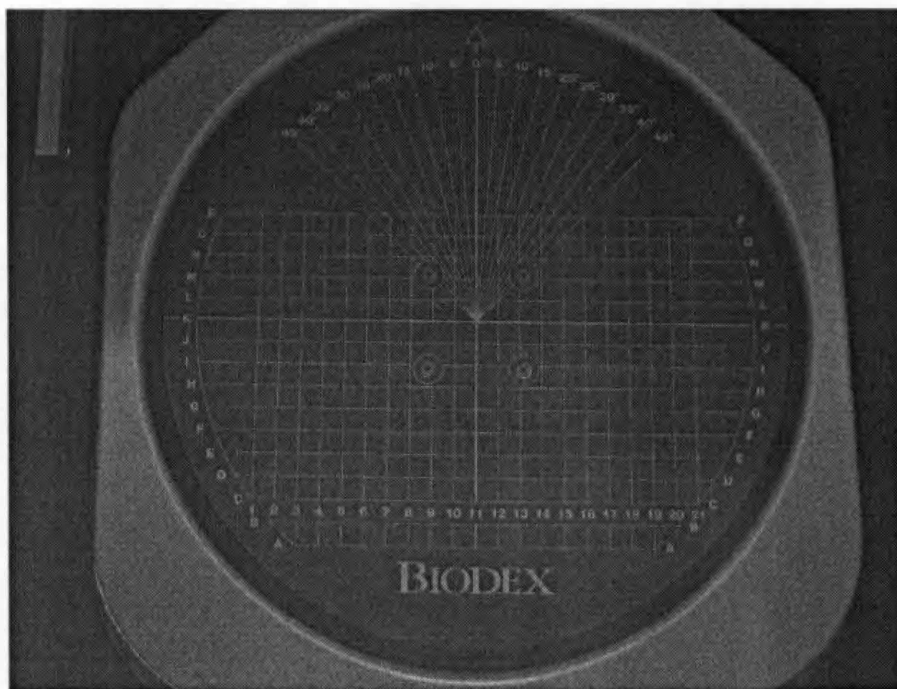


Figure F-5. Biodex Balance System Platform

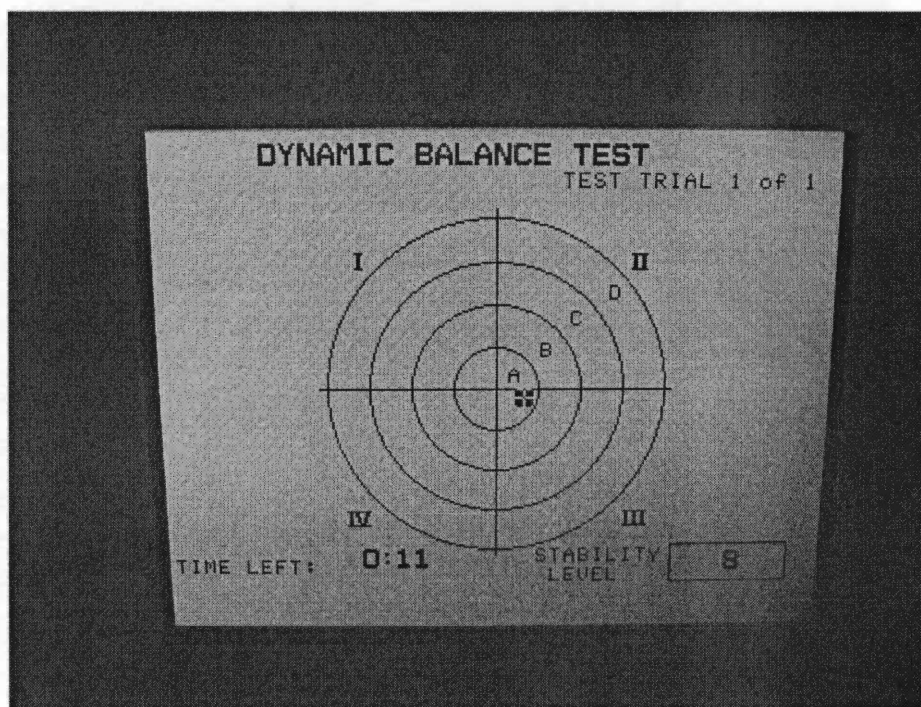


Figure F-6. Biodex Balance System Visual Feedback

Appendix G

Subject	Age	Gender	Height	Weight
1	18	M	175	160
2	19	F	165	140
3	20	M	180	170
4	21	F	170	150
5	22	M	185	180
6	23	F	175	160
7	24	M	190	190
8	25	F	180	170
9	26	M	195	200
10	27	F	185	180
11	28	M	200	210
12	29	F	190	190
13	30	M	205	220
14	31	F	195	200
15	32	M	210	230
16	33	F	200	210
17	34	M	215	240
18	35	F	205	220
19	36	M	220	250
20	37	F	210	230
21	38	M	225	260
22	39	F	215	240
23	40	M	230	270
24	41	F	220	250
25	42	M	235	280
26	43	F	225	260
27	44	M	240	290
28	45	F	230	270
29	46	M	245	300
30	47	F	235	280
31	48	M	250	310
32	49	F	240	290
33	50	M	255	320
34	51	F	245	300
35	52	M	260	330
36	53	F	250	310
37	54	M	265	340
38	55	F	255	320
39	56	M	270	350
40	57	F	260	330
41	58	M	275	360
42	59	F	265	340
43	60	M	280	370
44	61	F	270	350
45	62	M	285	380
46	63	F	275	360
47	64	M	290	390
48	65	F	280	370
49	66	M	295	400
50	67	F	285	380
51	68	M	300	410
52	69	F	290	390
53	70	M	305	420
54	71	F	295	400
55	72	M	310	430
56	73	F	300	410
57	74	M	315	440
58	75	F	305	420
59	76	M	320	450
60	77	F	310	430
61	78	M	325	460
62	79	F	315	440
63	80	M	330	470
64	81	F	320	450
65	82	M	335	480
66	83	F	325	460
67	84	M	340	490
68	85	F	330	470
69	86	M	345	500
70	87	F	335	480
71	88	M	350	510
72	89	F	340	490
73	90	M	355	520
74	91	F	345	500
75	92	M	360	530
76	93	F	350	510
77	94	M	365	540
78	95	F	355	520
79	96	M	370	550
80	97	F	360	530
81	98	M	375	560
82	99	F	365	540
83	100	M	380	570
84	101	F	370	550
85	102	M	385	580
86	103	F	375	560
87	104	M	390	590
88	105	F	380	570
89	106	M	395	600
90	107	F	385	580
91	108	M	400	610
92	109	F	390	590
93	110	M	405	620
94	111	F	395	600
95	112	M	410	630
96	113	F	400	610
97	114	M	415	640
98	115	F	405	620
99	116	M	420	650
100	117	F	410	630
101	118	M	425	660
102	119	F	415	640
103	120	M	430	670
104	121	F	420	650
105	122	M	435	680
106	123	F	425	660
107	124	M	440	690
108	125	F	430	670
109	126	M	445	700
110	127	F	435	680
111	128	M	450	710
112	129	F	440	690
113	130	M	455	720
114	131	F	445	700
115	132	M	460	730
116	133	F	450	710
117	134	M	465	740
118	135	F	455	720
119	136	M	470	750
120	137	F	460	730
121	138	M	475	760
122	139	F	465	740
123	140	M	480	770
124	141	F	470	750
125	142	M	485	780
126	143	F	475	760
127	144	M	490	790
128	145	F	480	770
129	146	M	495	800
130	147	F	485	780
131	148	M	500	810
132	149	F	490	790
133	150	M	505	820
134	151	F	495	800
135	152	M	510	830
136	153	F	500	810
137	154	M	515	840
138	155	F	505	820
139	156	M	520	850
140	157	F	510	830
141	158	M	525	860
142	159	F	515	840
143	160	M	530	870
144	161	F	520	850
145	162	M	535	880
146	163	F	525	860
147	164	M	540	890
148	165	F	530	870
149	166	M	545	900
150	167	F	535	880
151	168	M	550	910
152	169	F	540	890
153	170	M	555	920
154	171	F	545	900
155	172	M	560	930
156	173	F	550	910
157	174	M	565	940
158	175	F	555	920
159	176	M	570	950
160	177	F	560	930
161	178	M	575	960
162	179	F	565	940
163	180	M	580	970
164	181	F	570	950
165	182	M	585	980
166	183	F	575	960
167	184	M	590	990
168	185	F	580	970
169	186	M	595	1000
170	187	F	585	980
171	188	M	600	1010
172	189	F	590	990
173	190	M	605	1020
174	191	F	595	1000
175	192	M	610	1030
176	193	F	600	1010
177	194	M	615	1040
178	195	F	605	1020
179	196	M	620	1050
180	197	F	610	1030
181	198	M	625	1060
182	199	F	615	1040
183	200	M	630	1070
184	201	F	620	1050
185	202	M	635	1080
186	203	F	625	1060
187	204	M	640	1090
188	205	F	630	1070
189	206	M	645	1100
190	207	F	635	1080
191	208	M	650	1110
192	209	F	640	1090
193	210	M	655	1120
194	211	F	645	1100
195	212	M	660	1130
196	213	F	650	1110
197	214	M	665	1140
198	215	F	655	1120
199	216	M	670	1150
200	217	F	660	1130
201	218	M	675	1160
202	219	F	665	1140
203	220	M	680	1170
204	221	F	670	1150
205	222	M	685	1180
206	223	F	675	1160
207	224	M	690	1190
208	225	F	680	1170
209	226	M	695	1200
210	227	F	685	1180
211	228	M	700	1210
212	229	F	690	1190
213	230	M	705	1220
214	231	F	695	1200
215	232	M	710	1230
216	233	F	700	1210
217	234	M	715	1240
218	235	F	705	1220
219	236	M	720	1250
220	237	F	710	1230
221	238	M	725	1260
222	239	F	715	1240
223	240	M	730	1270
224	241	F	720	1250
225	242	M	735	1280
226	243	F	725	1260
227	244	M	740	1290
228	245	F	730	1270
229	246	M	745	1300
230	247	F	735	1280
231	248	M	750	1310
232	249	F	740	1290
233	250	M	755	1320
234	251	F	745	1300
235	252	M	760	1330
236	253	F	750	1310
237	254	M	765	1340
238	255	F	755	1320
239	256	M	770	1350
240	257	F	760	1330
241	258	M	775	1360
242	259	F	765	1340
243	260	M	780	1370
244	261	F	770	1350
245	262	M	785	1380
246	263	F	775	1360
247	264	M	790	1390
248	265	F	780	1370
249	266	M	795	1400
250	267	F	785	1380
251	268	M	800	1410
252	269	F	790	1390
253	270	M	805	1420
254	271	F	795	1400
255	272	M	810	1430
256	273	F	800	1410
257	274	M	815	1440
258	275	F	805	1420
259	276	M	820	1450
260	277	F	810	1430
261	278	M	825	1460
262	279	F	815	1440
263	280	M	830	1470
264	281	F	820	1450
265	282	M	835	1480
266	283	F	825	1460
267	284	M	840	1490
268	285	F	830	1470
269	286	M	845	1500
270	287	F	835	1480
271	288	M	850	1510
272	289	F	840	1490
273	290	M	855	1520
274	291	F	845	1500
275	292	M	860	1530
276	293	F	850	1510
277	294	M	865	1540
278	295	F	855	1520
279	296	M	870	1550
280	297	F	860	1530
281	298	M	875	1560
282	299	F	865	1540
283	300	M	880	1570
284	301	F	870	1550
285	302	M	885	1580
286	303	F	875	1560
287	304	M	890	1590

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.

