THE EFFECT OF FOOT EXERCISE UPON FOOT FUNCTION

AND BALANCE

by

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CHAPTER I

INTRODUCTION AND STATEMENT OF PROBLEM

I. INTRODUCTION

Over the years, the subject of feet has been of interest to people concerned with movement, not only from the standpoint of pathological conditions including pain and malformations, but also from the standpoint of function as a result of evolutionary and environmental trends. Because of the erect characteristics of man, the feet must function to support the entire body weight and help to balance the unstable, tower-like body. During body locomotion, the feet must not only supply the locomotive force, but they must remain the base of support and balance for the body. The vulnerable position of the feet lends itself to stresses and strains of locomotion and body balance. Faulty mechanics of support and movement accentuate the burden placed upon the feet. It, therefore, is highly desirable to have feet which are able to withstand efficiently and effectively the demands placed upon them.

During the past several decades, exercises for the feet have been emphasized in conjunction with exercises for other body parts. Through body mechanics classes in schools, exercise programs in the ladies' magazines, and through the medium of television, the general public has been made aware of various types of exercise, including those specifically for the feet. Exercises designed to strengthen the arch and to "trim" the ankles are two of the most common types.

In physical education classes of body mechanics, much emphasis is placed upon static and dynamic functioning of the feet and legs. Often these classes are concerned with posture training, and with exercises designed to improve and maintain proper body alignment. Exercises for flexibility, strength and endurance are emphasized for all body parts including the feet and legs. Performance of fundamental movement patterns puts exercises into practice through proper use of the body and extremities.

Dynamic functioning of the feet is important in the performance of various skills. Footwork, or the patterned movement of the feet and legs, is of major concern in aquatics, dance and sports activities. In each of these various areas of movement, much time is spent conditioning the performer so that effective use of the feet and legs will result.

The importance of foot strengthening exercises seemed to the author to be an obscure matter. Little research has been done to determine the importance of exercises for the feet in relation to general motor skills, foot structure and foot function. Most foot exercises described in body mechanics and posture books tend to place emphasis upon the building and maintaining of a high longitudinal arch. Also flexibility of the foot and ankle receive major consideration within descriptions of exercises. Those exercises which strengthen the inverter muscles and stretch the everter muscles, thus helping to prevent pronation of the feet, are considered important. The reason is that when the feet are in a pronated position, the weight of the body falls medially and depresses the arch. It is felt that proper exercise will correct the condition, place the weight on the stronger lateral borders of the feet, hence allowing the arched structures to function normally. However, the values of exercises promoting proper foot functioning were not defined for adults having "normal", not pathological, feet.

Therefore, the purpose of the study was to determine whether or not there is a real value for including exercises specifically for the feet in programs of exercise for adults, such as body mechanics classes which may meet twice a week for a semester. The exercise sessions conducted by the researcher consumed the approximate amount of time that would be spent on foot and leg exercises in a normal, one-semester body mechanics class. The factors considered included measures of ankle flexibility, arch angle, strength of the foot and body balance. It was felt that since ankle flexibility, foot strength and body balance are of major importance in performance of motor skills, these would be the criteria upon which to base the importance of foot strengthening exercises.

II. STATEMENT OF PROBLEM

The study was conducted to determine the effects of foot strengthening exercises upon measures of body balance, foot and ankle flexibility, footprint angulation and foot strength. The purpose was to determine the value of the inclusion of exercises for the feet and legs into programs of physical education for adult college women.

CHAPTER II

REVIEW OF LITERATURE

The bipedal characteristics of Homo sapiens present him with many assets as well as liabilities. Man, in his upright standing position, has placed upon two feet the burden of supporting the entire body weight, and at the same time maintaining body balance. The framework of the feet in man has assumed the function that is performed by the entire skeleton in quadrupeds. In the course of evolution, man's center of weight has been elevated to a point above the bony support of the two feet. In order to maintain postural stability, the heels, which correspond to the hind legs of the quadruped, eventually dropped to the ground assuming the function of posterior support.[19]

I. FUNCTION AND STRUCTURE

Anteriorly, the metatarsal bones supply the base of support, a function formerly furnished by the quadrupedal forelimbs.[19] In man the distinct functions of the feet are 1) providing static support for the entire body in standing position by acting as pedestals for the legs[21], 2) providing the required leverage action in raising and propelling the body in motion, and 3) acting as a shock absorber for body action, whether the movement be intended or unexpected.

Structurely, the framework of the foot is composed of twenty-six bones:

seven tarsals, five metatarsals, and fourteen phalanges. The irregularly shaped tarsal bones which are held together primarily by ligaments have the principle function of receiving body weight and transferring it to the other parts of the foot.[21] The talus bone is of key importance; indeed, it is referred to as the keystone of the elastic arched structure, which is the foot viewed in its entirety. As the connecting link between the leg and the foot[27], the talus receives the body weight from the tibia above, and transfers the weight posteriorly to the calcaneus, and anteriorly to the scaphoid (navicular) and cuboid bones. In turn, the scaphoid transmits force to the remaining tarsal bones, the three cuniforms. Finally, the cuniforms together with the cuboid transfer force anteriorly to the metatarsals.[21]

According to Fait[7], the bony structure, depending on how the bones fit together, is the determining factor of foot stability.

> For example, the calcaneus gives the best support to the talus if its contact point with the talus is flat (horizontal) rather than slanting. If it slopes forward and downward, as it does in some individuals, the weight pushes the talus down the slope of calcaneus causing a broken arch or flat foot.[7:101]

However, Morton stated[19] that foot stability depends upon proper weight distribution: one-half to the heel, one-sixth to the first metatarsal and two-sixths to the second through the fifth metatarsals. He further stated that only when the first metatarsal is as long as the second can this distribution exist. If the second metatarsal is longer, it bears an undue amount of body weight.[19]

Holding together the bony structures of the foot are the ligaments. The importance of these tough bands becomes quite evident upon examination of the number present in the foot and ankle. Both the deltoid ligament which is attached to the medial malleolus and the lateral ligament which stems from the lateral malleolus have three bands which fan inferiorly. One band from each goes slightly anteriorly; one, slightly posteriorly; and the other, in an inferior direction. The bifurcated ligament, located on the dorsal foot, is a Y-shaped ligament which goes to the cuboid and scaphoid bones from its attachment at the base of the calcaneus. The medial limb of the bifurcated ligament helps form the socket in the talocalcaneonavicular joint for the talus.

Probably the most important ligament present in the foot is the plantar calcaneonavicular or spring ligament which functions to support the head of the talus, the main bearer of body weight. Attachments for this all-important ligament are from the sustentaculum tali and plantar surface of the scaphoid. The other end blends with the deltoid ligament.

On the plantar surface are the long and short plantar ligaments which together cover the plantar area of the foot from the calcaneus to the bases of the second, third and fourth metatarsals.

In addition to the previously mentioned ligaments, there are dorsal and plantar ligaments which attach to and hold together the heads of the metatarsals.(24)

> The ligaments maintain the relations of the bones as the foot moves to its various extreme positions. These positions vary with the lengths of the ligaments, which have no power of contraction, are not subject to voluntary control and do not stretch appreciably except under continued strain. The muscles of the foot control its motions and flexibility, and supply its power. Their tendons serve not only as attachments, but also as reinforcement for the joints.(9:322)

In the study of the musculature of the foot, consideration must be given not only to the intrinsic muscles, but also to those of the lower leg. These extrinsic muscles and their tendons, because of their attachments on the foot, are the primary foot and ankle movers. In general, the anterior lower leg muscles flex the foot (dorsiflexion) and extend the toes. In walking, they serve to "...elevate the anterior pillar of the longitudinal arch thus preventing 'foot drop' or scraping of the ground as the foot leaves the ground."[(6:195)] Instrumental in foot extension (plantarflexion) and toe flexion are the posterior lower leg muscles. The tendons of two of the muscles, the gastrocnemius and the soleus, fuse to form the Tendon of Achilles which inserts on the tuberosity of the calcaneus. The posterior leg muscles are the primary heel raisers in locomotion such as walking or running, but also serve to stabilize the ankle preventing body weight from falling forward in standing. Muscles which evert and assist in extending the foot are the lateral muscles of the lower leg.

The less important foot movers, the intrinsic muscles, act to move the toes; the dorsal muscle extends and draws the four medial toes laterally, while the plantar muscles flex the toes, and depending upon their attachments, either abduct or adduct the toes from one another.[(6)]

The actions of the foot muscles have an indirect as well as a direct result. Indirectly, they help determine the position of the line of body weight; directly, they act on the joints causing movement.[(50)]

Of all the joints, the ankle joint is the most important and has the greatest mobility. As a hinge joint, its two movements are dorsal and plantar flexion.[23] It is formed where the upper rounded portion of the talus (astragalus) fits into a mortise formed by the lateral and medial malleoli, "...the transverse tibiofibular ligament, the anterior and posterior ligaments of the lateral malleolus, and the interossei..."[27:258] Unlike most joints which are enclosed in continuous membranous capsules, the ankle joint capsule differs in that it is not continuous but is "...reinforced by several strong ligaments."[27:258]

Joint actions exhibited by other foot parts are much less than that of the ankle joint. Very limited gliding actions such as flexion and extension, inversion and eversion, abduction and adduction are characteristic of the tarsal joints. Possibly the greatest degree of motion is present in the talonavicular joint which is a modified, shallow ball-and-socket joint. The joint permits movements around three axes.[28] It has been shown by Hall that in this area around the sub-talar and transverse tarsal joint there is considerable rotation which is important "...when walking over rough ground and maintaining balance generally, particularly when standing on one foot."[48:290] Some believe "...that the movement of this joint has proprioceptive function in the maintainance of balance."[48:290]

The movements of the intermetatarsal joints, non-axial in nature, are gliding movements which function to spread and flatten the arch under body weight, and to return the arch to its normal shape when the weight is removed.

Besides the ankle joint, the greatest movement within the foot is at the metatarsophalangeal joints. The movements of these modified ovoid joints are flexion, extension, and somewhat limited abduction and adduction.[28]

The many and various structures of the foot - the bones, ligaments, muscles and joints - all are interdependent in making this appendage, the foot, one that is structurally and functionally strong.

II. MALFORMATIONS AND DISORDERS

It is not uncommon for most people sometime during their life to experience some sort of foot malfunction or discomfort.[22] Structural deformities resulting from neglected foot weaknesses and usage, improper shoes, inherited characteristics, and from disease frequently give rise to secondary disorders.

Pes planus, commonly called flat foot, describes the condition of a fallen longitudinal arch. The cause is a controversial issue; one opinion is that it is caused by weak muscles[23], while another is that it is caused by loose ligaments.[60] Another condition which involves a fallen arch, the transverse or metatarsal arch, is metatarsalgia. In this condition direct pressure is put upon the luxated bone or on digital nerves resulting in pain. Opposite the malformation of pes planus is pes cavus or claw foot. The longitudinal arch is raised, and the toes are clawed. The condition often occurs after poliomyelitis.

There are several malfunctions of the area around the toes and the adjacent metatarsal heads. Hallus valgus is the marked adduction of the proximal phalanx of the big toe toward the foot mid-line. A bone-joint condition is Kohler's disease marked by a broadened metatarsal head. The metatarsal-phalangeal joint becomes stiff and painful. Hallus rigidus and hallux flexus are conditions affecting the first metatarsal-phalangeal joint. Hallus rigidus is characterized by a stiffness at the head of the first metatarsal. Hallux flexus is a complete stiffness in which the great toe is plantar-flexed.(23)

A varus foot deformity is one in which the first metatarsal is abducted from the other metatarsals making the head prominent on the medial side of the foot. A secondary characteristic of the condition is that the great toe is pushed toward the mid-line of the foot when a shoe is worn.(31)

The most common congenital deformity is clubfoot or talipes. Two types, distinguished by opposite characteristics, are common. Talipes equinovarus is the deformity in which the foot is inverted and plantar flexed. Usually it is stiff and difficult to straighten. In talipes calcaneovalgus, the foot is everted and dorsi-flexed. Its laxness makes it easy to straighten, but the arch tends to remain weak.(9)

Secondary disorders often result from the above conditions. Whether or not they do evolve from structural conditions, they frequently are functional and can be relieved.

The reasons for weak feet are many, and overlap to some extent the reasons for structural malformations.

> The most common causes of weak feet are primarily inadequacies of structure, fatigue, and poor muscle tone (and the contributory factors of illness, infection, malnutrition, and inactivity), injury, overweight, improper footwear, and faulty use of the feet.(25:193)

Additionally, Rubin said,

> ...difficulties of the feet are a more severe problem nowadays because we spend all our time walking on flat surfaces..., so all of the

strains and stresses of walking are absorbed by the same portions of the foot.[54:37]

He continued, "...when too much shock continues to be concentrated in one spot, damage can eventually result."[54:37]

Cureton[40] stated signs of weak feet which can be observed, some of which are calluses on the ball of the foot, bunions, pronation of the foot, bulging scaphoid and medial malleolus bones, angulation of the heel cord, deformed toes and deterioration of skin under the toes.

Calluses on the ball of the foot may be a result of weakened transverse arch,[22] or may arise from wearing high heels and pointed toed shoes.[9] More specifically, a callus may develop beneath the second metatarsal, the reason being a controversial one. Some authorities believe it is caused by the dropping of the transverse arch causing this area to become weight bearing. Other authorities state that it is a result of a longer second metatarsal, making it, rather than the first metatarsal, the weight-bearer.[7]

In their early stages, the calluses are noticeable and tender. The later stages are marked by acute pain and cramps as a result of pressure being put upon tissues, nerves and blood vessels. A somewhat similar condition is Morton's Toe which is more localized to an area back of the third and fourth, or the fourth and fifth toes. The resulting pains are sudden and excruciating.[22]

Plantar warts, when they develop, usually are imbedded in the calluses on the ball of the foot. This location makes their detection difficult.[9]

The most common of all foot troubles are corns caused by pressure and friction, usually by shoes. Because of the pressure on a bony prominence, circulation is poor; therefore, skin becomes hard and thick.[9] This cone-shaped protuberance has no root, but is sensitive because of the pressure it exerts upon the nerves, especially when shoes are worn. Corns which develop between the toes are kept soft by moisture and perspiration.[22]

Another painful foot disorder is a bunion which may accompany hallux valgus. "A callus forms medial to the metatarsal head, and a bursa (bunion) develops between the callus and the bone; the bursa sometimes becomes inflamed or even infected."[9:335-6] Tight-toed shoes, fallen arches, and sometimes gout or rheumatoid arthritis are responsible for bunions. A similar condition which occurs on the little toe is known as Tailor's Bunion.[22]

Both improper shoes and cutting are responsible for another painful disorder, ingrown toenails. To prevent the nails growing into the skin, the nail should be cut straight across, and shoes should fit properly.[22]

Descriptions of malformations and disorders of the foot have not been exhausted, but some of the most common have been presented.

III. MECHANICS

Foot mechanics are dependent upon the structure of each individual foot and the efficiency of its use. Considerable importance is put upon the arched structures, their sources of support, and their functions and various positions under weight-bearing conditions, as well as non-weight-bearing positions.

Viewed from the medial side, the normal foot displays a longitudinal arch which runs from the calcaneus base to the head of the first metatarsal[21], the pillars of the arch. The highest point, therefore, the point subject to most strain because of its weak nature, is the sustentaculum tali-navicular joint.[24] This arch, the most significant arch of the foot, is described as flexible and dynamic, giving with the pressure of each situation and subject to voluntary control.[9] This self-adjusting mechanism has the chief function of propulsion.[24]

Supporting the arch are both muscles and ligaments, the most important one being highly debatable. One argument is that the "arch is maintained by the ligaments which span the individual bones on the plantar surface of the foot."[24:112] Conversely, Hicks stated that the arch can be supported by muscles alone when some muscles function as arch raisers while others are arch supporters.[49] Lewin compromised by saying, "The arch of the human foot is safeguarded and maintained by the reflex postural action of muscles: ligaments being merely second-line defenses."[12:15] He further explained that "when a foot is in action it is supported chiefly by muscles, but when standing it is supported mainly by ligaments."[12:24] Smout made the statement, similar to that of Lewin, that though the ligaments and shape of the individual bones are important, the muscles because of their tonus qualities and adaptability, are chiefly responsible for the arch integrity.[24]

Smith, testing with electromyographic equipment, determined that standing is a series of "...practically static phases of an average duration of 30 sec."[59:161]

> It is therefore believed that during the greater part of each static phase of standing the arched form of the foot is maintained against the force of body weight by a mechanism involving the passive strength of the tissues of the part. The bones, ligaments and fascial bands probably play the major role in this mechanism, but the observations which have been reported do not exclude muscles as passive structures playing a minor part.[59:161]

The lesser arches are the lateral longitudinal arch and the transverse arches. On the lateral side of the foot between the pillars formed by the heads of the fourth and fifth metatarsals and the calcaneum is the lateral longitudinal arch. Its support is by plantar ligaments, but more especially by the peroneus longus.

Pillared by the lateral borders of both feet and supported by transverse plantar ligaments, the transverse head of adductor hallucis, and mostly by the tendon of peroneus longus is the transverse arch.[24] This arch can best be seen when the feet are together since the complete arch spans from the lateral border of one foot to that of the other.[23]

> Although the arches of the foot are described as consisting of three parts it should be borne in mind that for all practical purposes the foot consists of one arch since the failure of any part of the arch leads to the collapse of the foot as a whole.[24:114]

At one time it was popular opinion that a high arch was indicative of a strong, efficient foot. However, studies have shown that this is not true. Clarke wrote that Cureton found that the height of the arch determined by the footprint angle or sandbox method did not indicate functional efficiency of the foot.[3] According to Rathbone, "...there seems to be no direct relationship between height of the arches or dome and weakness of the foot, or pain symptoms."[21:16] Wells stated that a low arch does not indicate a weak one unless it is associated with a pronated foot.[27] In summary, therefore, "integrity of structure and function are not necessarily identical. A perfectly normal looking foot may not function normally, and conversely an imperfect looking foot may give a perfect performance."[12:24]

The position of the feet in a weight-bearing situation is of importance because, structurally, some parts of the feet are much more capable of withstanding the stress of the body weight and the shocks of locomotion. Also, in correct position, the arches serve to protect from pressure the soft tissues containing plantar nerves and vessels.[23]

Morton stated that the normal stance is an out-toeing position of thirty degrees.[19] Conversely, however, others have declared that the feet should be parallel, or only very slightly toeing outward.[25] The weight should be borne by the outer borders of the foot.[24] The legs, by rotating the knees laterally, assist in putting the weight on the outer borders while simultaneously raising the arches.[13] In addition, the actions of the muscles are dependent upon where the body weight is centered within the base of support. This weight center should fall approximately half-way between the heels and the balls of the feet.[25] Hicks found that the muscles which helped establish a balance point functioned to produce an arch flattening effect when weight shifted either medially or anteriorly. When this situation occurs, the stress must be taken by beam or arch mechanisms.[50]

Pronation and supination are two weight-bearing positions which deviate from the normal. Pronation, characterized by inward rolling of the ankles, is often accompanied by involuntary abduction of the forefoot, eversion of the soles, inward hip rotation, and out-toeing (or occasionally in-toeing). This abnormality, directly caused by weak muscles, ligaments and inadequate bony structure, results in the weight being thrown medialward and the ankles being depressed.

Supination, the counterpart of pronation, is noted by the outward rolling of the ankles accompanied by adduction of the forefoot, inversion of the sole, and outward hip rotation. The body weight is thrown laterally.[25]

In addition to the described mechanics of the foot in a weight-bearing situation, the mechanical action of the plantar aponeurosis, a ligamentous structure covering the plantar surface of the foot, is important in walking. Hicks summarized this action as follows:

> 1. The plantar aponeurosis at its distal end is attached through the plantar pads of the metatarso-phalangeal joints to the proximal phalanges. The attachment is mechanically very strong.
> 2. When the toes are extended they pull the plantar pads and hence the aponeurosis forward around the heads of the metatarsals, like a cable being wound on to a windlass. The arch is caused to rise because the distance between the metatarsal heads and the calcaneum is thereby shortened.
> 3. The toes are forced into an extended position in toe-standing and walking by the action of body weight, the arch is caused to rise by this ligamentous mechanism without the direct action of any muscle.[49:30]

Non-weight-bearing movements and positions include dorsal and plantar flexion, abduction and adduction, outward and inward rotation, and inversion and eversion.

Dorsal and plantar flexion occur in a sagittal plane around a frontal axis. In dorsal flexion the sole of the foot is pulled upward. Limited dorsal flexion may be indicative of weak and painful feet.

Foot movements in a horizontal plane on a vertical axis are abduction, adduction, and outward and inward rotation. Initiated within the foot, the movement of abduction is within the tarsal joints. While the sole remains parallel with the floor, the anterior part of the foot swings laterally. Rather than being a useful movement, it is one which occurs when the medial ligaments and muscles are weakened and stretched. Adduction is the counterpart of abduction, and is marked by a medial flaying of the forefoot. "This also is less a useful voluntary movement than a position into which the feet are forced if the ligaments of the medial border of the feet are abnormally contracted."[25:187]

Outward and inward rotation, lateral and medial rotations of the whole foot with the sole parallel to the floor, are movements which are hip-joint initiated.

In the frontal plane on the horizontal sagittal axis, the movements inversion and eversion take place. Inversion describes a movement of the tarsal joints which causes the sole of the foot to face medially, while eversion, the counterpart of inversion, causes the sole to face lateralward.[25]

IV. MEASUREMENTS

Flexibility

Flexibility of the ankle is usually divided into two component parts, plantar and dorsal flexion. Plantar flexion normally ranges from approximately 35[12] to 60[25] degrees when measured from an initial starting position of the foot at a 90-degree angle to the leg. Dorsal flexion ranges from 10 to 20 degree in the normal foot beginning in the same starting position.[12] [21] [25]

Several methods have been devised for measuring ankle flexibility. Mathews[17] described the procedure using a Leighton flexometer. The total range of flexibility was noted by locking the dial of the flexometer at one extreme of the flexion arc, and by locking the pointer at the other extreme. Precautions during testing included keeping the knee of the limb being tested straight, and allowing no sideward turning of the foot.[17]

Kelly[52] measured ankle flexibility with a goniometer, a protractor-like instrument with a stationary and a movable arm. The goniometer was placed so that the joint of the arms was at the medial malleolus, the stationary arm secured on the knee, and the movable arm on the head of the first metatarsal. The total range of flexion was the difference between the flexion and extension scores.[52]

Lewin[12] described the measurement of ankle flexibility using Conwell's flexo-extensometer, which looks like a goniometer. The attachment points and scoring methods were also similar to those of the goniometer. Pohndorf[64] also described a similar method by using a protractor made of clear Lucite.

Strength

Several devices have been used for testing foot strength, including the dynamometer, tensiometer and spring balance.

The dynamometer is a graduated scale which measures the pounds of force exerted during movement. A dial indicates the pounds of force being exerted, and a maximum indicator remains on the spot recording maximum effort by the subject.(16)

The Martin Test measures breaking strength using the dynamometer. To the dynamometer a leather loop is attached to one end, while a handle is attached to the other end. The loop is placed around the foot. The tester pulls the handle until the subject gives way after resisting as much as possible. The test has specific directions for measuring strength of the muscles which plantarflex, dorsiflex, invert, and evert the foot.(14)

Another testing device is the tensiometer which measures "...the pulling force on a cable."(16:56) As the cable becomes more taut, it depresses a mechanism which is attached to a dial indicating the amount of force. As in the dynamometer, there is a maximum indicator.(16)

Clarke(36) (38) (39) devised strength tests using the tensiometer including directions for the places of cable attachments, direction of pull, and position of the subject. Tests of muscles causing dorsal and plantar flexion, eversion, and inversion were described.

Kelly(52) described testing supinator and pronator strength with a spring balance. With the band placed perpendicularly to the longitudinal axis of the foot, supinator and pronator strength were measured in pounds on the spring balance. The score was obtained by subtracting pronator strength from supinator strength. A positive score indicated stronger supinators.(52)

Clarke(35) found the cable tensiometer to be more precise than other instruments for measuring muscle strength. "The objectivity coefficients for the tests obtained with the tensiometer varied between .90 and .95."(35:398) He explained the term "objectivity coefficients" as being "...coefficients of correlation obtained from correlating test-retest results utiiizing different testers."(35:398)

Foot Contour

Using a pedograph, a machine for recording footprints, an evaluation of the weight-bearing surface of the foot can be made. Clarke's Footprint Angle is used to measure the height of the longitudinal arch using the footprint. One line is drawn from the border of the imprint of the calcaneous to the head of the first metatarsal. The second line is from the point of contact of the first line and the metatarsal head to "...the point just touching the edge of the print on the inside of the arch."(17:193) The angle at the junction of the two lines is measured by a protractor.(17)

The pedorule, another foot evaluating device, is used "...to measure the position of the foot in relation to the leg."(16:267) Therefore, it measures the amount of deflection from a straight line made by the tendon of Achilles.

Truslow's Foot Ratio is the ratio of arch height to foot length, and is used to determine functional efficiency of the foot.(16)

Balance

Balance is usually thought of in terms of its two components, static balance and dynamic balance.

McCloy(14) defined static balance as the type in which the movements, and the adjustments to the movements, are small. The examples he gave for the circumstances requiring static balance are walking the tight wire or balance beam. Willgoose, narrowing the concept, defined static balance as "the ability to maintain a specified position. . . "(29:249)

Dynamic balance indicates ". . . steadiness and stability in leaping from one spot on the floor to another."(14:106) It is also described as maintaining a certain posture during movement.(29) McCloy(14) suggested that the elements involved in balance were the same for both static and dynamic, but to different degrees. In physical activities, balance probably depends upon:

> (1) Kinesthetic responses, both sensory and motor. These responses are probably compounded physiologically of both joint sense and muscle sense. Since they seem always to work together, however, they appear in analyses as one element.
> (2) Visual response, or the aid that is obtained from the eyes.
> (3) The semicircular-canal system. The part that the semicircular canals play in the finer forms of balance is still an unanswered question. There is some statistical evidence to indicate that these canals, with the ampullae, function separately as well as together in certain forms of balance.(14:103)

Composing the labyrinths of the inner ear are the cochlea, sacculus, utriculus, and semicircular canals. The functioning of the sacculus and utriculus is affected by the static equilibrium of the head and body in relation to the pull of gravity. Hence, they function to determine up and down. These tiny chambers have end organs which are in contact with sensory nerve fibers. Inside each chamber is a cluster of otoliths, ear stones, which are composed of a calcium carbonate concentration. Any altered position of the head causes the otoliths to stimulate the hair-like nerve fibers causing a sense of imbalance. This phenomenon is aided by vision.

The semicircular canals are six in number- three in each labyrinth. One canal in each labyrinth lies in one of the three spatial planes. The fibers of the eighth cranial nerve, which are connected to the canals, are stimulated by the movement of the fluid within these structures. This motion produces a consciousness of the imbalance and also signals the reflexes to adjust it.[(2)]

Willgoose described three tests of balance, two of which concern static balance while the other is a measure of dynamic balance. The divers stance is a test in which the subject closes his eyes, and stands on his toes for twenty seconds. In the squat stand, the subject squats, places elbows against the medial knee surfaces, leans forward raising feet off the floor, and holds the position ten seconds. The test of dynamic balance is one of dizziness recovery in which the subject walks a straight line after turning around his finger on the floor.[(29)]

The Springfield Beam-Walking test, developed by Seashore, measures the ability to maintain balance when walking beams of various widths. The apparatus includes nine oak beams, each ten feet long, four and one-half inches from the floor, and ranging in width from four inches to one-half inch. Each beam is marked in quarter lengths. The subject, hands on hips and starting at a specified mark, must take ten steps without falling off, stepping crosswise, or taking hands from hips. If any one of the faults is committed, a second chance is given starting at the point where the mistake occurs. The quarter of the beam the subject is in when the second fault is committed is noted. The score is obtained by scoring one point for each quarter on each of the nine beams.[57]

Two additional tests of balance are the Bass Stick Test for testing static balance and the Bass Test of Dynamic Balance, or the stepping stone test. In the stick test, the subject stands with one foot lengthwise on the stick which is one inch high, one inch wide and twelve inches long. The number of times the subject steps off within a one-minute period is recorded. The same type recording is made with the subject standing with the foot crosswise on the stick.

In the Bass Test of Dynamic Balance, the subject must leap into each of ten circles laid out on the floor, land on the ball of the foot, and remain in each circle at least five seconds. One penalty point is scored each time any one of the errors is committed. The errors are: touching the heel to the floor, moving the foot while in the circle, hopping on the foot in the circle (error for each hop), touching the floor outside the circle, touching the floor with the other foot, and touching the floor with any other part of the body.[14]

V. EXERCISES FOR THE FEET

The function of the muscles in aiding the other foot structures in the maintenance of strong, healthy feet is an important one.

Mechanically, the actions of the muscles can be determined by their positions and directions at the joints they cross. With regard to the muscles of the arch, any muscle crossing over the axis of a ray joint will have a flattening effect, while any muscle crossing beneath the axis of a ray joint will have a raising effect on the arch. The muscles crossing beneath the joint can be overcome or stretched by a large arch flattening force such as a balance point which is forward, in which case the arch is subject to strain.[50]

Sheffield[58] in an electromyographic study of foot muscles found that those muscles on the posterior part of the leg and on the plantar surface of the foot were the main plantar flexors; and, the anterior leg and dorsal foot muscles were active during dorsal flexion. The tibialis posterior passing obliquely from the lateral posterior side of the lower leg to the medial and plantar surface of the foot[6], aided by the flexor digitorum longus, supinates the foot. Pronation is caused mainly by the peroneus longus[58] which passes from the lateral side of the leg, under the lateral border of the foot, to the base of the first metatarsal.[6]

In the same study, Sheffield found that all the above muscles were active when balancing on one foot, and that when standing on toes with heels elevated, there was little or no activity for the extensor muscles.[58]

Cureton[40] emphasized the fundamental importance of the condition of the muscles which supinate the foot, counteracting the tendency of the foot to pronate.

In order for the feet to be strong, healthy, and to function efficiently, they, just as any other body part, must receive attention. Exercise is only one suggested method for both prevention and correction of weak musculature and faulty mechanics.

The line of demarcation between normal and weak feet is not clear-cut, except perhaps in the absence or presence of pain. Distinctions between preventive and corrective approaches are also often unrealistic. Many of the basic principles for improvement or correction are also valuable when applied in prevention of incipient cases. These principles include removal of cause if still present, rest- including use of supports, teaching correct foot mechanics, improvement of muscle tone and strength, and selection of proper footwear.[(25:200)]

Daniels specified purposes of exercises, including those exercises for maintaining foot flexibility, improving muscle tone for effective foot mechanics, "...and especially are they aimed at maintaining the longitudinal and transverse arches."[(4:332)]

Both preventive and corrective strengthening exercises stress raising the medial borders of the foot (the longitudinal arch) and also placing body weight on the lateral borders. Not only are they executed in weight-bearing positions, but also in non weight-bearing positions. Corrective exercises, in particular, are begun without the added strain of body weight. As the muscles become stronger, weight gradually is added until the feet support the entire body weight during exercise.

Several precautions should be taken into consideration during the administration of foot exercises. Any exercise which requires rising on the toes should be executed with feet inverted to prevent plantar stretching. The reason is that the action strengthens and shortens the gastrocnemius and soleus muscles thus forcing more weight on the balls of the feet. The plantar structures tend to stretch allowing the arches to fall. However, if the foot is inverted, plantar stretching is prevented.

Care in the "curl toes" exercise must also be taken. If the foot is flexible, the distal end of the first metatarsal will be thrust upward. It should remain down in position to be the main front bony support.

> If the exercise of inversion is used to cause development of the posterior tibials, the anterior tibial which is a synergist and also acts in inversion may be made stronger, so that its supinating action further flattens the arch.(13:175)

The best exercise for keeping an inverted position and the weight on the outer borders is the outward rotation of the thighs, the reason being that the outer leg rotators are stretched when the feet are pronated and the arch is depressed. During this exercise, the big toe should be kept on the floor.[13]

VI. RELATED RESEARCH

Flexibility

Research data relating flexibility of the foot and ankle to the function and structure of the foot in general are very limited. Cureton[41], after testing foot efficiency in several locomotor skills, flexibility, strength, and balance, found a correlation of $.014 \pm .066$ between flexibility at the ankle and the angle of the arch.

Lawrence[63] concluded after studying flexibility and stability of feet that there was no significant relationship between the two measures on the same foot. Further conclusions were that heavier subjects tended to show more flexibility and stability than did lighter subjects. Also, long, narrow feet tended to be more flexible than wider feet.[63]

Strength

In a study conducted on fifty-one seven-year-old children, Rarick and Thompson(55) found that the correlation between ankle extensor strength, as measured by Clarke's cable tension method, and leg muscle size in boys ranged from .58 to .63, and in girls, .22 to .52. The mean extensor strength for boys was 83.41; for girls, 77.48.(55)

Kelly(52), who also conducted a study on children, found no differences at the 2% level of confidence among normal, pronated and painful feet regarding supinator, pronator and toe flexor strength in relation to body weight.

In studies concerned with the relationship of foot strength to arch height, there is some controversy, although most of the evidence is that there is no significant relationship. The data of a study on children's feet by Kelly

> ...did not show pronated and painful feet to be muscularly weak feet. The data question the value of routine use of foot strengthening exercises in the treatment of pronation. Perhaps a test of muscle strength is justified as one basis for determining the type of treatment for disaligned feet.(52:306)

Bressler(33) reported that there is not necessarily an accompaniment of impaired function of weak feet to a flat foot condition. In relating the arch angle to foot strength, Cureton(41) reported that according to Elbel and Gruenberg, there was insufficient relationship. However, Cureton(40) quoted a statement in a later study by F. L. Meredith saying that

> "...flat foot means only weak feet, the weakness being of an entirely preventable sort. Because the foot is weak, it is both flat and inefficient. The weakness is a general weakness of all the muscles and ligaments of the foot and of the muscles of the leg that govern foot motion."(40:369)

Refuting Morton's theory that flatfootedness is caused by improper balance which occurs when the second metatarsal is longer than the first, Fox(45) conducted a study using two groups of college women. One group showed no marked difference in the length of the first and second metatarsals, while the other group did exhibit marked differences. Foot function was evaluated by three tests, vertical jump, toe flexor strength and a bounce test. She concluded that the relationship between foot function and shortness of the first metatarsal was insignificant. In addition, she found that "angle of walk and hallux valgus are only very slightly related to shortness of the first metatarsal."(45:285) Deviations which appeared definitely to be related to pronation were carrying body weight on the medial side of the foot, and prominence of the scaphoid and medial malleolus.(45)

Contour

Several studies and research projects have been conducted attempting to determine what, if any, significance the weight-bearing surface of the foot has in tests of performance, under various conditions.

Rogers(65) obtained low correlations when the weight-bearing surface of the foot was compared to performance on the standing broad jump and fifty-yard dash. He suggested that, in order to overcome the variables of nutrition, rest, sleep, athletic experience, mental attitude and maturation, the same tests should be given over a period of time so that increase in performance could be compared with increased weight-bearing foot surface.(65)

In a study to determine the effect of body weight on the contour of the plantar surface of the foot conducted by Bressler[33], 4,322 college men were examined. Of these, 2,648 were considered having normal feet, while 1,674 had some degree of flat footedness. He found that there was an indication of a positive relationship between flat feet and body weight.

> Not only was the flat-footed group heavier than the normal group, but the evidence indicates that flat feet may vary directly with weight, the greater the weight the greater the percentage of flat-footed subjects.[33:112]

Bressler further stated that Morton inferred a relationship between the two variables, flatfootedness and body weight. However, he recognized Morton's treatise emphasizing the cause of flat feet being a deficient first metatarsal bone.[33]

Clarke[37], using the prints obtained from the pedograph, devised a method of determining arch height by calculating the footprint angle. He established a set of norms for average college men which showed an angle of 42 degrees for the average, 30 to 35 degrees for border-line cases, and below 30 degrees for the ones who needed foot correction. Within the report of his study Clarke wrote: "As flat feet are strengthened, arch-angles increase steadily. An arch angle of 15^{o} at the beginning of treatment and 35^{o} at the end represents a distinct improvement in the foot."[37:107]

Cureton[41] determined the validity of Clarke's footprint angle by comparing it to the vertical depth of the imprint of the arch in moist sand. The correlations on two sets of data were $.857 \pm .016$ and $.958 \pm .007$. Mathews[17] condensed the results of Cureton's study as follows:

Of the 600 men tested, Cureton reported that 150 had arch angles under 21 degrees and only four or five men complained of pain. Apparently the height of the longitudinal arch does not represent either strong or weak feet. Actually, on the basis of Cureton's findings, the footprint angle serves no other purpose than to motivate the pupil in directing attention to the feet.(17:194)

Danford(42), measuring with a pedorule, found a coefficient of .30 between pedorule and pedograph measurements. He quoted Williams as saying:

> "The swelling and fullness along the inner side of the foot are accompanied by a bending inward of the tendon of Achilles. In the normal foot the tendon of Achilles makes a straight line, but in a weak foot the lower end appears to be deflected outward."(42:45)

Danford concluded that measurements of the pedorule are more valid than the pedograph for classifying those with faulty feet into correction groups.(42)

Balance

In a study of factors in motor educability, McCloy(53) listed balance as one of the sixteen factors. The functions of balance depend upon the factors involved which include contribution of the eyes to balance; usage of the eyes when the movement is back and forth, as when standing on a narrow beam crosswise; usage of the eyes when balance involves motions sideways, as when a beam runs lengthwise to the foot; kinesthetic sensitivity; the balance mechanism of the two vertical sets of semi-circular canals; the balance mechanism of the horizontal semi-circular canals; and, "'tension giving reinforcement'"(53:35), which is "...the result of a heightened sensitivity of the balance mechanisms brought on by the increasing tension on the sole of the foot."(53:36) This last factor, McCloy said, needed "...further confirmation."(53:36)

Estep[44] wrote that studies indicated that the slight movements of static balance had little effect in causing the labyrinth to function, but that the major role in the control of body sway was performed by the receptors in the ankle joints. The factors which influence static equilibrium are "...vision, shoes, foot position, apprehension and distraction, and attention."[44:6] She stated there was little improvement of static balance due to practice. From the results of the study, Estep concluded that there "...is a positive relationship between static equilibrium and ability in gross motor activities."[44:14] A 1% level of confidence was reported for the positive relationship to the sport motor ability group, while a 5% level of confidence was reported for the positive relationship to the rhythm motor ability group.[44]

Bass[32], using tests previously described, analyzed intercorrelations of the tests "...to determine the different factors concerned in each test of the battery of tests studied, and in the function of balance as a whole."[32:33] She concluded that balance is dependent upon a number of different factors, one of which is the function of the eyes. Other factors include those which do not relate to vision.[32]

Espenschade[43] studied dynamic balance using a group of fifty-eight boys who were given the Brace Test semi-annually for a period of four years. The results showed that there is a decrease in the rate of motor ability growth at the time of puberty, and that "...it is reasonable to believe that balance may be less stable at this time and that a decrease in rate of growth in this ability should occur in adolescence."[43:274] It was also concluded that height and weight are not related to dynamic balance, but that dynamic balance does relate to abilities important in the physical education program.[43]

VII. CONCLUSION

The human foot functions to support the body weight and to help maintain balance. While it is true that the function depends upon the foot structure, it is also true that the foot structure depends upon function. Many variables enter into the analysis of the function-structure relationship some of which are body weight, the location of the center of the weight, usage of the foot, muscle attachments, effects of disease and malformations, foot flexibility and muscular development.

CHAPTER III

PROCEDURE

I. SELECTION OF SUBJECTS

Subjects were selected at random from the freshman class of 1963 at The Woman's College of the University of North Carolina. In order to facilitate testing and the administration of the exercise program, all subjects were obtained from one living unit of a freshman residence hall. At the initial meeting of the subjects, the girls were informed about the study in general: the types of tests to be used, the exercise program, and the amount of time that would be involved on their part for testing and exercise. Those who were interested and who found it feasible to do so were asked to participate. Of the subjects who indicated willingness to participate, four were unable to complete the test, and one moved to another dormitory during the exercise program. The data in this study, therefore, relate to the thirty-two subjects who completed the testing-exercise program.

II. TESTS AND ADMINISTRATION

Foot and Ankle Flexibility

The Leighton Flexometer was used to test foot and ankle flexibility. The subject was instructed to remove the right shoe and to sit in a designated chair. She was then instructed to stretch her right leg across another chair placed in front of her, and to extend her foot beyond the edge of that chair. The test administrator strapped the flexometer on the medial side of the foot. The strap of the instrument was placed as far up the foot toward the ankle as possible, and was fitted securely to prevent slipping. The test administrator made certain the subject's knee remained extended by manually holding it in place. The subject was then instructed to flex her foot toward her knee as far as possible. The dorsal flexion reading was recorded. The subject was then instructed to extend her foot toward the floor as far as possible. The plantar flexion reading was recorded. The total amount of ankle flexion was obtained by subtracting the dorsal flexion reading from that of plantar flexion.

Foot Contour

Each subject's footprint was obtained by using Dr. Scholl's Pedo-graph machine and paper designed for the machine. The subject was instructed to place the heel of her right foot (barefooted) against the edge of the machine. Then she was instructed to firmly place her body weight on her right foot. The footprints were evaluated in terms of the footprint angle as devised by Clarke.[16]

Foot Strength

To determine foot strength, the amount of force exerted on a cable tensiometer, model T5-6007-117-00, was recorded. The readings were converted to pounds using the provided tensiometer scale for a No. 1 riser with a 1/16 inch cable. (See Appendix for the interpolated conversions.)

The subject was instructed to remove the right shoe, and to sit on the examining table. The table used had a rectangular hole, 20x7 inches, into which the subject was instructed to put her right lower leg. The joint of the knee was at the edge of the hole. The subject's left leg was extended on the table in front of her and beside the hole. Her arms were folded across her chest. Attached to the subject's foot around the metatarsal heads was a leather strap. Slipped onto the strap was a 1/16 inch cable with a hook on the opposite end. The attachments on the table included three aluminum clamps- two 2-inch clamps and one 1-inch clamp. To each clamp was connected four links of chain into which the hook on the cable could slip. The 2-inch clamps and chains were attached to a wooden table support directly beneath the subject's foot, and to a wooden support perpendicular to the leg. The 1-inch clamp was connected to an iron pipe which spanned the hole, and which was positioned above the subject's foot. For each strength measurement being conducted- dorsal flexion, plantar flexion, inversion and eversion- the hook was slipped into the segment of chain which put the foot into its preliminary position. The chains facilitated adjustments for the various lengths of feet and legs among the subjects.

To measure dorsal flexion strength, the cable was attached to the chain directly below the subject's foot. The foot was in a relaxed starting position with the toes hanging downward. The test administrator instructed the subject to pull her toes as far toward her knee as hard as possible.

To test eversion strength, the cable was hooked to the side chain attachment. The foot was in relaxed position, toes hanging down. The subject was instructed to turn the sole of the foot, exerting as much effort as possible, toward the wall (the opposite direction from the attachment).

Plantar flexion strength was tested by hooking the cable to the chain directly above the subject's foot so that the sole of the foot was approximately perpendicular to the leg. The subject was instructed to push the forefoot down, exerting as much force as possible.

In order to measure inversion strength, the side attachment was used. The subject assumed her original sitting position, but on the opposite side of the table. Because of the length of the hole, the iron pipe, heavily padded, was put beneath the subject's knee joint. The purpose was to put the foot into a position perpendicular to the side attachment. Once again the subject was instructed to turn the sole of the foot forcefully toward the wall.

For each of the four measures of strength, the test administrator adjusted the hook into the proper chain making certain the foot was in proper position and that the cable was reasonably taut. When the cable tensiometer was hooked onto the cable, specific instructions were given to the subject in relation to the attachment position. The tensiometer reading was recorded after each measurement.

Weight

Each subject was weighed on Detecto-Medic scales manufactured by

Detecto Scales Inc., Brooklyn, N. Y. The weight was recorded to the nearest pound.

Balance

The Bass Stick Test was used as a measure of static balance. For twelve periods of one minute each, the subject alternated between standing with the foot lengthwise on the stick and crosswise on the stick. Practice trials were given for each position. For the lengthwise position, the subject was instructed to find a comfortable balance position. In standing crosswise on the stick, she was instructed to balance on the ball of the foot. For each one-minute period, the test administrator counted and recorded the number of errors which included stepping off the stick and touching the floor with any part of either foot or with any part of the body. Only the right foot was tested. The subjects wore tennis shoes during the testing.

The Bass Dynamic Test (the stepping stone test) was used for testing dynamic balance. According to specifications, circles 8 1/2 inches in diameter were drawn on the floor with white tempera paint. The test was explained and demonstrated by the test administrator. The errors which included stepping on the circle line, hopping in the circle, touching the heel to the floor, and touching the floor outside the circle with the other foot or any body part were also explained and demonstrated. Each subject performed the test three times. The total amount of time and the number of errors were recorded after each of the three trials. The subjects wore tennis shoes during the test. (Directions for both balance tests, and a diagram of the stepping stone test are in the Appendix.

III. TEST SCHEDULING AND ADMINISTRATION

Each subject was asked to sign up for a half hour period during the two afternoons the preliminary tests were given. No more than six subjects were allowed to come for testing in any one half-hour period.

Graduate students majoring in physical education volunteered to help administer the tests.

Because of the length of time required for administering the stick test for balance, three sticks were used. Three test administrators scored and recorded errors. In an half-hour period when six subjects were scheduled for testing, the stick test was administered to three subjects while the remaining three rotated among the three other testing stations.

To the three rotating subjects, the dynamic balance test was explained. After the explanation, one subject went to the strength testing-weighing station; one subject went to the flexibility-pedograph testing station; the third subject remained to take the dynamic balance test. The order of rotation was from the strength test to the flexibility and pedograph tests; from there to the dynamic balance test; and, then to the strength test. When the subjects completed each of these three tests, they went to the stick test station. The same procedure was followed when those who completed the stick test became the rotators.

One test administrator was at the flexibility-pedograph station; two were at the strength-weight station; and, two were at the stepping stone test. At the strength-weight station, one administrator adjusted the apparatus; the other recorded the data and weighed the subject. Administering the stepping stone test were a timer and a scorer. Because of the high degree of subjectivity of the test, the same scorer scored all Bass Dynamic Balance tests. Using a stopwatch, the timer counted the seconds aloud according to test directions.

Adjustments in the entire testing procedure were made when fewer than six subjects were tested in any one half-hour period.

IV. GROUPS

The subjects were divided as equally as possible into two groups on the basis of their weights. One group, the experimental group, participated in a series of foot strengthening exercises. The control group did no exercises.

V. EXERCISE SERIES

Twelve exercise sessions were conducted by the researcher in the basement of the subjects' dormitory. The sessions were held every night, Monday through Friday, at 10:15 P.M. Each period lasted fifteen minutes. The work load and exercise tempo were increased each night. Ten subjects completed all twelve sessions; five completed eleven sessions; and, one completed ten sessions. (Exercise battery appears in the Appendix.)

VI. RETEST

The same test battery was used to retest both groups. The test sessions were scheduled on two days immediately following the exercise program. The procedures of administration were similar to those of the initial testing. (Raw data collected from both testing sessions may be found in Appendix.)

CHAPTER IV

PRESENTATION AND INTERPRETATION OF DATA

I. PRESENTATION OF DATA

The purpose of the study was to determine the effect of foot strengthening exercises on ankle flexibility, balance and foot contour or the angulation of the footprint. The experimental group was given a series of foot strengthening exercises during a period of two and one-half weeks. Within this period of time, twelve exercise sessions, each fifteen minutes in length were conducted by the researcher. The control group was given no exercise.

After the initial testing of all subjects, the sample was halved. The pairings were made on basis of the subjects' weights, since there was the possibility that foot strength, flexibility and balance might be influenced by body weight. In order to determine whether or not there were any statistically significant differences between the two groups initially, the factors of flexibility, dorsal flexion strength, plantar flexion strength, inversion strength and eversion strength were compared by using Fisher's "t" for uncorrelated means.[5] The "t" scores for the two groups at the initial testing are presented in Table I. The results showed no statistically significant difference at the 1% level of confidence. (The author has chosen the 5% level of confidence as a guideline for statistical analyses. However, only those correlation coefficients and "t"

TABLE I

SIGNIFICANCE OF DIFFERENCE BETWEEN TWO GROUPS SELECTED ON BASIS OF WEIGHT WITH REGARD TO ANKLE FLEXIBILITY AND FOOT STRENGTH SCORES AFTER INITIAL TESTING

Factors	Mean Diff.	"t"
Flexibility	4.8676	1.8054
Dorsal flexion strength	-7.3197	-1.4866
Plantar flexion strength	-1.6899	- .5747
Inversion strength	- .6756	- .2850
Eversion strength	-1.5533	- .7181

values significant at the 1% level of confidence were considered when the worth of foot strengthening exercises was evaluated.)

Ankle Flexibility, Angulation, and Dorsal and Plantar Strength Correlations

The Pearson Product Moment Method of correlation(5) was used to determine the possible relationships of plantar flexion strength to ankle flexibility, dorsal flexion strength to ankle flexibility, and plantar flexion to dorsal flexion strength. Results were obtained for the experimental group, the control group, and for the total sample after both the first and second testings. In addition, another set of factors, flexibility and footprint angulation, was correlated. These last two factors, ankle flexibility and angulation, exhibited a statistically significant change in the experimental group between testings and after exercise, indicating a possible relationship between these two factors. Correlation coefficients were obtained for both the experimental and control groups after the first and second testings.

Of all the correlation coefficients obtained, three of the scores were statistically significant, but only one at the 1% level of confidence. The correlation coefficient significant at the 1% level of confidence was the relationship of dorsal flexion strength to plantar flexion strength in the control group after the first testing. After the second testing, the experimental group showed a significant relationship at the 4% level of confidence between these same two factors, plantar flexion strength and dorsal flexion strength. After the first testing, the experimental group exhibited a significant relationship between plantar flexion strength and flexibility, but again only at the 4% level of confidence. The correlation coefficients may be found in Table II.

Tests of Significance

Two different tests of "t" were utilized using the data of all eight test factors. First, Fisher's "t" for correlated means[5] was used to determine if statistically significant changes had resulted within the experimental group and within the control group between testings. Second, Fisher's "t" for uncorrelated means[5] was used to determine differences between the two groups after the first testing, and again after the second testing.

Comparison of Data After the First and the Second Testing

In the comparison of the first set of data with the second set for the experimental group, four "t" values were statistically significant at the 1% level of confidence. The factors exhibiting significant change included ankle flexibility, both tests of balance, and footprint angulation.

In the control group two scores were significant at the 1% level of confidence. Changes were noted in eversion strength and in the stick balance test. Table III presents the "t" values for differences within each of the groups after the first and second testings.

Comparison of the Groups After the First and the Second Testing

When comparing the experimental group with the control group on basis

TABLE II

CORRELATION COEFFICIENTS OF PLANTAR STRENGTH-FLEXIBILITY, DORSAL FLEXION STRENGTH-FLEXIBILITY, DORSAL FLEXION STRENGTH-PLANTAR FLEXION STRENGTH, AND FLEXIBILITY-FOOTPRINT ANGULATION IN THE EXPERIMENTAL, CONTROL AND TOTAL GROUPS

	After test	Experimental r	Control r	Total r
Plantar strength-flexibility	1	.5333**	-.3282	.1758
	2	.4647	-.0892	.2086
Dorsal strength-flexibility	1	.3205	-.0129	.0962
	2	.2760	.1871	.2417
Plantar strength-dorsal strength	1	.3440	.6657*	.4578
	2	.5296**	.4076	.4562
Angulation-flexibility	1	.2980	-.2129	----
	2	.3899	.0295	----

*Significant at 1% level of confidence
**Significant at 4% level of confidence

TABLE III

SIGNIFICANCE OF DIFFERENCE WITH REGARD TO TEST FACTORS AFTER FIRST AND SECOND TESTINGS WITHIN THE EXPERIMENTAL GROUP AND THE CONTROL GROUP

Factors	Experimental Mean of Diff.	Experimental "t"	Control Mean of Diff.	Control "t"
Flexibility	7.5000	4.8257*	1.0625	.5508
Dorsal strength	.7038	.1979	.0744	.0217
Plantar strength	1.7713	.9597	2.5525	1.3736
Inversion strength	1.3281	.8286	.5625	.3809
Eversion strength	2.5000	1.4231	4.2969	3.7475*
Dynamic balance	10.8125	3.5840*	8.8750	2.4848**
Stick balance	33.6875	3.7816*	29.0625	3.1477*
Angulation	3.1250	4.8966*	1.7500	1.5144

*Significant at the 1% level of confidence
**Significant at the 5% level of confidence

of the eight test items, no significant differences were found after the first testing session. After the second testing, no statistically significant differences were noted between the two groups with the exception of the scores obtained from the stick balance test. These scores were statistically significant at the 5% level of confidence. The "t" values are presented in Table IV.

Balance Stick Scores

The stick test of static balance included twelve one-minute periods of alternately balancing with the foot lengthwise to the stick and balancing with the foot crosswise to the stick. The test was scored by counting the errors which included stepping off the stick or touching the floor with any body part during each one-minute period. After empirically noting a vast improvement between the first and sixth (last) scores of the sample after the first testing, the author utilized Fisher's "t" for correlated means to determine whether or not the change was statistically significant. The first and sixth crosswise stick balance scores for both the experimental and control groups after the first and second testings were used in the computations. For both the experimental and control groups, the change between the first and last scores after the first testing was statistically significant at the 1% level of confidence. However, after the second testing, no change was exhibited between the first and last scores for either of the two groups. Table V presents the "t" values for differences between the first and last scores on the crosswise stick balance test.

TABLE IV

SIGNIFICANCE OF DIFFERENCE BETWEEN EXPERIMENTAL GROUP AND CONTROL GROUP WITH REGARD TO TEST ITEMS AFTER FIRST AND SECOND TESTING

Factors	1st Test		2nd Test	
	Diff. of Means	"t"	Diff. of Means	"t"
Flexibility	- 5.5625	-2.0486	1.1250	.5870
Dorsal strength	8.1512	1.4066	7.4281	1.1814
Plantar strength	1.7969	.5518	1.0157	.4034
Inversion strength	1.4063	.5844	2.1094	.8191
Eversion strength	1.8750	.8362	.0782	.0345
Dynamic balance	2.5000	.4140	4.3750	1.0395
Stick balance	-10.6250	- .6819	-15.2500	-2.3448**
Angulation	.3125	.2201	- 1.0625	- .4047

**Significant at the 5% level of confidence

TABLE V

SIGNIFICANCE OF DIFFERENCE BETWEEN FIRST AND LAST SCORES OF THE CROSSWISE STICK BALANCE IN EXPERIMENTAL AND CONTROL GROUPS AFTER FIRST AND SECOND TESTING

	Experimental		Control	
After test	Mean of Diff.	"t"	Mean of Diff.	"t"
1	5.8750	3.7290*	6.3750	3.9599*
2	.7500	.8324	.5000	.8452

*Significant at the 1% level of confidence

II. INTERPRETATION OF DATA

Comparison of Flexibility to Foot Strength and Angulation

The comparison of foot flexibility to dorsal and plantar strength within the experimental, control and total groups after the first and second testings showed no statistically significant relationship except on one occasion. The experimental group, after the first testing, had a correlation coefficient statistically significant at the 5% level of confidence between plantar flexion strength and flexibility. The variability among the correlation coefficients indicates a lack of relationship between the factors of foot strength and ankle flexibility. The findings are supported by Lawrence (63) who found no significant relationship between flexibility and stability of the feet.

The correlations of ankle flexibility to angulation of the footprint showed no statistical significance. Cureton(41), who also found no significant relationship between flexibility at the ankle and the angle of the arch, reported a correlation of $.014 \pm .066$ between the two measures.

Though only two of the six correlations of dorsal flexion strength to plantar flexion strength were statistically significant, the coefficients tended to show more consistent relationship than did the correlation coefficients of flexibility to strength measures and to angulation of the footprint. This fact may be explained by presuming that in the same foot the flexor and extensor groups of muscles function as a complete unit. Hence, depending upon the work load, they function together, reciprocally, as the occasion demands.

II. INTERPRETATION OF DATA

Comparison of Flexibility to Foot Strength and Angulation

The comparison of foot flexibility to dorsal and plantar strength within the experimental, control and total groups after the first and second testings showed no statistically significant relationship except on one occasion. The experimental group, after the first testing, had a correlation coefficient statistically significant at the 5% level of confidence between plantar flexion strength and flexibility. The variability among the correlation coefficients indicates a lack of relationship between the factors of foot strength and ankle flexibility. The findings are supported by Lawrence [63] who found no significant relationship between flexibility and stability of the feet.

The correlations of ankle flexibility to angulation of the footprint showed no statistical significance. Cureton[41], who also found no significant relationship between flexibility at the ankle and the angle of the arch, reported a correlation of $.014 \pm .066$ between the two measures.

Though only two of the six correlations of dorsal flexion strength to plantar flexion strength were statistically significant, the coefficients tended to show more consistent relationship than did the correlation coefficients of flexibility to strength measures and to angulation of the footprint. This fact may be explained by presuming that in the same foot the flexor and extensor groups of muscles function as a complete unit. Hence, depending upon the work load, they function together, reciprocally, as the occasion demands.

Effects of Foot Strengthening Exercises

The experimental group showed a statistically significant change between testings in regard to four of the test items - ankle flexibility, footprint angulation and dynamic and static balance.

Though the exercises were not geared to improve ankle flexibility, it may be surmised that the conscious effort of additional foot movement through exercise could have served to increase ankle flexibility. Also, the possible fact that the subjects probably felt a deeper motivation to improve during the second testing cannot be disregarded.

The angle of the footprint decreased in the experimental group at a statistically significant 1% level of confidence. It may be possible that in spite of the relatively short training period, the effect of foot exercise was such that there was slight hypertrophy with regard to the bulk of the muscle supporting the arch. Cureton stated:

> If the plantar muscles are relatively strong, there will be relatively more flesh present underneath the arch. This might cause an "apparent" flat-foot, whereas, the foot is in fact a strong and well-muscled one.(41:71)

Additionally, the fact that the subjects were possibly more "foot-conscious" during the second testing than they were during the first testing may have influenced the way they stood on the pedograph machine. If there was a tendency to pronate the foot, the arch would respond by being depressed. However, the author does not feel this was the reason. The pedograph machine, while being a valid instrument for measuring the contour of the supporting surface of the foot, is not a critical instrument. Hence, there is room for error due to extraneous factors. The place of support by the hand, or the lack of it, may possibly have influenced the placement of the weight either medially or laterally resulting in a smaller or larger arch angle.

In both the dynamic and stick balance tests, the experimental group changed significantly, at a statistically significant 1% level of confidence, between the first and second testings. Both of the Bass balance tests require sustained control within the feet in order to perform the tests effectively. The feet and ankles are of major importance in controlling body sway, as reported by Estep.(44) Therefore, it can be hypothesized that the exercises did aid in making the foot more sensitive to positioning in balance.

<u>Changes Between Testing Within the Control Group</u>

Three statistically significant changes occurred, two at the 1% level of confidence and one at the 5% level of confidence, within the control group between testings. Statistically significant changes at the 1% level of confidence were noted in eversion strength and the stick test of balance. The statistically significant change at the 5% level of confidence was in the dynamic test of balance.

The author cannot explain the significant amount of increase which was noted in the test of eversion strength. It is possible that the subjects in the control group were motivated to prove themselves superior to the experimental group. It is also possible that by chance they had availed themselves of certain exercise routines not consciously recognized.

The improvement on the dynamic balance test which was statistically significant at the 5% level of confidence, was probably due to a learning factor. It may be conjectured that since the change within the control group was statistically less than that within the experimental group, that exercise was the possible differing factor.

On the stick test of static balance, the control group improved statistically between testings at a 1% level of confidence. Because of the amount of change recorded between testings, not only within the control group, but also within the experimental group, the stick balance scores were scrutinized. It was discovered that on the crosswise stick balance portion of the test, the difference between the first and last scores recorded in the first testing was great. This variation was statistically significant at the 1% level of confidence after the first testing. After the second testing, there were no statistically significant differences between the first and last scores. Hence, there is a very strong indication that since both groups showed statistically significant improvement between the first and last testing sessions, and also between the first and last scores on the crosswise stick balance in the first testing, static balance was improved through practice. Not only was static balance improved, but there is some evidence that the learning was retained over a period of time.

The preceding premise refutes a statement by Estep[44] in which she said that there was little improvement of static balance due to practice.

Comparison of Groups Before and After Exercise

After the first testing, no differences were recorded between groups on basis of all eight test factors. After the second testing, a single item, the stick balance test on which the experimental group had the lowest (best) score, showed a statistically significant difference at the 5% level of confidence. Therefore, it can be presumed that exercise may have been the cause for the overall difference on the stick test for balance.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of the study was to determine the actual merit of including foot strengthening exercises in programs of physical education. Bases for judgment were the effects of foot strengthening exercises on measures of foot and ankle flexibility, foot contour, foot strength, and body balance.

The randomly selected subjects who participated in the study were members of the freshman class of 1963 at The Woman's College of the University of North Carolina. In order to facilitate test and exercise administration, all of the subjects were selected from one of the freshmen residence halls. Only those who expressed an interest in the study and who found it feasible to do so were asked to participate. Thirty-two of the thirty-seven volunteers completed the test-exercise sessions.

Preliminary Testing

All of the subjects were tested prior to the administration of the exercise battery. The tests included those for measuring ankle flexibility, foot contour, foot strength, and balance.

The Leighton Flexometer was used to measure ankle flexibility. Total ankle flexibility was scored by subtracting the dorsal flexion reading from the plantar flexion reading.

The pedograph was utilized in obtaining each subject's footprint. The footprint was evaluated in terms of its angle as obtained by using Clarke's footprint angle.

In order to measure foot strength, a system of cables, hooks and attachments was devised. Four measures of strength were made: dorsal flexion strength, plantar flexion strength, inversion strength, and eversion strength. Depending upon the strength measurement to be made, the cable was hooked to the proper attachment. A cable tensiometer was used to determine the amount of force exerted on the cable by the subject. The tensiometer readings were converted to pounds using the provided tensiometer scale for a No. 1 riser with a 1/16 inch cable.

The Bass Stick Test and the Bass Dynamic Test were used to test static and dynamic balance. On the stick test the subjects were scored on the number of errors committed during twelve one-minute periods of alternately balancing on the stick lengthwise and crosswise with the right foot. The Bass Dynamic Test (the stepping stone test) was performed three times by the subjects. The total number of errors were recorded and evaluated as described in the Bass test.

Also, each subject was weighed, and the weight was recorded to the nearest pound.

Experimental and Control Groups

After the preliminary testing, the subjects were divided as equally as possible on basis of their weights. In order to make certain the two groups were similar, tests of "t" were conducted on the four strength measurements and ankle flexibility scores for each group. No statistically significant differences were found between the two groups.

One group was chosen to participate in a series of exercises; the other group was to have no exercise. A total of twelve exercise sessions were conducted by the researcher during a period of two and one-half weeks. The sessions, which lasted fifteen minutes, were conducted in the basement of the subjects' residence hall. Ten subjects completed all twelve sessions, five completed eleven sessions, and one completed ten of the sessions.

Retest

After the completion of the exercise battery, both groups of subjects were retested using the same initial test.

Treatment of Data

Correlation coefficients were computed to determine the relationships of plantar flexion strength to ankle flexibility, dorsal flexion strength to ankle flexibility, and plantar flexion strength to dorsal flexion strength. Data from the scores of the experimental, the control and the total groups after both the first and second testings were utilized. In addition, correlation coefficients for the relationship of footprint angulation to ankle flexibility were computed for the experimental and control groups after the first and the second testings.

In order to determine changes made by each of the groups between testings, and differences between the two groups after the first testing and after the second testing, "t" tests of significance were used. All eight test items - the four strength measures, ankle flexibility, footprint angulation, and the two measures of balance - were used in the comparisons.

Findings

1- There appeared to be little relationship between foot strength measures and ankle flexibility.

2- There was no significant relationship between ankle flexibility and footprint angulation.

3- Measures of dorsal flexion strength and plantar flexion strength tended to correlate high showing a positive relationship one to another.

4- Experimental group showed statistically significant change at the 1% level of confidence between testings on four test items - ankle flexibility (improvement), footprint angulation (decreased), static balance and dynamic balance (improvement).

5- Control group showed three statistically significant changes between testings. Changes statistically significant at the 1% level of confidence were on eversion strength and static balance. A statistically significant change at the 5% level of confidence was recorded for dynamic balance.

6- Differences between first and last scores of the crosswise balance portion of the stick test were statistically significant at the 1% level of confidence for both groups after the first testing. There was no noted difference between the first and last scores on the crosswise stick balance after the second testing for either group.

7- Comparison of the two groups after the first testing showed no differences between the two groups on basis of all eight test factors.

8- Comparison of the two groups after the second testing showed one difference statistically significant at the 5% level of confidence. On the stick test for balance, the experimental group had a lower (better) score than the control group.

Conclusions

The emphasis of posture training in physical education classes including those taught at the college level has been increased during the past several decades. Within the programs of posture training, exercises for all body parts have been included, and a major body area of concern has been the feet and legs. The degree of importance of the effect of foot strengthening exercises on foot function and structure was questioned by the author.

The feet are subject to more exercise than most other parts of the body. They must provide both support and balance for the body in addition to being the locomotive force. It is imperative that they adapt to various normal, daily conditions such as walking on smooth and rough, flat and sloping surfaces, walking up and down stairs, changing direction, being confined in shoes of various widths and heel heights, and adapting to an unlimited number of situations. Thus, it would be reasonable to question the importance of exercises for the feet for the development of strength. However, it was felt that some additional factors might be affected such as changes in foot contour, footprint angulation and body balance.

On basis of the findings of this study the following conclusions have been made:

1- The lack of significant difference between those who participated in the exercise program and those who did not participate indicates there is little structural and functional value in exercises designed for strengthening the feet of adult, college-aged students.

2- The value of foot exercises probably may be justified in the assumption that they help the student become aware of the proper functioning and care of the feet.

3- The results indicated that static balance can be learned and improved through practice, and that this learning may be retained over a period of time.

Recommendations

Upon evaluating the research design and instrumentation of this study, it was felt by the author that the following recommendations would be important to further research in this area:

1- A dynamic balance test which can be scored more objectively than the Bass Dynamic Balance Test should be chosen.

2- It should be made certain within limits of reason that the subjects stand on the pedograph machine in the same manner during both testings. The administrator can aid by being certain the machine is placed in only one location and that the same hand support is provided.

3- The same test should be conducted before and after conducting the same exercise battery in a body mechanics class for the duration of a semester.

4- The same test-exercise study on elementary school-aged children could be conducted and results compared to those of this study in order to help determine the effects of growth factors and establishment of habit patterns on test results.

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APPENDIX

TENSIOMETER INTERPOLATIONS*

Tensiometer Reading	Pounds	Tensiometer Reading	Pounds	Tensiometer Reading	Pounds
2	5	17	26.25	32	48.33
3	6.25	18	27.5	33	50
4	7.5	19	28.75	34	52.5
5	8.75	20	30	35	55
6	10	21	31.66	36	56.66
7	12.5	22	33.33	37	58.33
8	15	23	35	38	60
9	16.25	24	36.25	39	61.25
10	17.5	25	37.5	40	62.5
11	18.75	26	38.75	41	63.75
12	20	27	40	42	65
13	21.25	28	41.66	43	67.5
14	22.5	29	43.33	44	70
15	23.75	30	45	45	72.5
16	25	31	46.66	46	75

*Tensiometer readings for a No. 1 Riser (1/16 inch cable) converted into pounds using tensiometer conversion scale.

RAW DATA AFTER FIRST TESTING FOR EXPERIMENTAL GROUP

Ankle Flex. (degrees)	Dorsal Flex. Strength	Plantar Flex. Strength	Inversion Strength	Eversion Strength	Dynamic Balance	Static Balance	Footprint Ang. (degrees)	Weight
66	28.75	12.5	15	10	86	38	53	102
40	12.5	5	6.25	5	73	63	51	110
48	52.5	10	10	21.25	88	71	38	112
51	52.5	17.5	10	10	51	85	46	123
42	33.33	10	8.75	8.75	43	30	43	104
48	35	10	20	16.25	37	48	48	119
66	56.66	10	23.75	18.75	74	197	40	113
62	67.5	17.5	21.25	22.5	66	25	42	118
53	60	18.75	20	30	57	26	44	152
58	60	25	16.25	10	83	20	54	125
62	45	31.66	17.5	18.75	82	45	67	133
54	60	28.75	20	10	88	70	41	137
72	46.66	38.75	21.25	23.75	85	74	58	130
55	38.75	30	21.25	12.5	94	14	55	120
53	48.33	23.75	27.5	17.5	64	29	48	140
67*	31.66*	17.5*	8.75*	10*	61*	60*	58*	121*
53	35	20	20	12.5	77	34	26	122

*Did not complete exercise battery and second testing.

RAW DATA AFTER FIRST TESTING FOR CONTROL GROUP

Ankle Flex. (degrees)	Dorsal Flex. Strength	Plantar Flex. Strength	Inversion Strength	Eversion Strength	Dynamic Balance	Static Balance	Footprint Ang. (degrees)	Weight
61	22.5	10	7.5	12.5	74	93	38	128
62	46.66	23.75	21.25	18.75	83	81	52	136
68	30	7.5	5	8.75	52	42	45	105
64	41.66	22.5	26.25	23.75	92	71	36	142
64	33.33	10	6.25	6.25	48	176	44	118
62	28.75	12.5	15	18.75	58	107	51	122
59	40	16.25	15	12.5	68	85	44	118
50	45	23.75	22.5	21.25	81	23	51	117
70	70	26.25	25	10	90	16	50	125
68	25	7.5	8.75	8.75	44	99	44	97
52	25	10	8.75	10	50	81	48	135
60	33.33	16.25	12.5	10	82	4	45	112
49	50	31.66	26.25	8.75	84	31	48	126
61	33.33	20	22.5	15	77	39	50	119
59	52.5	17.5	10	7.5	78	53	51	123
63	25	25	23.75	25	47	38	52	108

RAW DATA AFTER SECOND TESTING FOR EXPERIMENTAL GROUP

Ankle Flex. (degrees)	Dorsal Flex. Strength	Plantar Flex. Strength	Inversion Strength	Eversion Strength	Dynamic Balance	Static Balance	Footprint Ang. (degrees)
65	37.5	10	16.25	12.5	84	11	47
58	8.75	7.5	5	7.5	84	22	49
51	48.33	25	27.5	18.75	98	26	35
64	45	21.25	10	20	78	39	42
52	37.5	10	8.75	8.75	67	8	37
61	37.5	10	21.25	17.5	72	22	47
70	37.5	27.5	17.5	15	60	37	37
62	65	15	15	16.25	64	7	42
65	70	23.75	25	21.25	74	14	39
64	33.33	25	23.75	17.5	95	19	48
68	70	36.25	21.25	23.75	91	10	60
66	65	23.75	23.75	27.5	96	38	43
66	33.33	25	10	17.5	87	48	55
65	67.5	27.5	25	22.5	100	4	53
67	52.5	23.75	30	22.5	83	15	44
63	35	26.25	20	18.75	88	10	26

RAW DATA AFTER SECOND TESTING FOR CONTROL GROUP

Ankle Flex. (degrees)	Dorsal Flex. Strength	Plantar Flex. Strength	Inversion Strength	Eversion Strength	Dynamic Balance	Static Balance	Footprint Ang. (degrees)
70	48.33	12.5	18.75	18.75	73	34	36
70	35	22.5	21.25	16.25	81	80	44
55	10	10	8.75	7.5	80	21	33
67	70	25	22.5	25	77	37	42
63	27.5	26.25	10	10	66	63	46
56	48.33	25	22.5	25	92	25	49
64	52.5	17.5	10	22.5	80	27	43
66	46.66	26.25	25	28.75	89	24	49
57	60	25	27.5	22.5	93	11	50
64	10	6.25	7.5	10	49	46	44
60	21.25	22.5	7.5	7.5	79	59	40
60	27.5	26.25	12.5	17.5	90	1	40
48	38.75	23.75	12.5	10	68	54	48
65	50	22.5	28.75	25	87	17	50
61	45	17.5	10	12.5	82	17	51
63	33.33	12.5	21.25	27.5	65	58	56

BASS STICK TEST OF STATIC BALANCE

Equipment: Stick - 1" side, 1" high, 12" long

1- Performers stand in two lines.

2- Performers in one line stand with one foot lengthwise on stick.

3- Second line count number of times performer steps off stick within one-minute period.*

4- Then each performer stands with foot crosswise on stick.

5- Second line count (as above).

6- Each performer does each of the two tests six times.

7- Score: Sum the times of step-downs for all six trials for each of the two tests.[14]

*Number of errors were recorded by test administrators in this study.

BASS TEST OF DYNAMIC BALANCE

Administrators

1- Instructor who explains test, and who counts the number of errors silently during performance.

2- Timer who, using a stopwatch, counts each five seconds aloud beginning with number "one" when the performer steps into the next circle.

Equipment and Facilities:

1- Stopwatch, pencil and scorecard

2- "Stepping stones" are drawn according to directions onto the floor. (See page 79)

Directions:

1- Performer stands with right foot on starting circle.

2- Leaps (not steps) into first circle with left foot.

3- Leaps to second circle with right foot; to third with left, etc.

4- Must entirely leave floor when leaping to circles.

5- Must land on ball of foot; heel must not touch floor.

6- Remains in each circle five seconds in a stationary position. (Timer counts seconds aloud, and begins with number "one" when performer leaps into a new circle.)

Errors:

1- Touch heel to floor.

2- Move foot while in circle.

3- Hop on foot in circle. (Error for each hop)

4- Touch floor outside circle.

5- Touch floor with other foot.

6- Touch floor with any other part of body.

Scoring:

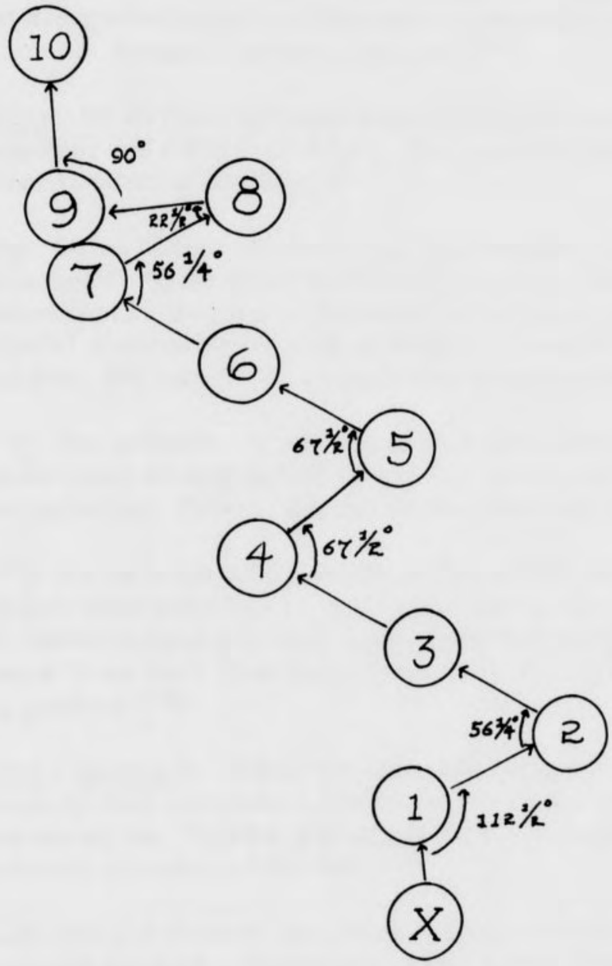
1- 50 plus number of seconds of duration of test minus three times the errors. (Each error counts one penalty point.)

2- If more than five seconds are taken in the circles, deduct extra time from total time.

3- Three trials are scored. Final score equals the average of the three trials.

4- A negative score equals zero.[14]

DIAGRAM OF BASS TEST OF DYNAMIC BALANCE



Circles, 8 1/2 inches in diameter, are drawn on the floor.

"X" is the starting circle.

Distance from "X" to "1" is 18 inches.

Distance between other circles is 33 inches.

FOOT STRENGTHENING EXERCISE BATTERY

1- Foot Push-Out: Sit on floor. Soles of feet together and feet as near the body as possible. Outer borders of feet remain in contact with the floor as the feet are pushed away from the body as the soles of the feet continuously touch. Return to starting position.[11]

2- Arch Raising: Sit on floor with hands on floor behind back, knees flexed, and feet together and flat on the floor. Keep toes and heels on floor while raising inner borders of the feet.[4]

3- Toe Pulling: Sit on bench. Feet are parallel and ten inches apart, and resting on a towel. Heels are directly under knees. Make a mound of towel between feet by pivoting on heels and using toes. After each pull return to parallel position by pivoting on heels. To flatten towel, raise heels, plantarflex feet, use toes. Can be done with weight on towel.[21]

4- Toe Curl #1: Sit on bench. Curl toes of both feet under strongly while rolling ankles apart so that weight is on outer borders of feet and the arches are pulled up. Relax. Repeat 20-30 times per minute.[10]

5- Toe Curl #2: Sit on bench with feet six inches apart, toes pointed straight ahead. 1) Curl toes under hard. 2) Keeping toes curled, heels in contact with floor, knees in same position, swing both feet until toes touch. 3) Raise forefeet from floor from same position in #2. 4) Relax and return to starting position.[10]

6- Leg Rotation - Arch Lift: Stand with feet parallel and three or four inches apart. Heads of first metatarsal are on the floor, and inner borders of the feet are drawn up. Tighten gluteal muscles and rotate knees out. Weight is thrown to center of the foot.[21]

7- Walk: Stand with feet parallel and weight on outer borders of feet. Walk 50 steps forward and back. Press ball of foot down. Keep feet parallel.[15]

8- Rising on Toes: Stand. Rise on toes, swinging heels to pigeon-toed position, hold, then sink down slowly letting weight go to outer borders of feet.[10]

9- Pigeon-Toed Walk: Stand with feet in exagerated pigeon-toed position. 1) Walk with feet crossing over and in front of each other alternately. 2) Walk correctly, toeing in slightly, with weight on outer borders of the feet.[13]

10- Sway: Stand with feet parallel and six inches apart. Sway back and forth from heel to ball of foot. (15)

11- Step Balance: Stand on edge of step with ball of foot; heels hang off. 1) Stand on tiptoe. 2) Lower and drop heels as low below level of toes as possible. (30)

12- Foot Board: Stand with outer borders of heels against edges and toes curled over top edge of board. Walk the length of the board.

EXERCISE SESSIONS

	Exercise	Duration of Exercise
I.	Foot Push-Out	5 times
	Arch-Raising	10 times
	Toe Curl #1	20 times
	Toe Curl #2	5 times
	Leg Rotation	5 times
	Walk	50 steps
	Rising on Toes	5 times
	Sway	10 times
	Step Balance	6 times
II.	Foot Push-Out	6 times
	Arch Raising	12 times
	Toe Pulling	2 times
	Toe Curl #1	20 times
	Toe Curl #2	5 times
	Leg Rotation	5 times
	Walk	50 steps
	Rising on Toes	5 times
	Pigeon-toe Walk	50 feet
	Sway	10 times
	Step Balance	6 times
III.	Foot Push-Out	7 times
	Arch Raising	14 times
	Toe Pulling	3 times
	Toe Curl #1	30 times
	Toe Curl #2	6 times
	Leg Rotation	10 times
	Walk	50 steps
	Rising on Toes	6 times
	Pigeon-toe Walk	50 feet
	Sway	12 times
	Step Balance	6 times
IV.	Foot Push-Out	8 times
	Arch Raising	16 times
	Toe Pulling	3 times
	Toe Curl #1	45 times
	Toe Curl #2	6 times
	Leg Rotation	12 times
	Rising on Toes	6 times
	Walk	50 steps
	Pigeon-toe Walk	50 feet
	Sway	12 times
	Step Balance	8 times
V.	Foot Push-Out	5 times
	Arch Raising	18 times
	Toe Pulling	3 times
	Toe Curl #1	100 times
	Toe Curl #2	10 times
	Leg Rotation	15 times
	Rising on Toes	7 times
	Pigeon-toe Walk	50 feet
	Sway	12 times
	Step Balance	10 times
VI.	Foot Push-Out	10 times
	Arch Raising	20 times
	Toe Pulling	4 times
	Toe Curl #1	110 times
	Toe Curl #2	12 times
	Leg Rotation	18 times
	Rising on Toes	7 times
	Pigeon-toe Walk	50 feet
	Sway	14 times
	Step Balance	12 times

EXERCISE SESSIONS

	Exercise	Duration of Exercise
VII.	Foot Push-Out	11 times
	Toe Pulling (weight)	2 times
	Toe Curl #1	125 times
	Toe Curl #2	14 times
	Leg Rotation	20 times
	Rising on Toes	8 times
	Pigeon-toe Walk	50 feet
	Sway	14 times
	Step Balance	14 times
VIII.	Foot Push Out	12 times
	Toe Pulling (weight)	3 times
	Toe Curl #1	130 times
	Toe Curl #2	16 times
	Leg Rotation	22 times
	Rising on Toes	8 times
	Pigeon-toe Walk	50 feet
	Sway	16 times
	Step Balance	16 times
	Foot Board	3 times
IX.	Toe Pulling (weight)	3 times
	Toe Curl #1	140 times
	Toe Curl #2	18 times
	Leg Rotation	25 times
	Rising on Toes	9 times
	Pigeon-toe Walk	50 feet
	Sway	16 times
	Step Balance	18 times
	Foot Board	5 times

	Exercise	Duration of Exercise
X.	Toe Pulling (weight)	3 times
	Toe Curl #1	145 times
	Toe Curl #2	20 times
	Leg Rotation	25 times
	Rising on Toes	9 times
	Pigeon-toe Walk	50 feet
	Sway	16 times
	Step Balance	20 times
	Foot Board	7 times
XI.	Toe Pulling (weight)	4 times
	Toe Curl #1	150 times
	Toe Curl #2	22 times
	Leg Rotation	28 times
	Rising on Toes	10 times
	Pigeon-toe Walk	50 feet
	Sway	18 times
	Step Balance	22 times
	Foot Board	8 times
XII.	Toe Pulling (weight)	4 times
	Toe Curl #1	160 times
	Toe Curl #2	24 times
	Leg Rotation	30 times
	Rising on Toes	10 times
	Pigeon-toe Walk	50 feet
	Sway	20 times
	Step Balance	24 times
	Foot Board	10 times