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EFFECTS OF ANKLE FOOT ORTHOSIS APPLICATION ON STANDING BALANCE IN THE ELDERLY

By

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THESIS

Submitted to the Department of Physical Therapy of Grand Valley State University
Allendale, Michigan
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1993
EFFECTS OF ANKLE FOOT ORTHOSIS APPLICATION ON STANDING BALANCE IN THE ELDERLY

ABSTRACT

The purpose of this study was to quantify changes in balance as measured by the Balance Master as a result of ankle foot orthoses (AFO) application to a sample population. Data from trials with AFO and without AFO were obtained from six men and twelve women ages 65-79. Paired T-tests were used to analyze data for areas of significance. Significant areas included rhythmic weight shifting (right/left), limits of stability (LOS) forward direction, LOS right forward direction, and LOS backward direction with p values ranging from p=0.0048 to p=0.0451. AFO application may have altered the range of motion available for movement strategies needed for dynamic stability. The rigidity of the AFO may have aided static stability. The results suggest the need for further research on balance and AFO use in various populations.
DEDICATION

We would like to dedicate this thesis to our families and friends who have supported us throughout our college experience and served as our “cheering section.”

A special dedication from Jeralyn is to her sister Beki for the inspiration she was throughout her life towards this accomplishment, as well as to Jim, for the wonderful encouragement he was to the very end.
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CHAPTER 1
INTRODUCTION

Balance is an intricately controlled behavior. Numerous studies have been done on balance and a large quantity of information exists in the literature. These studies explore various aspects of balance. However, the assessment of balance behavior needs to be comprehensive because the control of equilibrium is both neurologically and mechanically complex.\textsuperscript{1,2} Balance is influenced by three major sensory systems. The somatosensory (proprioceptive, cutaneous, and joint), visual, and vestibular systems provide the major sensory inputs for the postural stabilizing reflexes needed for maintaining and restoring balance. Although each sensory input has an optimum range of frequency and velocity at which it best stabilizes postural sway, a redundancy of the contributions of the three sensory systems to postural control exists.\textsuperscript{3-8} Nevertheless, in situations where one or more input is lost, the remaining sensory inputs can compensate and ensure stability.\textsuperscript{9,10}

With aging, various physiological and physical changes occur. The degree of these changes varies among individuals. Heredity, disease processes, and level of wellness are some of the main contributors. As a result of age-related changes, the elderly
population is at a high risk of disequilibrium. Balance and postural stability are critical components for ambulation and other functional activities. The elderly have a decreased ability to maintain balance and stability. In the United States, one third to one half of the elderly population age 65 and older experience one or more falls each year. Falls and the resulting immobility are common occurrences among the elderly and primary reasons for medical intervention.

Physical therapists use ankle foot orthoses (AFO) to provide stability and to improve ambulation for patients demonstrating deficits in the normal mechanisms necessary for function. Individuals with peripheral neuropathies and hemiplegia are the primary candidates for an AFO. O’Sullivan states that aging significantly increases the incidence of stroke especially after the age of 65. The annual incidence rate increases from 1 to 2 per 1000 individuals for the general population to 3.5 per 1000 individuals ages 55 to 64. However, between 65 and 74 years of age the incidence increases to 9 per 1000 individuals. This population is frequently seen in physical therapy due to the increased incidence of neurological and orthopedic insults.

Our study was designed to see if an AFO imposes any additional detrimental effects on balance in this already compromised
population. Testing was carried out on an elderly population ages 65 to 79. The purpose of this study is to determine if the application of a polypropylene prefabricated AFO to the dominant lower extremity of ambulatory individuals, ages 65 to 79, with no previous history of significant orthopedic or neurological insult, as reported by the individual, reduces the individual's ability to maintain dynamic balance as measured by the Balance Master®.
Balance maintenance is an intricately controlled activity.\textsuperscript{21} Maintaining dynamic postural stability is demonstrated by a person's ability to remain upright while moving. To accomplish this, information must continually be acquired about the body's position and movement through space and an effective response must be predetermined and executed. Sensory information is acquired from the visual, vestibular, and somatosensory systems.\textsuperscript{22,23} The central nervous system (CNS) then orders rapid, automatic postural responses in both feedforward and feedback modes. These postural responses require power from muscles, range from joints, and endurance.\textsuperscript{23}

**Sensory Systems**

The sensory systems provide redundant information regarding the body's position in space.\textsuperscript{3-8,22} Functional reserve represents the excess or redundant function available in virtually all physiologic systems. Redundant functions and reserves within postural control may be lost gradually (with the aging process) and deficits may remain unapparent until some critical threshold is reached or some
unusual stress tests the systems maximal function.$^{2,3}$ The physical changes that occur with aging may affect the functional reserve in terms of balance maintenance and thus decrease the elderly individual's ability to maintain balance. The introduction of an unusual stress to the elderly individual may have a more significant effect on function than would be evident in a younger individual as the reserves of redundancy may be reduced or absent in the elderly.$^{2,3}$ Woollacott$^9$ addresses the relationship of balance maintenance to sensory changes as she considers the concept of functional reserve in the elderly. Decreases in the effectiveness of any one of the peripheral sensory systems with age could decrease the redundancy of sensory information normally available to the participant. With such a decrease, shifts in the relative weighting of inputs may be less effective when environmental changes require it.$^9$ AFO's are proposed to reduce the sensory input of the foot in contact with the ground as well as proprioceptive input. Therefore, the proposed study seeks to see if the application of an ankle foot orthoses (AFO) could cause elderly individuals to reach this theoretical critical threshold and significantly compromise balance maintenance.

Although sensory information is obtained from three systems, a complete loss of equilibrium during stance will not necessarily occur if one of the systems is deficient or lost. A shift in
dominance to one of the remaining senses results when the dominant sense is impaired. If more than one of the three primary senses is deficient, dysequilibrium will definitely occur. Information from all three systems are standards of comparisons among themselves to screen for any discrepancies.

Visual input significantly assists involuntary postural adjustment and facilitates the restoration of balance during initial perturbations of equilibrium. Vision becomes even more important for maintaining balance when compensation for a deficiency or loss in one or both of the remaining sensory systems is required. Research has indicated that individuals rely so heavily on visual input that an inaccurate visual stimulus may be perceived as orientationally correct.

The vestibular system serves a dual role for balance regulation. During postural sway, this system modifies the activation of the appropriate postural muscles. Also, it determines the degree of postural sway by providing a fixed gravitational reference. Visual and somatosensory information are compared against this reference. This gravitational reference tends to be lost first with vestibular impairment.

Somatosensory information consists of cutaneous, proprioceptive, and joint receptor input. Acting alone, this
information is not sufficient to initiate postural correction. Studies propose that the proper postural control pattern cannot be accurately selected without somatosensory information from the feet or ankles. With reduced somatosensory information, proper postural control relies heavily on visual input. Dysequilibrium may increase with both distorted somatosensory input and diminished visual input. Regardless of surface area, individuals with loss of somatosensory input from the feet and ankles maintain postural balance by relying mostly on hip musculature.

**Movement Strategies**

In addition to sensory information, balance involves motor processes which control and coordinate the action of the trunk and leg muscles into discrete synergies and strategies of muscle activation that maintain the body within its base of support. These strategies are the tools used to respond to perturbations and to maintain neutral alignment. The use of a particular strategy depends on the configuration of the support surface, the size of the perturbation, and the abilities of the individual. Before voluntary movement is initiated, automatic postural reactions including ankle, hip, and stepping strategies are used to correct anterior-posterior body sway and to restore equilibrium in response to unexpected disturbances. Muscle contraction and movement begin at the ankle
joint in the ankle strategy and this strategy is most commonly used for small perturbations on a firm, wide surface.\textsuperscript{28,29} In this strategy, the body moves as a relatively rigid mass about the ankle joint and results in large and relatively slow movements.\textsuperscript{30} Thigh and trunk musculature are activated in a distal to proximal pattern with this strategy. When posterior sway occurs, the order of muscle activation is tibialis anterior, quadriceps, and abdominal muscles. During anterior sway, the sequence is gastrocnemius, biceps femoris, and paraspinal muscles.\textsuperscript{22}

Movement centers around the hip joint during the hip strategy and results in rapid movements that cover a short distance. Decreases in support surface lengths and forward or backward perturbations most often cause individuals with somatosensory loss to rely on hip muscles to maintain equilibrium.\textsuperscript{22} Individuals prevent dysequilibrium with activation of hip muscles in a proximal to distal direction when standing on surfaces shorter than the length of the feet.\textsuperscript{22} Stepping is used when the center of gravity is pushed beyond the limits of stability and balance is trying to be maintained.

The effective use of any such strategy depends on adequate range of motion about the primary axis joint and sufficient strength to initiate and control the movement. The ankle strategy is the most commonly used strategy in the elderly.\textsuperscript{28,29} This strategy continues
to be used until it is no longer effective for balance maintenance. As the support surface is reduced or range of perturbation is increased, an individual progresses from the ankle to hip strategy.  

The activation of ankle musculature helps retain an individual's center of gravity under normal sensory conditions. Adequate sensory input and appropriate postural strategies are necessary for maintaining balance.

Changes in balance maintenance associated with age were documented by Iverson et al. Balance and muscle performance data were collected on 54 men aged 60 to 90 years. Balance was assessed using the sharpened Rhomberg test (SR) and the one legged stance test (OLST) on each foot with eyes open and eyes closed. The documented decrements in balance times and force productions revealed a significant negative relationship between age and balance times. The force of the hip musculature was measured with a quantitative muscle tester (QMT), which is a strain-gauge, hand-held dynamometer. Key muscles tested were the hip flexors, extensors, and abductors. Force production was found to be positively correlated with balance times and was significantly influenced by the reported activity level of the subject. Decreases in force production were associated with decreased balance times as well as decreased activity levels. The authors hypothesized that
decreases in muscle mass prevalent in the elderly, especially of back extensors and proximal lower extremity muscles, were responsible for the changes found in balance times.

Briggs found similar results in his research testing 71 non-institutionalized elderly women aged 60 to 86 years. He also utilized the Rhomberg test and OLST as measures of balance. The purpose of his research was similar to that of Iverson and threefold in nature: to collect data on healthy elderly women; to determine the relationship between balance times and falls; and to determine the effect of wearing shoes on balance. His results, like Iverson's, showed an inverse relationship between the results of the Rhomberg test and OLST and age. The mean balance times and the Rhomberg decreased as age increased. The shoes-on and shoes-off conditions produced no significant differences in balance performance.\(^2^1\)

Woollacott, Shumway-Cook, and Nashner\(^9\) attempted to document changes in sensory organization and muscular coordination. Their aim was to determine whether reduced balance control in twelve 61 to 78 year olds was associated with alteration in neuromuscular function. The timing and organization of muscular responses of the automatic postural response system in this group were compared to that of the younger population. The study suggested an increase in latency time of the distal muscles in
response to anterior and posterior perturbations in the older group. In 5 of the 12 older subjects, the pattern of distal to proximal muscle activation was reversed.22

Other documented age-related changes in relation to postural control and sensory input include increased thresholds of excitability for cutaneous sensation and proprioception.9,32-35 Sekuler et al36 documented a significant reduction in visual spatial sensitivity in the elderly especially with relation to low spatial frequencies and slow moving targets. This finding is significant in that low frequency visual information is utilized in postural stabilization.33,34,37 The elderly may not be able to use visual information optimally for postural stabilization.

In summary, the elderly have an increased potential for incurring deficits in balance maintenance. The necessary muscular forces decrease and the muscle response time increases in elderly individuals. The ability to respond to altered sensory conditions is affected with age.

**Ankle Foot Orthoses**

External aids such as AFO's are often used as part of a comprehensive management of the accumulative effects of aging. Physical therapists frequently use AFO's as part of the treatment plan for individuals with a variety of diagnoses. The primary
candidates for AFO's are those with peripheral neuropathy and hemiplegia. According to Lehman, AFO's are the most commonly used orthotic device and serve at least three purposes:

1. Medial/lateral stability of the ankle during stance phase to prevent inadvertent twisting of this joint;
2. Toe pick-up during swing phase to prevent toe dragging and subsequent stumbling or falling; and
3. Push off simulation during the latter part of the stance phase, thus approximating more normal gait and reducing energy expenditure.

While AFO's may be beneficial, there are negative mechanical consequences to their use. According to Schenkman, the limitation of movement provided by the AFO also renders the ankle strategy no longer functionally useful. As mentioned previously, the ankle strategy is the most commonly used strategy for balance maintenance in the elderly. This loss of ankle joint range of motion prevents individuals from correcting anterior-posterior center of gravity displacements by bringing the tibia over the foot. Corrections for this displacement could be made by flexing at the hip and consequently bringing the body mass forward over the foot through reliance on more proximal musculature. This proximal response may be limited in the elderly due to the documented weakness of proximal musculature mentioned previously. Schenkman questions if, in the event of loss of dorsiflexion motion about the ankle, the individual can learn and adopt an alternate abnormal strategy to the traditional ankle strategy. The adoption of
an alternate abnormal strategy unilaterally may produce an incongruency in the use of strategies between the lower extremities, causing an unfavorable mechanical consequence. The braced extremity would use a more proximal strategy where as the unbraced extremity would initiate the normal distal to proximal pattern of recruitment. This imbalanced muscular recruitment pattern could potentially produce instability. Such incongruency of strategies may be a consequence of AFO use and further study of this possible consequence is needed.

According to Shumway-Cook, in healthy adults the preferred sensory input for the control of balance is somatosensory information from the feet in contact with the supporting surface. An AFO would prevent the feet from having direct contact with the ground. AFO application may compromise the somatosensory input from the feet and thus a major contributor to balance control may be altered or lost.

Manchester and Woollacott attempted to identify age-related changes in the contributions of somatosensory and visual inputs to balance control by comparing a group of sixteen 18 to 32 year olds to a group of sixteen 60 to 78 year olds. The researchers quantified electromyographic (EMG) responses following displacement on a movable platform. The amount of visual input was controlled while
somatosensory input at the ankle was controlled by keeping the ankle at approximately a 90 degree angle. Vestibular input subsequently became the primary factor in balance maintenance. Muscle response latencies remain consistent across age groups. The older group was less stable when ankle somatosensation and peripheral vision were controlled. The older population used proximal to distal pattern of activation (ie. hip strategy) more often.\textsuperscript{32} The AFO is hypothesized to limit the motion at the ankle as was done in this study by other means. It is also hypothesized to alter somatosensory input from the ankle and cause asymmetrical information from the ankles with unilateral AFO application.

AFO’s are commonly used orthotics in elderly patients and can be both beneficial and detrimental. AFO’s may reduce the effectiveness of the ankle strategy and decrease somatosensory input of the foot to the supporting surface. Consequently, balance could be affected. This study seeks to quantify changes in balance measures as a result of AFO application. No research has been found to support or negate these changes as a result of AFO application.

**Force Platforms**

Postural instability can be measured in various ways. Methods of measurement may be divided into three categories: measurement of body segment displacement during standing posture; measurement
of muscle activity responsible for the maintenance of posture; and measurement of the movement of the center of pressure. The latter method of measurement utilizes a biomechanics platform (force platform, force plate) consisting of a rigid plate supported by force transducers, usually placed at the corners, that can sample the three orthogonal components of applied forces and force moments. Three aspects of postural control have been evaluated using force platforms: steadiness, symmetry, and dynamic stability. Steadiness is defined as the ability to keep the body as motionless as possible. Symmetry is the ability to distribute weight evenly between the two feet in upright stance. Dynamic stability is defined as the ability to transfer the vertical projection of the center of gravity (COG) around the supporting base. According to Goldie et al., symmetry and dynamic stability measures are easily defined through force platform outputs.

Underlying all these indices is an assumption that unsteadiness is proportional to the variability of the force platform outputs and that the measures described therefore have face validity. However, steadiness has not been theoretically defined in terms of force platform measures. Furthermore, there is no external criterion against which the validity of measures can be established.

Goldie found center of pressure and force measures to be representative of changes in stance difficulty. She tested 28 healthy subjects in four basic stance positions. Steadiness of
stance was evaluated using force platforms. This study lent support for the face validity of force platform measures.\textsuperscript{43} Biomechanic measures of postural instability may be more precise and less dependent on observer variability than conventional measures, such as making objective follow-up measurements testing interventions on balance and gait.\textsuperscript{42}

**Balance Master**

The Balance Master\textsuperscript{®} is a highly quantitative tool used for balance assessment. The basic components of balance control assessed include center of gravity/center of mass (COG/COM), postural alignment, limits of stability (LOS), and rhythmic weight shifts. Six standard protocols have been established to measure these components and to evaluate both static and dynamic control of the patient's COG. Subtests one through three assess postural alignment by having the individual stand on the force plate with eyes open, with eyes closed, and with focusing on a visual target on the computer screen. Subtests four and five evaluate an individual's ability to perform rhythmic weight shifts in the lateral and anterior-posterior directions. Subtest six evaluates the patient's ability to move through various angles within the LOS.\textsuperscript{44} The LOS for standing balance is defined as the maximum angle a body can achieve
from the vertical without losing one’s balance. A fall, stumble, or step will occur once the LOS is exceeded.\textsuperscript{22} According to Nashner,\textsuperscript{30} the LOS is 8 degrees in the anterior direction, 4 degrees in the posterior direction, and 16 degrees in the lateral direction. Weakness of ankle or hip musculature can adversely affect an individual’s LOS.\textsuperscript{22} Results of the six subtests are numerically computed on the basis of quality, control, and speed. Quality is based on error or deviation from a straight line in the path to the target. Control is determined by the sway or steadiness upon reaching the target, and speed is assessed by the transition time or speed of movement to reach the target.\textsuperscript{44}

**Summary**

Equilibrium is dependent upon the three sensory systems and muscle strategies working within the functional reserve. With aging, these components tend to have reduced functional capabilities and more readily experience breakdown. The additive effects of age-related changes can be demonstrated in the elderly population. The introduction of an external aid such as an AFO may further alter the effectiveness of the components required for balance control in the elderly. Limited studies exist in the literature addressing the effect of AFO's on balance. The Balance Master\textsuperscript{®} is an objective measure for assessing balance regulation. Patla\textsuperscript{45} has determined
that "the development of a data base on normal changes in balance
control with age is essential, not only to our understanding of the
effects of disease processes, but also to assist us in helping the
elderly to enjoy a better quality of life." We hypothesize that the
application of an AFO to a well elderly population will reduce an
individual's ability to maintain dynamic balance, as measured by the
Balance Master®. If data is found to support this hypothesis,
additional research on select populations, such as hemiplegic or
neurologically involved subjects, would be advocated with the goal
of more effective patient care.
CHAPTER 3

METHODOLOGY

Subjects and Study Site

Volunteers for this study were recruited from local senior citizen centers. Potential participants were given verbal and written information regarding both the nature of our research, screening for eligibility, and the procedures that would take place. At the end of the information session, individuals were given a chance to ask any questions or request further explanation. When all questions had been answered to the satisfaction of the individuals, they were asked to read over and sign an informed consent form (Appendix A) prepared by the principal investigators.

Procedures

Individuals were screened by the principal investigators. Each individual was asked to fill out an information sheet regarding their past medical history and functional status at the present time (Appendix B). In an effort to increase the homogeneity of our sample, each participant met the following eligibility criteria: (1) aged 65-79 years, (2) ambulatory without assistive devices, (3) independent in activities of daily living, (4) able to statically
stand for seven minutes, (5) good visual acuity as determined by scores on the Snellen Vision Screen, (6) deny history of any significant neurological insult including cerebrovascular accident (CVA), Parkinson's disease, multiple sclerosis, dementia, peripheral nerve injury or deficit to the lower extremities, head injury, middle ear disease, or any other significant balance impairment resulting in more than two falls in the past six months, (7) deny history of significant orthopedic insult including hip or knee joint replacement, limb amputation, unhealed fractures, instability in hip, knee, or ankle joints, and (8) ankle range of motion (ROM) to neutral.

Eighteen eligible participants' height and weight were measured using a measuring tape to the nearest 0.5 inch and the intrinsic scale on the Balance Master®. Leg dominance was determined according to the Bruininks-Oseretsky Test of Motor Proficiency pretest for arm and leg dominance. A prefabricated AFO was placed on the previously determined dominant leg. Participants were instructed to walk a distance of 25 feet to check for fit and comfort. Further adjustments were made at the individual's request.

Balance was assessed using the Balance Master® 3.2 version following the standard protocol as stated in the Balance Master® user's manual. The Balance Master® protocol consisted of six
subtests arranged in the following order: (1) align/no target/eyes open, a static test measuring sway; (2) align/no target/eyes closed, a static test measuring sway without visual aid; (3) align center target, participant has to try to maintain the cursor within a target area at their approximate COG as determined by height and weight; (4) rhythmic weight shifts/lateral, participants are asked to follow a cursor at three different speeds by shifting their weight from left to right and right to left within a target area (Fig 1); (5) rhythmic weight shifts/anterior-posterior, participants were asked to follow a cursor at three different speeds by shifting their weight from forwards to backwards and backwards to forwards within a target area; and (6) limits of stability (LOS), participant is asked to shift their weight moving primarily at the ankles to targets placed at 75 percent of the estimated LOS (Fig 2). The LOS subtest includes eight transitions which identify the direction of weight shift required to reach the target. These transitions, numbered one through eight, begin in the twelve o'clock position (zero degrees) and proceed in a clockwise direction in 45 degree increments. Transition one begins with the individual shifting weight forward towards the zero degree position. Transition two requires the individual to weight shift in a right forward direction toward the 45 degree target position. The Balance Master R protocol was followed with the exception that
participants were tested in appropriate footwear to accommodate the application of an AFO. A standard walker was adjusted to the participant's height. In the event of a loss of balance, individuals were instructed to reach for the walker.

Each individual was tested twice with the Balance Master® machine, once with an AFO and once without an AFO. Sequencing of test conditions was randomly assigned. Following testing under the first condition, the participant was given a rest of 7 to 10 minutes.

The subjects were instructed to stand on the force platform. Foot placement was determined according to the Balance Master® protocol. Verbal prompts were read by the investigator directly from the screen to the individual prior to each subtest. Opportunity was given for further explanation before the testing began. Participants were informed when the test would begin and when it had ended.

**Data Reduction**

The data recorded without the AFO acted as control data and the data recorded with the AFO as the experimental data. Individuals served as their own controls. The data was analyzed comparatively for statistical significance. In subtests one through three, sway area was analyzed using a paired T-test with $p<0.05$. In
subtests four and five, speed and endpoint position were analyzed using a paired T-test with $p<0.05$. In subtest six, speed, path error and sway area were analyzed using a paired T-test with $p<0.05$. 
CHAPTER 4
RESULTS

Characteristics of Participants

Twelve women and six men ranging from 65 to 79 years of age participated in this research project. The mean age of the participants was 71.2 years. All participants were found to be right foot dominant according to the Bruininks-Oseretsky test for leg dominance. Thus, all AFO trials involved the right lower extremity.

Data Analysis

For each participant, scores of the trial with AFO and trial without AFO were analyzed for statistical significance using the paired T-test with p<0.05 (Tables 1, 2). The N values varied because portions of data could not be used for statistical analysis. Points of significance between trials with AFO and trials without AFO were isolated to two subtests of the Balance Master® protocol: rhythmic weight shifting (left/right) and LOS.

Within the rhythmic weight shifting (left/right) subtest, two areas of significance were found. During the three second pacing interval, trials without AFO had a greater mean time (seconds) standard deviation (SD) than trials with AFO (p=0.0048), (Figs 3, 4). The time standard deviation refers to standard deviation of the
time needed to cover the path length. During the one second pacing interval, trials without AFO had a greater mean offset SD (percent LOS) than trials with AFO (p=0.0252), (Fig 5). The offset SD refers to the average amount of variability from the mean distance away from the target.

Several areas of significance were revealed in the LOS subtest. Two areas were found in transition one in a forward direction. Trials without AFO had a greater mean target sway (percent maximum area) than trials with AFO (p=0.0284), (Fig 6). Target sway is the sway that occurs once the individual has reached the target position. Also, trials with AFO had a greater mean direction error (degrees) than trials without AFO (p=0.0451), (Fig 7). The direction error refers to the degree deviation from the desired path to the target. Four areas of significance were found in transition two in a right forward direction. First, trials with AFO had a greater mean patient position (percent LOS) than trials without AFO (p=0.0046), (Fig 8). The patient position is the final location reached by each individual as measured by a percent of the individual’s available LOS. Second, trials without AFO had a greater mean patient position (degrees) than trials with AFO (p=0.0135), (Fig 9). The patient position in this case refers to the final location reached by each individual as measured by the degrees of variance.
from the first 45 degree interval. Third, trials with AFO had a
greater mean distance error (percent LOS) than trials without AFO
(p=0.0052), (Fig 10). The distance error is the distance as expressed
by a percent that the individual fell short of reaching the 75 percent
LOS. Finally, trials without AFO had a greater mean direction error
(degrees) than trials with AFO (p= 0.0135), (Fig 11). The final areas
of significance were found in transition five in a backward
direction. Trials with AFO had a greater mean movement time
(seconds) and path sway (percent path length) than trials without
AFO (p=0.0267 and p=0.0085 respectively), (Figs 12, 13). The
movement time is the amount of time needed to move to the target,
and the path sway is the amount of sway that occurred enroute to
the target.

Hypothesis/Research Question

Our hypothesis states that the application of an AFO to the
dominant lower extremity of well elderly will reduce an individual's
ability to maintain dynamic balance, as measured by the Balance
Master®. This hypothesis was supported by the statistical
significance found in select areas of the rhythmic weight shift
(right/left) and the LOS subtests. For all other subtests, trials with
AFO and trials without AFO did not show statistically significant
results; therefore, the research hypothesis was rejected.
CHAPTER 5

DISCUSSION AND IMPLICATIONS

Discussion/Suggestions for Research

Several areas noted in our literature review, as well as our data and subjective observations during trials, may have significant impact on further research. Our study is one attempt to objectively quantify changes in balance noted with AFO use. The data revealed areas of significance in relation to trials with AFO and without AFO in the elderly; however, limitations of this study may prevent any specific conclusions from being drawn. Our results support the hypothesis that AFO application does influence some factors associated with balance maintenance as measured by the Balance Master in our sample population.

In subtests one through three, the obtained p values were not significant. During these subtests, no statistical difference was found between trials with AFO and without AFO. These findings may suggest AFO have no measurable effects on static standing balance.

The first area of significance was found in the rhythmic weight shifting (left/right) subtest. Trials with AFO had less variability in the sampled times at the three second speed than trials without AFO (p=0.0048). Trials without AFO demonstrated
greater variability in the sampled times. A possible explanation may be an increase in tactile feedback to the lower leg as a result of AFO application. This increase in feedback may have allowed easier error correction and speed modification in weight shifts side to side. Horak and Shumway-Cook suggest that AFO application may compromise the somatosensory input, therefore, losing a major contributor to balance maintenance. The AFO may provide a rigid framework fostering more consistent movement times. Trials without AFO may have had less tactile input making correction and modification relatively delayed and inconsistent.

According to the Balance Master protocol, right and left boundary targets were placed at 50 percent of the individual's calculated LOS. Individual's actual LOS was calculated in the Balance Master protocol as a result of height and weight measurements. An idea for future study would be to examine the effects of AFO application in weight shifts (right/left) beyond the 50 percent boundary as in the protocol. This increase in percent LOS may elicit more discrepancies between AFO and non-AFO trials.

Another significant area within the rhythmic weight shifting subtest is that AFO trials were found to have less variability in the distance from the target line during weight shifts at the one second pacing (p=0.0252). The above explanation may also apply in this
situation. An increase in tactile input provided by the configuration of the AFO may facilitate error correction and modification and thus increase target accuracy.

Additional areas of significance were revealed in the LOS subtest regarding the quantity and the quality of movement. In regards to the quality of movement in the forward direction, the results obtained for direction error and target sway in the forward and the right forward directions seemed to conflict. Trials with AFO in the forward direction had greater direction error in obtaining the specified target \( (p=0.0451) \); yet, once at the target AFO trials had less target sway than trials without AFO \( (p=0.0284) \). AFO application may alter the amount of ROM available for forward weight shift movement strategies needed for dynamic stability yet aided static stability once volitional movement ceased. The rigidity of the AFO may limit the ability for the graded control needed for precise incremental movement but may provide support while statically positioned. However, in the right forward direction, direction error was greater in trials without AFO. This apparent contradiction is difficult to explain based on the sample size in this study. Further testing with larger sample sizes could lend support and perhaps offer further explanation regarding AFO and non-AFO trial differences.
Also in the right forward transition, trials with AFO showed a greater distance error from the target LOS than in trials without AFO (p=0.0052). As suggested earlier, the rigidity of the AFO may limit the ability for graded control needed for precise incremental movement.

In regards to the quantity of movement, areas of significance were found in the LOS subtest when participants were required to shift weight in the right forward direction. In trials with AFO participants were more consistent in their ability to reach a larger percentage of their target LOS than in trials without AFO (p=0.0046). Once again, the participant may have been able to use the rigidity of the AFO to give additional external support to reach the target LOS in the right forward direction.

The target LOS proposed by the Balance Master® protocol was at 75 percent of the calculated LOS. The limitations of ankle ROM as a result of AFO application may not have been significant within this 75 percent LOS. Further investigation may show AFO application to have more significant effects on weight shifting as the individual approaches his actual LOS.

Another significant area in shifting weight in the right forward direction is patient position measured in degrees(p=0.0135). Trials with AFO tended to deviate anteriorly (forward) in contrast to
trials without AFO which tended to deviate laterally (right). Since the posterior structure of the AFO is in contact with the posterior aspect of the leg, the AFO could more readily facilitate an anterior translation rather than a lateral translation.

Finally, another area of significance regarding the quality of movement was when participants were asked to shift weight posteriorly to a target LOS (at 75 percent calculated LOS). Trials with AFO yielded a greater movement time (p=0.0267) and a greater path sway (p=0.0085) than trials without AFO. Once again, a possible explanation may be due that the rigidity of the AFO limited graded control. Movement with AFO would consist of graded plantarflexion with primary control of the ankle provided by tibialis anterior. With an AFO, the ankle is fixed at a 90 degree angle keeping the tibialis anterior in a relatively shortened position. Control within the shortened position may be more phasic or sporadic in nature yielding a less accurate target path and more lengthy time of movement.

**Limitations**

To further clarify this study and the results obtained, the limitations inherent to our study need to be discussed.

First, a potential learning effect could have occurred while testing participants. Since the first trial was the participant’s
first introduction to the task, changes noted during the second trial could be attributed to a learning effect rather than the presence or absence of an AFO. Randomization of the order of trials with AFO and without AFO minimize any discrepancy. Although our data did not depict such results, subjective observations of increased understanding and ease of task with subsequent trials support this concept. Further research to determine a standard number of trials necessary to eliminate a learning effect as a potential factor would be of interest.

Another limitation to our study was that a relatively small sample size was used and that it was a sample of convenience. Volunteers were recruited primarily from local senior citizen centers. A majority were regular attendees of an exercise class for the elderly. Our sample is not a true reflection of a cross section of the elderly population but rather a small group of well elderly as determined by our screening procedure. Consequently, our results can not be applied to the general population. Our results do serve as significant stimulus for further research in this area.

The use of the Balance Master® as a measure of changes in balance as a result of AFO application may also be a limitation. The indicators of stability used by the Balance Master® are based on center of pressure (COP) measures. This may not have been the most
ideal measure of the effects of AFO application. The Balance Master protocols were designed to measure balance by using the ankle strategy as a primary means to maintain stability. According to Schenkman, the limitation of movement provided by the AFO renders the ankle strategy no longer functionally useful. The ability to measure balance maintenance as a function of the ankle strategy by the Balance Master could be compromised. Our study was not designed to measure other components of balance; for example, changes in quantity and quality of balance strategies. It is difficult to ensure that participants used primarily the ankle strategy to accomplish the task. Visual observations suggested the use of other strategies. As documented in our literature review, as the support surface is reduced or range of perturbation is increased, an individual progresses from the ankle to the hip strategy.

Limitations inherent to the use of force plates as measures of balance must also be considered. The basic assumption underlying all methods of force plate measures evaluating balance is that forceplate parameters are a measure of unsteadiness. However, unsteadiness has not been defined in terms of force plate measures.

Implications

The inconclusive results of our study prevent any specific clinical implications from being proposed as significance was found...
in aspects of only two of the six subtests. However, our study does show a need for further research with regards to the effects of AFO application to various populations, with an emphasis on functional relevance. A study by Miller and Newton\textsuperscript{46} utilizing similar methods yielded inconclusive results as to discrepancies in balance maintenance between AFO and non AFO trials. Miller and Newton\textsuperscript{46} made recommendations for further research with AFO use in specific populations. Methods more comprehensive than force platforms are indicated including measures of; movement strategies, assessment of response symmetry, and implications on function.
REFERENCE LIST


22. Flores AM. Objective measurement of standing balance. 


46. Miller BM, Newton RA. The effect of ankle foot orthosis on postural sway. Poster presentation at combined sections meeting; February 6, 1993; San Antonio, Tex.
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>SUBTEST</th>
<th>PARAMETER</th>
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<tbody>
<tr>
<td>ORD417</td>
<td>Rhythmic weight shift (left/right)</td>
<td>Time SD</td>
</tr>
<tr>
<td>ORD435</td>
<td>Rhythmic weight shift (left/right)</td>
<td>Offset SD</td>
</tr>
<tr>
<td>ORD815</td>
<td>Limits of Stability (forward)</td>
<td>Target Sway</td>
</tr>
<tr>
<td>ORD819</td>
<td>Limits of Stability (forward)</td>
<td>Direction Error</td>
</tr>
<tr>
<td>ORD826</td>
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<td>Patient Position</td>
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<td>Patient Position</td>
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<td>Limits of Stability (right/forward)</td>
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<td>ORD829</td>
<td>Limits of Stability (right/forward)</td>
<td>Direction Error</td>
</tr>
<tr>
<td>ORD853</td>
<td>Limits of Stability (backward)</td>
<td>Movement Time</td>
</tr>
<tr>
<td>ORD854</td>
<td>Limits of Stability (backward)</td>
<td>Path Sway</td>
</tr>
</tbody>
</table>

Table 1. Definition of the orders and parameters of significance.
| VARIABLE | N  | MEAN       | STD ERROR OF MEAN | T       | PR>|T| |
|----------|----|------------|-------------------|---------|------|
| ORD417   | 17 | -0.35117647| 0.10750473        | -3.27   | 0.0048|
| ORD435   | 12 | -1.49666667| 0.57813616        | -2.59   | 0.0252|
| ORD815   | 12 | -0.47500000| 0.18841645        | -2.52   | 0.0284|
| ORD819   | 18 | 3.41666667  | 1.57963448        | 2.16    | 0.0451|
| ORD826   | 18 | 4.82777778  | 1.48182465        | 3.26    | 0.0046|
| ORD827   | 18 | -4.00000000 | 1.45172874        | -2.76   | 0.0135|
| ORD828   | 18 | 4.77222222  | 1.48996218        | 3.20    | 0.0052|
| ORD829   | 18 | -4.00000000 | 1.45172874        | -2.76   | 0.0135|
| ORD853   | 15 | 2.04266667  | 0.82495106        | 2.48    | 0.0267|
| ORD854   | 15 | 181.18800000| 39.19419792       | 3.06    | 0.0085|

Table 2. Results of paired T-test analysis of data from trial with AFO and trial without AFO for each individual. Mean is obtained by subtracting value for trial without AFO from trial with AFO. Negative mean values indicate larger value for trial without AFO. Positive mean values indicate larger value for trial with AFO.
FIGURES
Patient Name: 
Data File: 8bot,sm 
Target/Prot. Type: SP04, 
Therapy Mode: Beep,Feedback. 
Post-Test Comment:

**Rhythmic weight shift - Left/Right**

**PATH**

**SWAY AREA**

**Numerical Summary**

<table>
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<tr>
<th>Pacing Time</th>
<th>Amp Mean (% LOS)</th>
<th>Amp SD</th>
<th>Offs Mean (% LOS)</th>
<th>Offs SD</th>
<th>Time Mean (sec)</th>
<th>Time SD</th>
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<tr>
<td>3 sec</td>
<td>49.06</td>
<td>5.26</td>
<td>0.39</td>
<td>1.30</td>
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<td>2 sec</td>
<td>53.92</td>
<td>1.90</td>
<td>0.90</td>
<td>1.50</td>
<td>2.04</td>
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<tr>
<td>1 sec</td>
<td>66.77</td>
<td>5.08</td>
<td>-0.27</td>
<td>3.04</td>
<td>1.14</td>
<td>0.11</td>
</tr>
</tbody>
</table>

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Figure 1. Balance Master® version 3.2 subtest four: Rhythmic weight shift (Left/Right).
Figure 2. Balance Master® version 3.2 subtest six: Limits of stability.
Figure 3. Key to figures 4 - 13.
Figure 4. Rhythmic weight shift (Left/Right), three second pacing, plotting mean time standard deviation. Trials without AFO had a greater mean time standard deviation than trials with AFO (p=0.0048).
Figure 5. Rhythmic weight shift (Left/Right), one second pacing, plotting offset standard deviation. Trials without AFO had a greater mean offset standard deviation than trials with AFO (p=0.0252).
Figure 6. Limits of stability, forward direction, plotting target sway (percent maximum area). Trials without AFO had a greater mean target sway than trials with AFO (p=0.0284).
Figure 7. Limits of stability, forward direction, plotting direction error (degrees). Trials with AFO had a greater mean direction error than trials without AFO (p=0.0451).
Figure 8. Limits of stability, right forward direction, plotting patient position (percent LOS). Trials with AFO had a greater mean patient position than trials without AFO (p=0.0046).
Figure 9. Limits of stability, right forward direction, plotting patient position (degrees). Trials without AFO had a greater mean patient position than trials with AFO (p=0.0135).
Figure 10. Limits of stability, right forward direction, plotting distance error (percent LOS). Trials with AFO had a greater mean distance error than trials without AFO (p=0.0052).
Figure 11. Limits of stability, right forward direction, plotting direction error (degrees). Trials without AFO had a greater mean distance error than trials with AFO (p=0.0135).
Figure 12. Limits of stability, backward direction, plotting movement time (seconds). Trials with AFO had a greater mean movement time than trials without AFO (p=0.0267).
Figure 13. Limits of stability, backwards direction, plotting path sway (percent path length). Trials with AFO had a greater mean path sway than trial without AFO (p=0.0085).
APPENDICES
APPENDIX A

Informed Consent Form

Title: Effects of Ankle Foot Orthoses Application on Standing Balance in the Elderly

Facility: Grand Valley State University Department of Physical Therapy Allendale, MI 49401

Committee Members: Barbara Baker, MPT (chairperson) Karen Ozga, MPT George Sturm, PhD

Investigators: Jeralyn Gray, BS, SPT Tammy Krueger, BS, SPT Denise Krynicki, BS, SPT

Purpose of Study: This study seeks to quantify changes in standing balance due to the application of an AFO.

Procedures: I understand that this study requires my participation for approximately 45 minutes. During this time I will be fitted for an AFO. Also, I will be asked to stand on a platform and shift my weight, which will measure my standing balance. I will also be asked to answer questions and demonstrate some aspects regarding my functional independence.

Changes: I understand that I will be informed of any changes in the nature of this study or the aforementioned procedures before they occur.
Risks or discomfort: I understand that these procedures involve no unusual risk as these are standard assessments used by therapists. I also understand that I may request a copy of the results of this study upon completion.

Assurances: I understand that at any time I may withdraw from this study with no adverse reactions from the principal investigators.

Report: I understand that I will be given an identification number at the beginning of this study and that my name will not be used. I understand that the results of this study may be published in such a way as to not disclose my identity. I am aware that my records remain confidential.

Physical Injury: In the event of physical injury immediate and appropriate measures will be taken.

I have carefully read this informed consent and have had adequate explanation of the proposed procedures.

Date_________ Time_________ Subject ____________________________

Date_________ Time_________ Witness____________________________

I the undersigned have explained and described in detail the proposed procedures in which the above individual has consented to participate.

Date_________ Time_________ Investigators________________________
### APPENDIX B

**Patient Information Form**

<table>
<thead>
<tr>
<th>Name ___________________________</th>
<th>ID # ________</th>
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<tbody>
<tr>
<td>Age ________</td>
<td>AFO ___ 1st</td>
</tr>
<tr>
<td>Height ________</td>
<td>___ 2nd</td>
</tr>
<tr>
<td>Weight ________</td>
<td></td>
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**Ankle ROM to neutral**  
Y N

**Dominant leg**  
R L

### MEDICAL HISTORY:
Do you now have or ever been diagnosed with any of the following:

<table>
<thead>
<tr>
<th>Neurological</th>
<th>Orthopedic</th>
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<tr>
<td>Y N Stroke</td>
<td>Y N Hip or knee replacement or major surgery</td>
</tr>
<tr>
<td>Y N Parkinson's disease</td>
<td>Y N Limb amputation</td>
</tr>
<tr>
<td>Y N Multiple Sclerosis</td>
<td>Y N Unhealed fractures</td>
</tr>
<tr>
<td>Y N Dementia</td>
<td>Y N If yes, where?</td>
</tr>
<tr>
<td>Y N Head Injury</td>
<td>Y N unstable hip, knee, or ankle</td>
</tr>
<tr>
<td>Y N Middle ear disease</td>
<td></td>
</tr>
<tr>
<td>Y N Significant Balance impairment (resulting in &gt; 2 falls in past 6 mos.)</td>
<td></td>
</tr>
<tr>
<td>Y N Peripheral nerve injury to legs (numbness or weakness)</td>
<td></td>
</tr>
</tbody>
</table>

### FUNCTIONAL HISTORY:

| Y N Can you walk without any assistance including canes or walkers? |
| Y N Are you able to do your own care? |
| Y N Dressing? |
| Y N Bathroom? |
| Y N Fixing meals? |
| Y N Light cleaning? |
| Y N Can you stand in place for 7 minutes? |

### PLEASE RATE YOUR OVERALL WELL BEING:

Excellent ___________________________ / ___________________________ poor average
AUTOBIOGRAPHICAL STATEMENT

JERALYN J GRAY: Jeralyn has a Bachelors of Science degree in biology from Grand Valley State University, Allendale, Michigan. She is currently pursuing a Masters of Science degree in physical therapy also from Grand Valley State University.

TAMMY L KRUEGER: Tammy has a Bachelors of Science degree in health science from Grand Valley State University, Allendale, Michigan. She is currently pursuing a Masters of Science degree in physical therapy also at Grand Valley State University.

DENISE K KRYNICKI: Denise has a Bachelors of Science degree in health science from Grand Valley State University, Allendale, Michigan. She is currently pursuing a Masters of Science in physical therapy also at Grand Valley State University.