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The Effects of an Articulated Ankle-Foot Orthosis on Dynamic Balance in Elderly Subjects with Hemiplegia

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The Effects of an Articulated Ankle-Foot Orthosis on Dynamic Balance in Elderly Subjects with Hemiplegia

By

Cathi Logan
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THESIS

Submitted to the Department of Physical Therapy at Grand Valley State University, Allendale, Michigan in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN PHYSICAL THERAPY
1998
The Effect of an Articulated Ankle-Foot Orthosis on Dynamic Balance in Elderly Subjects with Hemiplegia

ABSTRACT

The purpose of this study was to determine if a difference exists in dynamic balance of elderly subjects with hemiplegia when the affected lower extremity is braced with an articulated ankle-foot orthosis (AFO) versus unbraced. Participants were volunteers with a history of a cerebral vascular accident resulting in hemiplegia who required the use of an articulated AFO for ambulation. Balance data was obtained from the random limits of stability test on the Balance Master® version 3.4. Path length and limits of stability were analyzed using a multifactorial ANOVA. The AFO did not have a statistically significant effect on path length or limits of stability. The subject, target position, and trial number all showed significant effects on path length and limits of stability. Since only four people volunteered for this study, the results cannot be extrapolated to a larger population. However, this study provides the theoretical framework for future research.
DEDICATION

We would like to dedicate this thesis to our husbands for their continuous support and patience while we pursued our Master's degrees in Physical Therapy.
ACKNOWLEDGEMENTS

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1. our committee members for their help and support, with a special thanks to our chairperson for all of her advice and guidance throughout this project.

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3. Sandy Nagel, PT, who helped orient us to the use of the Balance Master® and Carla Wylie, PT, who helped coordinate the available times to use the Balance Master®.

4. the participants in this study who volunteered their time to help us with our research project.
PREFACE

Operational Definitions

**Ankle-Foot Orthosis (AFO):** A plastic or metal brace that extends from the foot to below the knee. This device can be either solid or have hinges, and is used to keep the ankle in an optimal position or range of positions (Duncan & Badke, 1987; O'Sullivan & Schmitz, 1994; Shurr & Cook, 1990).

**Ankle strategy:** The muscles around the ankle are activated to assist in maintaining balance. For this strategy to be effective, the support surface must be longer than the feet (O'Sullivan & Schmitz, 1994; Guccione, 1993).

**Balance Master:** A force platform system used to measure balance. The person stands on the thin platform, and a computer connected to the platform detects the person’s movements (NeuroCom, 1990).

**Dynamic Balance:** A person’s ability to maintain his/her balance while moving part or all of the body (O'Sullivan & Schmitz, 1994).

**Hemiplegia:** A common result of a brain lesion, such as a stroke, where strength and sensation are decreased to varying degrees on one side of the body (O'Sullivan & Schmitz, 1994; Pierson, 1994).

**Hip strategy:** The muscles around the hip are activated to assist in maintaining balance. This strategy is normally used when the ankle strategy is not enough to regain balance or if the support surface is shorter than the feet (Guccione 1993; O'Sullivan & Schmitz, 1994).
**Limits of Stability (LOS):** Often represented as an inverted cone around a person with the apex at the feet, this is the farthest point at which the person can lean without moving the feet before having to take a step to regain balance (O'Sullivan & Schmitz, 1994; Woolf, 1981).

**Path Length:** The person's trajectory when weight shifting to the highlighted target while performing the Random Limits of Stability Test (NeuroCom, 1990).

**Proprioception:** The main type of sensation from a joint which provides information concerning the movement and position of the parts of the body (Woolf, 1981).

**Random Limits of Stability Test:** The test consists of eight targets set at a specific percentage of the person's theoretical limits of stability. The computer randomly highlights the targets, and the person must weight shift from center to move a cursor on the screen to the designated target (NeuroCom, 1990).

**Somatosensory:** The system of the body that conveys information about the state of the body and its immediate environment (Woolf, 1981).

**Target Position:** This refers to the location of the target in the Balance Master's Random Limits of Stability test in reference to the person's affected side of the body.
**Theoretical Limits of Stability:** The Balance Master® mathematically determines what the person’s limits of stability should be according to the person’s height, weight, and age (NeuroCom, 1990).
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CHAPTER ONE
INTRODUCTION

Aging is an inevitable process of life which spares no bodily system. Many physical and physiological changes occur during this process. These changes include an overall decrease in muscle mass, strength, and endurance (O'Brien, 1994). Normal age-related changes also include a decrease in selective muscle control, slower reaction times, longer mental processing times, and an overall decrease in speed of movement. In the sensory system, the body requires greater sensory stimulation to achieve the same response as in a younger individual. In addition, aging results in decreased joint proprioception; compromised ability to detect light touch, pressure, and vibration; decreased ability to detect linear and angular acceleration; and impaired visual acuity. All of these changes could impede balance responses (Craik, 1993).

Maintaining balance is a very complex process which involves the use of somatosensory, visual, vestibular, and musculoskeletal systems (Anacker & DiFabio, 1992). Balance is important in performing daily functional activities, and this becomes a concern in the elderly population. Without the ability to maintain balance, independence can be lost. In the well-elderly population, balance is diminished due to normal age associated changes. These changes decrease the amount of information contributed by the sensory and musculoskeletal systems for maintaining upright posture and for making adjustments when maintaining and exceeding limits of stability (LOS). LOS are reached when the center of pressure is displaced to its maximum point before going beyond the person's base of support. A fall may occur when a person
exceeds his/her LOS and is unsuccessful in performing the necessary postural adjustments.

"Aging can bring an increased risk of experiencing debilitating falls. Deterioration in postural balance may be a major contributor to many of these falls, resulting in an impaired ability to correct for the many postural disturbances experienced in everyday life..." (Maki, Holliday & Topper, 1994, p. M72). Falls are an increasing problem and are very common in the elderly population (Perlin, 1992). Falls are estimated to occur in 30% of people 65 years and older (Ryan, Dinkel & Petrucci, 1993). The aged are at a higher risk for falls because of the numerous, inevitable age-related changes. According to Perlin (1992), injuries are the sixth leading cause of death in the elderly, with most of these casualties due to falls.

The normal changes associated with aging are compounded when the elderly individual suffers from a cerebrovascular accident (CVA) (Dunleavy, 1995). A CVA is commonly known as a stroke and often results in many deficits. The primary motor problem that is seen after a stroke is muscle weakness (Chu & Reddy, 1995; Dunleavy, 1995; Nepomuceno et al., 1994). Weakness is most pronounced on one side of the body and is commonly known as hemiplegia. Changes in muscle tone can also occur after a stroke. Tone can range from flaccidity (absence of tone) to spasticity (excessive tone). Similarly, an alteration of sensation can be seen on one side of the body (O'Sullivan & Schmitz, 1994; Shumway-Cook & Woollacott, 1995). According to Shumway-Cook and Woollacott (1995), after a stroke, people often exhibit a delay in postural response time. The alterations in strength, tone, sensation and postural response are variable in intensity and occurrence. Having one or more of these impairments could result in balance deficits.
Many people with hemiplegia are prescribed an ankle-foot orthosis (AFO) to correct for dorsiflexion weakness, plantarflexor hypertonicity or ankle instability. The application of an AFO is warranted because it provides the safest, fastest, most efficient means of improving function (Chu & Reddy, 1995; Duncan & Badke, 1987). The AFO improves function, but at the same time, it restricts the amount of motion available at the ankle. Although research has shown that the application of an AFO improves functional performance, very little information can be found that demonstrates the consequences of AFOs on balance. However, Siegel and Bernardoni (1993) stated that “... the foot plate of a standard plastic ankle-foot orthosis (AFO) interposes a barrier between the sole of the foot and the floor, blocking the kinesthetic input these feet require for balance” (p. 983). There is also a paucity of research pertaining to how AFOs alter proprioceptive and other sensory information.

**Purpose of Study**

The purpose of this study is to determine if there is a significant difference in dynamic balance of elderly people with hemiplegia when the affected lower extremity is braced with an articulated AFO versus unbraced. One of the major premises of this study is that a person wearing an AFO is unable to use full ankle range of motion needed to assist in maintaining balance. Another premise is that the AFO limits the amount of sensory feedback from the foot needed to stimulate the muscles around the ankle to maintain balance. Measurements will be taken on the Balance Master® to ascertain the effects of AFOs on dynamic balance.

This research could benefit many different realms of patient care with our focus being on physical therapy. Clinically, physical therapists could utilize this information when implementing balance related activities. Some of the current
balance exercises include weight shifting to the involved side; hip, trunk, and postural strengthening; and muscle control exercises. Physical therapists also impose perturbations to elicit postural responses as a way of retraining balance (Nawoczenski & Epler, 1997; O'Sullivan & Schmitz, 1994; Tangeman, Banaitis, & Williams, 1990). Most exercises are incorporated into everyday activities to facilitate use of learned activities in daily life. These exercises aim "...to regain motor control, strength, physical conditioning and mobility, and return to independent living" (Gresham et al., 1995, p. 193). If the hypothesis is found to be true, the therapists can educate the patients specifically about the differences in balance with and without the AFO. In addition to current exercises, the therapist can offer the patient different options to maintain balance while wearing the AFO because of the inability to use ankle musculature.

Hypothesis

The hypothesis is that the application of an articulated AFO on the affected lower extremity of elderly people with hemiplegia will adversely affect dynamic balance as tested by the Balance Master*.
CHAPTER TWO
LITERATURE REVIEW

Introduction

Many different factors involved in our study must be discussed in order to fully understand the geriatric hemiplegic population. This review will describe each component separately and will show how they affect balance. In this literature review, we will discuss normal aging, balance, falls, hemiplegia, orthotics, and the Balance Master®.

Normal Aging

Biological aging is a developmental process that begins at birth and continues throughout life, terminating at death. It is characterized by alterations in the ability of an organism to maintain homeostasis (Butler, 1980). “Normal aging brings deterioration in many functions, which may produce an increased tendency to fall. Among such physiologic factors are loss of vision, loss of ability to maintain balance, muscle weakness (particularly of the lower extremities), and loss of mental alertness” (Perlin, 1992, p. 237).

Among the numerous changes that occur in the visual system, one is a decrease in the ability to see in low light. Others include a decreased proficiency of the eye to adapt to abrupt changes in light, an inability to judge distances effectively, a decrease in color differentiation, and the inability to discriminate very close or peripheral objects. In addition, reflections off shiny objects can severely hinder an elderly person’s vision (Guccione, 1993).

The vestibular system is also adversely affected by aging. A marked decline in the sensitivity of the vestibular apparatus occurs. Other signs and
symptoms related to the aging vestibular system can include vertigo, nystagmus, and postural imbalance (Guccione, 1993).

The somatosensory system consists of the integration of the central nervous system with the peripheral nervous system. With advancing age, many changes occur that hinder a person’s ability to detect sensory information. The sensory nerve fibers and the receptors that detect light touch and vibration both dramatically decrease in number. The activation threshold of the neurons increase, thus making it harder to detect sensory information from the body. The receptor decrease, the decline in sensory nerve fibers, and the change in the activation threshold are all responsible for sensory deficits (Guccione, 1993).

Researchers have shown that there is a deterioration of position sense with increasing age (Craik, 1993). However, research shows a minimal amount of information pertaining to the extent of the age related changes in proprioception. According to Anacker & DiFabio (1992), a decrease in proprioception at the ankles could contribute to the incidence of falls. Chandler and Duncan (1993) corroborate this notion by saying, “loss of proprioception is also a fixed deficit and may be a potential contributor to the patient’s instability” (p. 248). Balance is impacted tremendously in the aging population because of the normal age associated changes that occur in the sensory system. To produce appropriate balance responses, visual, vestibular, and somatosensory information must be integrated (Anacker & DiFabio, 1992).

Approximately one percent of muscle strength is lost each year after the age of 30 (O'Brien, 1994). Of the many inevitable aging changes that occur in the musculoskeletal system, a decrease in muscle mass is the most predominant. This decline is seen more in the lower extremities as compared to the upper extremities (Perlin, 1992). The type I and type II muscle fibers
deteriorate, which contributes to the decrease in muscle mass. Type II muscle fibers, also known as fast twitch fibers, are responsible for quick, strong contractions. Aging causes a notable decrease in the number of type II fibers. The type I fibers are not affected to the same extent. These fibers are called slow twitch and are used for endurance contractions such as maintaining posture. Finally, there is a decrease in the number of action potentials generated, thereby decreasing the number and strength of muscle contractions (Guccione, 1993).

**Balance**

Many factors influence balance, such as sensation, muscle strength, range of motion, and motor control. An impairment in any of these areas can interfere with the ability to effectively maintain balance. The sensory system consists of visual, vestibular, and somatosensory divisions. Together, these three components provide critical information for balance, although all three are not required to maintain balance (Anacker & DiFabio, 1992). To avoid disequilibrium, a person can overcome a deficit in one component by relying on the other two. Visual input is one way an individual orients his/her body in space in reference to objects in the environment. Vision is also helpful in anticipating necessary postural adjustments when facing variations in the support surface. The vestibular system is a vital component used for balance maintenance. This system detects linear and angular movements of the body. If this intricate system is not intact, a person has more difficulty maintaining an upright position.

The somatosensory system includes light touch, deep pressure, pain, temperature, and proprioception. Both feedback and feed forward information are used by the central nervous system in maintaining balance. Feed forward is
used to describe the production of movement patterns that do not require conscious processing by the brain. In other words, feed forward consists of the automatic movements produced by the body, such as reaching with an outstretched arm (Duncan & Badke, 1987; Leonard, 1990). On the other hand, feedback requires the brain to use sensory input for analyzing and revising movement patterns. Feedback is utilized in new and complex situations, as in walking in the dark. Therefore, information from the sensory system allows the musculoskeletal system to perform efficiently (Duncan & Badke, 1987). The three sensory components are interrelated, but the use of the components vary between people, and different environmental conditions affect which component the person will use (Shumway-Cook & Woollacott, 1995). For example, in the dark, vision would not be used as much as vestibular and somatosensory components.

An important factor in maintaining balance is the presence of an effective musculoskeletal system. In order for the musculoskeletal system to operate efficiently and to have optimal strength, the body must be in ideal postural alignment. Adequate joint range of motion must be available to allow for the desired movement. Muscle strength is a key component in initiating and maintaining postural adjustments. Postural muscles are activated according to the position needed to perform the task. Muscles that primarily contract to perform an action can also be used to maintain body alignment (Leonard, 1990).

When a group of muscles is activated to sustain balance, this is called a strategy. The three strategies employed in maintaining balance are the ankle strategy, the hip strategy, and the stepping response (Guccione, 1993; Leonard, 1990). These strategies are tools used to assist the individual in maintaining
neutral body alignment and in response to perturbations. The size of the support surface, the magnitude of the perturbation, and the individual's abilities determine which strategy is used. The ankle strategy is used to stabilize the body's position by contracting muscles to produce a torque around the ankle. Minimal movement occurs at the hip. This strategy can only be used if the support surface is longer than the length of the foot and if the individual has intact sensory systems. The ankle strategy is performed when there is a sudden loss of balance. Specific muscle sequencing must occur when using this maneuver. The primary muscles involved are tibialis anterior, gastrocnemius, quadriceps, and hamstrings. The muscle contractions occur distally to proximally in response to the disturbance. For example, the tibialis anterior must contract before the quadriceps muscles when losing balance backward (Leonard, 1990). When older adults have diminished postural control, they tend to use a proximal to distal sequence (Guccione, 1993).

When the force produced around the ankle is not great enough to compensate for the loss of balance, or if the support surface is too short, the hip strategy must be employed. This tactic involves the contraction of the muscles around the hip to shift the body weight in an attempt to regain balance. In contrast to the ankle strategy, the muscles involved contract in a proximal to distal pattern. Muscles activated include the abdominals, quadriceps, paraspinals, and hamstrings. When both of these strategies are not enough to regain balance, the individual must take a step in order to prevent a fall, which is called the stepping response (Leonard, 1990). In order to accomplish this action, adequate strength, range of motion, sensation, and motor control of the trunk and lower extremities must be available.
Falls

Falls are not an inevitable part of the aging process, although the incidence drastically increases with age. According to Ryan, Dinkel and Petrucci (1993), 30% of the elderly will fall each year, and of those 5-10% will result in a serious injury. The elderly population is at a high risk of falling because of the detrimental effects of aging on balance control (Dunleavy, 1995). A decrease in balance results in an impaired ability to adjust to the numerous perturbations that occur in everyday life. Tripping, slipping, overcoming obstacles, and self induced displacements such as turning and reaching are just a few of the many contributing factors to falls (Dunleavy, 1995; King, Judge, & Wolfson, 1994; Maki, Holliday, & Topper, 1994). In addition to the balance deficits, "the inability of an aging neural system to integrate multiple sensory elements may be one factor that contributes to the risk of falling in older persons" (Anacker & DiFabio, 1992, p. 576). Other contributing factors include a history of previous falls, fear of falling, gait disturbances, sensory impairment, neurologic diseases, multiple medications, and cerebrovascular disease (Brady et al., 1993). Anacker & DiFabio (1992) state that the sensory input from the ankle is the most important factor for preventing falls, with vision being the second most important factor. This sensory information from the ankles is critical in order to know when an ankle strategy should be implemented. One common cause of sensory deficits that impact fall prevention strategies is a pathological condition, such as a CVA.

Hemiplegia

O'Sullivan defines a cerebrovascular accident as a sudden, focal neurologic deficit resulting from ischemic or hemorrhagic lesions in the brain. Clinically, a variety of deficits are possible, including impairments of sensory,
motor, mental, perceptual, and language functions...

Sensation is frequently impaired but rarely absent on the hemiplegic side. Proprioceptive losses are common. Loss of superficial touch, and pain and temperature sensation is also common and contributes to overall perceptual dysfunction and risk of self-injury (p. 327).

As a consequence, people with hemiplegia are forced to compensate for their sensory and motor deficits by utilizing abnormal mechanisms for maintaining posture (Pai, Rogers, Hedman, & Hanke, 1994). According to Wu, Huang, Lin, and Chen (1996), compensatory mechanisms may cause an unbalanced weight distribution through the lower extremities and displace the body's center of pressure, resulting in an asymmetrical posture. Asymmetrical posture is not ideal for activities of daily living because with the inability to fully weight bear, the functional base of support is severely diminished. This change in the base of support causes a decreased ability to maintain balance during normal activities. Therefore, asymmetrical posture is a major cause of falls (Wu, Huang, Lin, & Chen, 1996).

Turnbull, Charteris and Wall (1996) studied people with hemiplegia on a force platform system. They compared the weight shift capabilities in stance of people with hemiplegia to a control group of healthy peers. The authors found that the centers of pressure of people with hemiplegia were displaced toward the unaffected side, and the subjects were unable to shift their weight backward over the affected leg. These authors also confirmed that people with hemiplegia exhibit a decreased area of stability. This decrease suggests that people with hemiplegia might be either unwilling or incapable of shifting their weight away from the center of their support base. "This study clearly showed marked deficiencies in the ability of hemiplegic subjects to voluntarily shift weight over the lower limbs compared to normal subjects" (Turnbull, Charteris,
Pai, Rogers, Hedman and Hanke (1994) also studied weight shift abilities in people with hemiplegia on a force platform system. They found that subjects could successfully weight shift to the uninvolved side 48% of the time and toward the involved side only 20% of the time. Their study demonstrates that deficiencies in weight shifting capabilities occur both in the affected and unaffected sides following a stroke. Badke & Duncan (1983) suggested that since most stroke patients bear less weight (34-54% of their body weight) over the involved lower extremity, which reduces the amount of input to the neuromuscular system, sensory feedback is reduced. The decrease in sensory input further compounds the deficits seen with normal aging. The inability to successfully shift weight from one lower extremity to the other, along with the lack of information coming from the somatosensory system, further compromises the person’s capacity to perform the strategies necessary to preserve balance.

Another possible consequence of a stroke is cognitive impairment. Cognition deficits are very common and can impact a person’s functional ability. Depending on the location of the brain damage, several impairments could be evident. Many people with CVA have difficulty with memory, concentration, and perception (O'Sullivan & Schmitz, 1994). These deficits must be considered during the rehabilitation process. One perceptual deficit that is commonly found in people with left hemiparesis is called left neglect (Nepomuceno et al., 1994). With this impairment, the person does not see or perceive anything from the left side of the body. The degree of the impairment is variable, however, the presence of this deficit will inevitably hinder function. The risk of falling greatly increases because the person may be incapable of noticing obstacles in his/her
path. The identification of left neglect is important in this study. The participants must be able to see images in various locations on a computer screen. If the individual cannot perceive information from any part of the computer screen due to left neglect, he/she cannot participate in this study.

One of the most noticeable effects of a stroke is motor deficiency. Decreased strength, reduced coordination, and changes in muscle tone can be characteristics of this impairment. The impaired coordination after a stroke is further compounded by the decrease in type II muscle fibers occurring in the normal aging process. Therefore, an elderly person with hemiplegia is less able to perform quick, alternating movements needed to execute coordinated activities (Guccione, 1993). Changes in muscle tone occur in varying degrees, ranging from flaccid (no tone) to spastic (excessive tone). Weakness of the dorsiflexor muscles and/or spasticity of the plantarflexor muscles in the lower extremity can cause many problems, such as drop foot. Drop foot is the inability to adequately dorsiflex the foot and is a common deficit that occurs after a stroke (Chu & Reddy, 1995; Intiso, Santilli, Grasso, Rossi, & Caruso, 1994). Drop foot often involves instability at the ankle due to the muscles being too weak to control joint position. In addition, if the cause of drop foot is hypertonicity (excess tone) in the plantarflexors, the ankle is in a fixed position of plantarflexion (Bronstein, Popovich, & Stewart-Amidei, 1991; Duncan & Badke, 1987; Sammarco, 1995). This condition leads to toe drag during gait instead of the normal heel to toe contact (Bronstein, Popovich, & Stewart-Amidei, 1991; Duncan & Badke, 1987; O'Sullivan & Schmitz, 1994). Often an AFO is prescribed to these patients in an attempt to control foot position, whether due to muscle weakness or excessive tone (Chu & Reddy, 1995; O'Sullivan & Schmitz, 1994). The use of an AFO for drop foot maintains the foot in a position that
optimizes function and facilitates more efficient walking (Bronstein, Popovich, & Stewart-Amidei, 1991).

**Orthotics**

An orthotic is a temporary or permanent device that is applied to a specific part of the body to enhance function. These devices are constructed to manage deficits, such as abnormal tone, weakness, muscle imbalances, instability, joint range limitations, impaired tissue integrity, and pain. One specific type of orthotic is the double upright AFO. This AFO has two metal upright bars that can either be attached to the sole of the shoe or a foot plate that slides directly into the shoe. The typical ankle joint used with a double upright AFO can be adjusted to allow for free ankle motion, or limited to decrease dorsiflexion and/or plantarflexion. To limit plantarflexion, a stop is created by using pins to block further movement of the hinge (Duncan & Badke, 1987; Shurr & Cook, 1990). Another type of orthotic is the molded ankle-foot orthosis (MAFO) which can be rigid or articulated (Shurr & Cook, 1990). The difference between a rigid and articulated AFO is the available range of motion at the ankle. A rigid AFO has a solid ankle portion that is fixed in one position, which inhibits movement at the ankle joint. In contrast, an articulated AFO consists of two separate components connected by hinges at the ankle. This articulation allows for dorsiflexion and plantarflexion of the ankle. If the amount of movement around the ankle needs to be limited, the AFO can be altered to reduce the available range of motion (O'Sullivan & Schmitz, 1994).

Typically, plastic AFOs are made with polypropylene or polyethylene in a vacuum-forming procedure. These thermoplastic materials are custom fitted to the patient by using a positive plaster mold (Chu & Reddy, 1995; Shurr & Cook, 1990). “The major advantages to a totally plastic MAFO are improved
cosmesis, interchangeability of shoes, and extreme lightness" (Shurr & Cook, 1990, p. 129). An advantage of using a double upright AFO is its adjustability. It can be easily modified as the patient's needs change (Duncan & Badke, 1987). AFOs provide mechanical resistance to the distal lower extremity to enhance stability (Burdett, Borello-France, Blatchly & Potter, 1988; O'Sullivan & Schmitz, 1994). In general, patients who require an AFO include: those who have undergone surgery for tendon transfer or heel cord lengthening, those who have hemiplegia, or those with peripheral neuropathy (Burdett et al., 1988; O'Sullivan & Schmitz, 1994).

AFOs benefit patients with hemiplegia by alleviating drop foot, increasing stability of the ankle joint, and correcting for excessive plantarflexor tone. These improvements are achieved because the orthosis puts the joint in its correct biomechanical position (Burdett et al., 1988; Chu & Reddy, 1995; Duncan & Badke, 1987; O'Sullivan & Schmitz, 1994). An AFO is indicated when the person suffers from pain and severe instability at the ankle (Burdett, Borello-France, Blatchly & Potter, 1988; O'Sullivan & Schmitz, 1994). A disadvantage of using an ankle-foot orthosis is that it acts as a barrier between the bottom of the foot and the floor. This barrier alters the amount of sensory feedback received through the foot. Since people with hemiplegia may already have a decrease in sensation, the use of the orthotic may further compound their deficit by inhibiting some of the necessary sensory information required for maintaining balance (Siegel & Bernardoni, 1993).

In addition to affecting sensory feedback, the use of an articulated AFO may restrict ankle range of motion, which limits the ability to use an ankle strategy for balance. Therefore, when wearing this device, a person's ability to perform an effective ankle strategy is hindered, and he or she must rely on
either a hip strategy or stepping strategy to maintain balance (Nawoczenski & Epier, 1997). Gray, Krueger, and Krynicki (1993) used the Balance Master to study the effects of AFOs on balance in well-elderly individuals. This study included 18 individuals aged 65-79. A prefabricated solid AFO was applied to each participant on his/her dominant lower extremity, and both static and dynamic balance were assessed on the Balance Master. The results of this study showed a significant decrease in dynamic balance when the AFO was applied. According to Ryan, Dinkel, and Petrucci (1993), the higher the number of physiological, social, and environmental risk factors an elderly person faces, the greater the risk he or she has of falling. Therefore, due to the sensory deficits, the limited range of motion, and the inability to perform all three balance maintaining strategies, an elderly person with hemiplegia who wears an orthotic is likely to be at a high risk for falls.

**Balance Master**

A force platform system is an objective method of measuring a person's ability to control body sway and weight shifts. One particular force platform system is the Balance Master. This piece of equipment consists of two force transducers covered with two force plates which are situated side by side. A personal computer and monitor are attached to the transducers to assess the balance performance. This system assesses the location of the individual's center of pressure and the amount of sway during static standing. Dynamic standing is assessed by determining the movement path of weight shifts as well as the time required to reach the designated target during weight shifting. Theoretical limits of stability are calculated by using the individual's age, height, and weight. Targets are placed on the screen at a selected percentage of the theoretical limits of stability. Continuous feedback of the location of the center of
pressure during both quiet standing and weight shifting is also provided by the 
Balance Master® (Hageman, Leibowitz, & Blanke, 1995). This system not only 
measures the position of the center of pressure, but also the weight bearing 
distribution of the lower extremities (Wu, Huang, Lin, & Chen, 1995).

The computer program is designed to use six different functional tests to 
measure balance. The first three evaluate static balance, including sub tests 
with eyes open, closed, and with visual feedback provided by the cursor and 
targets on the computer screen. The last three tests measure dynamic balance. 
The first dynamic test is the lateral weight shift test. This requires the subject to 
shift his/her weight side to side in order to match the timing and movement of a 
cursor on the computer screen. The cursor oscillates horizontally between two 
target lines. The second dynamic test is the anterior posterior weight shift test. 
This test is the same as the lateral weight shift test with the exception that the 
subject must weight shift anteriorly and posteriorly to follow the cursor moving 
vertically on the screen. The protocol for both the lateral and anterior-posterior 
weight shift tests is set at 50% of the theoretical limits of stability. Finally, the 
third test assesses the participant's limits of stability (LOS) at a range of 75% of 
the person's maximum (Hageman, Leibowitz, & Blanke, 1995; Liston & 
Brouwer, 1996). The eight targets of the LOS test are arranged in a clock-like 
pattern equally distributed around the circle (see Appendix A). The computer 
randomly highlights the targets, and the participant is required to weight shift 
from the center position to move the cursor to the target. This procedure is 
repeated until every target has been highlighted.

Other assessment tools that are commonly cited in the literature to 
evaluate balance include the Fugl-Meyer Assessment (FMA), the Berg Balance 
Scale, and the Functional Reach Test. The FMA is a three point ordinal scale
that assesses both upper and lower extremities for motor recovery, synergies, and reflex activity. Reliability and validity have been established for the FMA; however, it is very time consuming, subjective, and complex. It assesses much more than balance, including pain, range of motion, sensation, and voluntary movement (Duncan & Badke, 1987; Gresham et al., 1995). This study focuses on balance and requires objective data. Consequently, this tool is not appropriate for use in this analysis.

The Berg Balance Scale has also been shown to be reliable and valid. This assessment tool focuses on balance during functional activities. It uses a four point ordinal scale to rank the person's performance (Gresham et al., 1995). This is a subjective scale and does not provide the precise objective information needed for this study.

The Functional Reach is a test used to assess ability and willingness to move to the outer borders of a person's limits of stability (Chandler & Duncan, 1993). The patient is required to stand in a comfortable posture and is then asked to reach forward as far as possible. A yardstick is affixed to the wall, and the distance between the starting and ending positions is measured in inches. This test is quantitative and is shown to be correlated with incidence of falling. However, due to the fact that the ankle strategy is not required to perform this test, the Functional Reach Test is not the most appropriate method to assess balance in this study.

The Balance Master™ was chosen as the assessment tool in this study because of its specificity to balance. For example, the Balance Master™ shows the location of the center of pressure in relation to the person's theoretical limits of stability. The Balance Master™ yields objective data that reflects the person's ability to weight shift with and without an AFO. An ankle strategy is the most
efficient way to perform tests on the Balance Master®. If the ankle strategy is limited, the data will reflect this as a decreased ability to weight shift to the designated targets. The Balance Master® is considered to be a safe instrument to use for challenging and assessing balance on subjects with hemiplegia while collecting objective data. (Liston & Brouwer, 1996; NeuroCom Int., 1990). The major premise of this study is that a person's ability to use an efficient ankle strategy when wearing an AFO is decreased.

The Balance Master® is able to detect differences in balance with and without the AFO because it is sensitive to changes in force distributions when using an ankle strategy. The Balance Master® is an appropriate tool to examine specific changes in balance that might occur in geriatric stroke patients when wearing an AFO (Hageman, Leibowitz, & Blanke, 1995; NeuroCom Int., 1990).

The Balance Master® is not only appropriate for measuring balance, it has also been shown to be valid and reliable. Liston and Brouwer (1996) studied the balance of 20 subjects with hemiplegia using the Balance Master®, the Berg Balance Scale, and the gait-velocity test. The data from all three tests were correlated to determine the validity of the Balance Master®. They determined that the Balance Master® data was valid because the associations among the tests were significant. The main finding of the study was that the random LOS test at 75% of theoretical limits of stability demonstrated good reliability. For the LOS test at 75%, movement time had an intraclass correlation coefficient (ICC) value of 0.88 and movement path had an ICC value of 0.84. Any ICC value above 0.75 is considered to demonstrate good reliability (Portney & Watkins, 1993). According to Liston and Brouwer (1996), "...in stroke patients the test-retest reliability of data obtained using the BM is greatest for complex tests of balance and that dynamic rather than static balance measures are valid.
indicators of functional balance performance" (p. 425).

Dettman, Linder, and Sepic (1987) studied the relationships between walking performance, postural stability, and functional performance in people with hemiplegia. This study revealed that performance on the limits of stability test correlated with walking capacity in people with hemiplegia. Hageman, Leibowitz, and Blanke (1995) studied 12 healthy adults on the Balance Master* to determine test-retest reliability using all six of the Balance Master* tests. They found that “Balance Master measures of movement time to targets (ICC [3,4] = .83), and path length to targets  (ICC [3,4] = .78) showed moderate reliability” (p. 963). Hageman, Leibowitz, and Blanke (1995) also studied 24 community dwelling individuals ranging in age from 20-75 years. The study assessed the effects of aging on balance using the Balance Master* and showed that the “Balance Master* measures are sensitive to impairments associated with aging and pathology...” (p. 3).

**Summary**

The intention of this literature review is to show the intricate relationships between normal aging, falls, hemiplegia, and orthotics and how they relate to balance. Normal aging is an inevitable process which causes balance deficits and increases a person’s risk for falls. Moreover, when an individual suffers from a stroke, the resulting sensory and motor deficits are compounded when there is application of an ankle foot orthosis. The AFO limits sensory information coming from the sole of the foot and restricts ankle mobility, both of which are vital when maintaining balance. Although research indicates that the use of an AFO enhances functional performance, the effects of an articulated AFO on dynamic balance have not been established in the literature. By using the Balance Master*, we intend to show how the use of an AFO affects balance.
in elderly people with hemiplegia.
CHAPTER THREE
METHODOLOGY

Subjects

The researchers obtained a list of 75 potential subjects from the orthotics department at a local rehabilitation hospital. Each person on the list was contacted by telephone to ask for voluntary participation. The telephone conversation included an explanation of the study and questions to determine the volunteer's eligibility. Questions pertained to the volunteer's medical history and functional ability (see Appendix B). Four subjects volunteered to participate in the study. Two of the subjects were male, and two were female. All subjects were at least 65 years old. There was no cost to the participants except their own transportation to and from the study site. Each person had a history of a stroke which resulted in either right or left sided hemiplegia and required the use of an articulated AFO. Participants were able to follow simple instructions, which was demonstrated by completing the informed consent form (see Appendix C) and answering medical history questions. They were also able to see targets on the computer monitor which was positioned at eye level approximately two feet away (Liston and Brouwer, 1996). The researchers tested vision by placing a piece of paper with 1/4 inch letters two feet away and asking the subjects to read each letter out loud. Each subject was ambulatory, with or without the use of an assistive device, and was able to stand independently without an assistive device. All participants were able to maintain a foot flat position when standing. Exclusionary criteria included: a history of neurological diseases and deficits other than those from the stroke; dementia; peripheral neuropathy; absent
sensation in the lower extremities; vestibular deficits; lower extremity amputation; unhealed fractures in the lower extremity; and soft tissue lesions on the sole of the foot. (Anacker & DiFabio, 1992; Hageman, Leibowitz, & Blanke, 1995; King, Judge, & Wolfson, 1994; Liston & Brouwer, 1996; Turnbull, Charteris, & Wall, 1996).

**Study Site**

The researchers conducted the study at Mary Free Bed Outpatient Therapy Center in Grand Rapids, Michigan. The Balance Master® was located in a separate room for privacy. Grand Valley State University’s Human Subjects Review Committee and Mary Free Bed Hospital’s Research Committee and Human Subjects Review and Ethics Committee all approved this study prior to data collection.

**Materials**

The researchers used the Balance Master® version 3.4 to collect data. This is a force-platform system and is described in detail in the literature review. To measure height, we used a standard tape measure that was permanently affixed to the wall. Vision was tested by asking each participant to read 1/4 inch letters on a piece of paper positioned at eye level and two feet in front of him/her (see Appendix D). A gait belt was secured around each participant’s waist to ensure safety. A standard walker was positioned in front of each subject in case of loss of balance during testing.

**Procedure**

One of the researchers completed a past medical history form (see Appendix B) for each subject after the participant verbally answered the questions. An informed consent form (see Appendix C) was read and completed by each volunteer upon arrival at the study site. The researchers
assigned an identification number to each participant that was used throughout the study to protect patient confidentiality. Once both forms were completed, a brief evaluation of sensation and vision was performed. Lower extremity sensation was tested using light touch according to Kendall’s dermatomal map for the lower extremity (Kendall, McCreary, & Provance, 1993). Vision was assessed by holding a piece of paper with letters 1/4 inches high two feet away from the participant. The letters were in a circular pattern. To be included in the study, each participant was required to correctly recite all of the letters in a clockwise direction starting at the top of the paper (see Appendix D).

Assessment of the participant’s ability to stand unassisted was by patient report. Height was measured to the nearest inch by having the participant stand against a measuring tape on the wall. If any questions regarding medical history on the patient information form were answered yes, the person was excluded from the study. If any questions under functional history on the patient information form were answered no, the person was excluded from the study.

The researchers randomly assigned the first participant into one of two categories by using a coin toss. A coin landing heads up meant that the person would start the test by donning the AFO. A coin landing heads down meant he/she would start without the AFO. The first participant started the testing with his AFO on. The next participant was assigned to start with his AFO off, and the following subjects alternated accordingly. Only one researcher gave instructions and administered the Balance Master® tests. The other researcher performed the preliminary tests, positioned the feet on the force platform, and guarded each participant during Balance Master® testing. Eliminating variability of instructions, testing styles, and testing procedures was important to maintain consistency, which enhanced intrarater reliability in this study. There was a
minimal risk of falling. In order to prevent a fall, a walker was positioned directly in front of each participant, and all participants were required to wear a gait belt. Each person was instructed to grasp the walker if needed. If a participant stepped off the force platform or grasped the walker, the trial was recorded as a mistrial, and the trial was repeated. If any participant experienced three mistrials within a test no data from that participant was used in analysis.

The researchers followed the Balance Master® protocols for the random limits of stability test with the exception that appropriate footwear was worn to accommodate the use of the orthotic. The patient was instructed to step on the force platforms with shoes. The researcher that administered the preliminary tests lined up the medial malleoli to the transverse force plate line. The other researcher gave initial instructions (see Appendix E) and read the directions displayed on the computer screen to each participant prior to testing. All participants had the opportunity to ask any questions before testing began. One practice trial was allowed prior to each test. Without moving his/her feet, the participant was required to use weight shifts to move the cursor on the computer screen to the designated targets. The test assessed the participant’s limits of stability. The eight targets of the Random LOS test were arranged in a clock-like pattern equally distributed around the circle (see Appendix A). The computer randomly highlighted the targets, and the participant was required to weight shift from the center position to hit the target with the cursor. This procedure was repeated until every target had been highlighted. Each participant performed three trials of the test. The participant then donned or doffed his/her orthotic and repeated the procedure.

Once the tests were finished, the participants were escorted out of the research room and were free to leave. The entire procedure took 40 to 60
minutes, depending on the participant’s ability. To maintain confidentiality, only one participant was allowed in the research room at a time.
CHAPTER FOUR
RESULTS AND DATA ANALYSIS

Data Analysis

This was a quasi-experimental study. Data was collected from the Balance Master® version 3.4 computer software program. The control data consisted of information recorded when the participants were not wearing their AFOs. The experimental data was that from the same participants when wearing their AFOs. Data obtained from the random limits of stability test included path length and limits of stability. Both path length and limits of stability were recorded as percentages. These percentages were analyzed using a multifactorial analysis of variance (ANOVA). A significance level of \( p < 0.05 \) was used. The independent variable was the presence of the orthotic, and the dependent variable was the balance performance.

Results

Information was compiled from five volunteers. However, one subject was eliminated because of a middle ear disease and the inability to remove his AFO from his shoe, which was a requirement of all participants. The four remaining subjects consisted of two women and two men ranging in age from 68-79 years and in height from 64-67 inches. The two men had a history of left sided CVAs, while the two women had right sided CVAs (see table 1).

The data was analyzed using a multifactorial analysis of variance to determine if the path length and limits of stability differed based on four factors: the use of an AFO, subject, target position, and trial number. The AFO factor was analyzed independently for both path length and LOS (see table 2).
subject factor was analyzed to determine how much variation was noted in performance among all participants (see table 3). The target position is defined as the location in reference to each participant's affected side (see table 4). All trials were numbered in order from 1-6 and were looked at separately to determine if a learning effect or fatigue factor was present (see table 5). The ANOVA was used to determine whether or not the observed differences of the sample were statistically significant.

When analyzing path length, the four factors that were simultaneously taken into account were subject, trial number, target position and the use of the AFO. The subject, trial number and target position were found to be the significant factors affecting the path length ($p = 0.00$, $0.05$, and $0.00$ respectively). The use of the AFO was not found to be statistically significant ($p = 0.52$) (see table 6). When all factors except the AFO and the patient were excluded, the use of the AFO was still not found to be significant ($p = 0.65$) (see table 7).

The same four factors were again analyzed together to determine their effects on the participants' LOS. Once more, the subject, trial number, and target position were found to be statistically significant ($p = 0.00$, $0.01$, and $0.00$ respectively). The effects of the AFO were not found to be significant ($p = 0.19$) (see table 8). As with path length, the use of the AFO was not found to be significant ($p = 0.24$) in regard to LOS when excluding target position and trial number (see table 9).
### Table 1

**Descriptive Statistics of the Subjects**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age</th>
<th>Height</th>
<th>Side</th>
<th>Onset of CVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Male</td>
<td>78</td>
<td>65 in</td>
<td>Right</td>
<td>1994</td>
</tr>
<tr>
<td>Two</td>
<td>Male</td>
<td>68</td>
<td>67 in</td>
<td>Right</td>
<td>1994</td>
</tr>
<tr>
<td>Three</td>
<td>Female</td>
<td>79</td>
<td>64 in</td>
<td>Left</td>
<td>1985</td>
</tr>
<tr>
<td>Four</td>
<td>Female</td>
<td>75</td>
<td>67 in</td>
<td>Left</td>
<td>1994</td>
</tr>
</tbody>
</table>

### Table 2

**Mean Subject Data for AFO Including all Subjects, Target Positions, and Trials During Random Limits of Stability Test**

<table>
<thead>
<tr>
<th>AFO</th>
<th>Mean path length (%)</th>
<th>Mean LOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>without</td>
<td>436.85</td>
<td>45.88</td>
</tr>
<tr>
<td>with</td>
<td>457.41</td>
<td>47.99</td>
</tr>
</tbody>
</table>

### Table 3

**Mean Subject Data for Each Subject Including all Target Positions, Trials, and With & Without AFO During Random Limits of Stability Test**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean path length (%)</th>
<th>Mean LOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>one</td>
<td>306.06</td>
<td>49.47</td>
</tr>
<tr>
<td>two</td>
<td>734.47</td>
<td>31.57</td>
</tr>
<tr>
<td>three</td>
<td>408.74</td>
<td>48.40</td>
</tr>
<tr>
<td>four</td>
<td>336.73</td>
<td>58.50</td>
</tr>
</tbody>
</table>
Table 4

**Mean Subject Data for Each Target Position Including all Subjects, Trials, and With & Without AFO During Random Limits of Stability Test**

<table>
<thead>
<tr>
<th>Target position</th>
<th>Mean path length (%)</th>
<th>Mean LOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>front</td>
<td>386.73</td>
<td>50.13</td>
</tr>
<tr>
<td>front unaffected</td>
<td>252.96</td>
<td>60.88</td>
</tr>
<tr>
<td>unaffected</td>
<td>246.20</td>
<td>55.07</td>
</tr>
<tr>
<td>back unaffected</td>
<td>446.75</td>
<td>46.26</td>
</tr>
<tr>
<td>back</td>
<td>618.08</td>
<td>40.36</td>
</tr>
<tr>
<td>back affected</td>
<td>587.25</td>
<td>40.51</td>
</tr>
<tr>
<td>affected</td>
<td>497.92</td>
<td>42.68</td>
</tr>
<tr>
<td>front affected</td>
<td>547.84</td>
<td>39.26</td>
</tr>
</tbody>
</table>

Table 5

**Mean Subject Data for Each Trial Including all Subjects, Target Positions, and With & Without AFO During Random Limits of Stability Test**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean path length (%)</th>
<th>Mean LOS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>one</td>
<td>517.96</td>
<td>44.52</td>
</tr>
<tr>
<td>two</td>
<td>510.75</td>
<td>42.91</td>
</tr>
<tr>
<td>three</td>
<td>478.08</td>
<td>43.99</td>
</tr>
<tr>
<td>four</td>
<td>394.62</td>
<td>50.95</td>
</tr>
<tr>
<td>five</td>
<td>418.89</td>
<td>49.62</td>
</tr>
<tr>
<td>six</td>
<td>364.39</td>
<td>49.48</td>
</tr>
</tbody>
</table>

Table 6

**ANOVA for Path Length by Subject, AFO, Trial Number, and Target Position**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>5506307.00</td>
<td>3</td>
<td>1835436.00</td>
<td>32.45</td>
<td>0.00</td>
</tr>
<tr>
<td>AFO</td>
<td>23076.37</td>
<td>9</td>
<td>23076.38</td>
<td>0.41</td>
<td>0.52</td>
</tr>
<tr>
<td>trial #</td>
<td>658871.41</td>
<td>5</td>
<td>131774.30</td>
<td>2.33</td>
<td>0.05</td>
</tr>
<tr>
<td>position</td>
<td>3400969.00</td>
<td>7</td>
<td>48582.80</td>
<td>8.59</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table 7

**ANOVA for Path Length by Subject and AFO**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>5609168.00</td>
<td>3</td>
<td>1869723.00</td>
<td>25.14</td>
<td>0.00</td>
</tr>
<tr>
<td>AFO</td>
<td>14952.20</td>
<td>1</td>
<td>14952.20</td>
<td>0.20</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 8

**ANOVA for LOS by Subject, AFO, Trial Number, and Target Position**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>17851.58</td>
<td>3</td>
<td>5950.53</td>
<td>47.92</td>
<td>0.00</td>
</tr>
<tr>
<td>AFO</td>
<td>219.03</td>
<td>1</td>
<td>219.03</td>
<td>1.76</td>
<td>0.19</td>
</tr>
<tr>
<td>Position</td>
<td>10209.23</td>
<td>7</td>
<td>1458.46</td>
<td>11.75</td>
<td>0.00</td>
</tr>
<tr>
<td>Trial #</td>
<td>1903.00</td>
<td>5</td>
<td>380.60</td>
<td>3.07</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 9

**ANOVA for LOS by Subject and AFO**

<table>
<thead>
<tr>
<th>Factors</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F-statistic</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>18294.27</td>
<td>3</td>
<td>6098.09</td>
<td>33.83</td>
<td>0.00</td>
</tr>
<tr>
<td>AFO</td>
<td>249.34</td>
<td>1</td>
<td>249.34</td>
<td>1.38</td>
<td>0.24</td>
</tr>
</tbody>
</table>
CHAPTER FIVE
DISCUSSION AND IMPLICATIONS

The results of this study suggest that the original hypothesis, the application of an articulated AFO on the affected lower extremity of elderly people with hemiplegia will adversely affect dynamic balance as tested by the Balance Master®, should be rejected. The researchers can conclude that the application of the articulated AFO had no significant effect on dynamic balance as assessed by the subjects’ limits of stability and path length. However, the other three factors examined (subject, test number, and position) did affect the LOS and path length. Subject and position were found to be the most significant factors for both path length and LOS.

Upon analyzing the data, several trends were noticed regardless of whether or not the subjects were wearing their AFOs. These trends were not statistically significant, however, they give insight into the participants’ performances. One trend was that there was a large variation in performance across the subjects for both path length and LOS. Another trend perceived was that a learning effect was present for path length. In each set of three trials, the mean values of the last performance were the best. This demonstrates that as the participants progressed through the test, their performances improved. This is indicative of a possible learning effect.

In addition to the learning effect, a fatigue factor was evident for LOS. The subjects performed the best at the beginning of each set of three trials. The subjects’ performances declined as testing proceeded. Their performance indicated that as testing progressed, the participants may have experienced
fatigue. Subject performance also varied with the target position. The subjects performed best for both path length and LOS when trying to reach the targets located toward the front, diagonally forward to the side of the unaffected lower extremity, directly sideways to the unaffected side, and diagonally backward to the unaffected side (see Appendix F). This trend in performance supports a study conducted by Turnbull, Charteris, and Wall (1996). They found that subjects with hemiplegia have difficulty weight shifting over the affected lower extremity and to the back as well as a decreased area of stability. Therefore, the subjects are unwilling or incapable of shifting weight from the center of their base of support.

The last trend noticed was that although performance with the AFO was not statistically different than without the AFO, path lengths were better when the subjects were not wearing their AFOs. A possible explanation could be that the articulated AFO creates a rigid barrier for movement in some of the desired directions. Therefore, the subjects used a less direct path to reach the targets when wearing their AFOs. Another possible explanation is that the articulated AFO may have limited the sensory feedback which could potentially hinder the participants’ performances. In contrast, the participants’ LOS were slightly better when wearing their AFOs. One possible reason why the subjects’ LOS were better with the AFOs was the AFOs gave them more confidence. These subjects were accustomed to wearing the AFOs during all activities. The articulated AFOs provide additional support to the ankle region. The subjects reported feeling uneasy with the decreased amount of support and were afraid of falling when the AFOs were removed. This observation does not support Gray, Krueger, and Krynicki’s study (1993). Their study found that a prefabricated solid AFO significantly hindered dynamic balance in well elderly
subjects. This difference in findings could be because the subjects in our study had hemiplegia and were accustomed to wearing the articulated AFOs. When we removed the AFOs, this lack of support was unfamiliar to these subjects. Another difference in these two studies is that the subjects with hemiplegia used hip strategies instead of ankle strategies.

The researchers had two main premises of this study. The first was that the articulated AFO would limit the participant from using full ankle range of motion needed to maintain balance. The results of this study showed the articulated AFO had no significant effect on dynamic balance. Although the articulated AFO does limit range of motion, all of the subjects were observed to use a hip strategy rather than the ankle strategy during testing. Therefore, the limited ankle range of motion was not a factor during the performance of the tests. The second premise of the study was the articulated AFO limits the sensory feedback from the foot needed to stimulate the muscles around the ankle to maintain balance. This alteration in sensory feedback appears to be overshadowed by the stability provided by the AFO. All of the participants have worn their AFOs daily for at least four years. This period of time has given their bodies time to adjust to the application of the AFO. Therefore, when the AFO is removed, the subjects must then readjust to the absence of the AFO. All participants reported that they were more confident and more comfortable performing the tests when wearing their AFOs.

Limitations

Many limitations of this study need to be discussed. The most prominent limitation is the very small sample size. Due to the lack of participants, a normal distribution of data was not obtainable. In addition, only having four subjects prevents the results from being generalized to a larger population. Another
limitation is the subjects expressed a fear of falling, especially without their AFO, and were hesitant to weight shift as far as possible before losing their balance. This could have skewed the results. A third limitation is one participant reported experience on the Balance Master while the others had no experience. This experience also could have skewed the results. Finally, a limitation is that testing balance on the Balance Master may have limited carryover to functional performance.

Along with the limitations, there are several factors that were not controlled but that could have had a significant effect on the outcome of the study. One factor is that gender may have had an unforeseen effect on the study. Age could also be a factor because this study included an age range of 68-79. This is a large range and could have had an effect on the participants' performances. Because of the limitations, especially the small sample size, the results of this study are not generalizable to a larger population. More research is needed to determine the true effects of an articulated AFO on balance.

Suggestions for Future Research

One modification to this study would be to study a larger geriatric population on the Balance Master. To increase the homogeneity of the sample set, research could be performed while the subjects were still participating in inpatient therapy. Testing could be done at different intervals such as immediately upon receiving an articulated AFO, one week later, and at other prescribed times. Another research idea is to examine if there are differences in performances between males and females. Furthermore, research could be performed to assess whether people who have left hemiplegia demonstrate differences in balance when compared to people with right hemiplegia. Finally, plastic articulated AFOs could be compared to metal articulated AFOs to see if
there is a significant difference in how they affect balance.

**Conclusion**

In conclusion, this study investigated how plastic articulated AFOs affected dynamic balance in subjects with hemiplegia. Within the group of participants, the articulated AFO did not have a statistically significant effect on balance. However, given the small sample size, these results cannot be extrapolated to a larger population. This study provides the theoretical framework for future research regarding the effect of articulated AFOs on balance.
REFERENCES


Appendices
Appendix A

Random Limits of Stability Test
### Patient Information Form

**Name _________________________________  ID # ____________**

AFO: R / L  metal / plastic

**Telephone ______________________________**

**Age __________**

**Height __________**

**Medical History:** Do you have or have you ever been diagnosed with any of the following:

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
<th>Parkinson’s disease</th>
<th>Y</th>
<th>N</th>
<th>leg amputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>N</td>
<td>Multiple Sclerosis</td>
<td>Y</td>
<td>N</td>
<td>unhealed leg fracture</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Other neurological deficit / disorder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Dementia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Peripheral Neuropathy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Head Injury</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Middle ear problems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Unhealed wounds on the sole of either foot</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*(Investigators fill out this portion)*

**Functional History:**

<table>
<thead>
<tr>
<th>Y</th>
<th>N</th>
<th>can person ambulate independently with or without an assistive device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>N</td>
<td>can person stand independently without an assistive device for 6 minutes by patient report</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>can person see letters 1/4 inches high two feet away</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>foot flat position when standing</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>can person follow simple instructions (as demonstrated by verbally answering the medical history portion of this form)</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>lower extremity sensation present</td>
</tr>
</tbody>
</table>
Appendix C

Informed Consent Form

I understand that this is a study of ankle foot orthoses (ankle braces) and their effect on standing balance. It is anticipated that at least 30 people will participate in this study. All testing will take place at Mary Free Bed Hospital. Entire testing procedure will take no longer than 30 minutes. The title of this research project is "The Effects of an Articulated Ankle Foot Orthosis on Dynamic Balance in Elderly Subjects with Hemiplegia".

I also understand that:

1. participating in the study will involve a ten minute initial screening interview regarding questions of current health and past medical history. The study also involves a six minute test on a Balance Master® Machine. The test will require each participant to shift his/her weight as needed to follow a computer program while standing on a thin platform. The platform will detect changes in weight distribution.

2. I have been selected for participation because I have had a stroke that resulted in weakness in one side of my body, and I require the use of an ankle foot orthosis (ankle brace).

3. it is not anticipated that this study will lead to physical or emotional risk to myself. The investigators will be guarding me at all times. I will wear a gait belt during the test and a walker will be in front of me while on the Balance Master® to ensure my safety.

4. the information I provide will be kept strictly confidential and the data will be coded so that identification of individual participants will not be possible.

5. a summary of the results will be made available to me upon my request.

I also acknowledge that:

1. I have been given an opportunity to ask questions regarding this research study and that these questions have been answered to my satisfaction.

2. In giving my consent, I understand that my participation in this study is voluntary and that I may withdraw at any time. In no way would nonparticipation or withdrawal from this study affect any treatment that I am receiving at Mary Free Bed Hospital and Rehabilitation Center.
3. I hereby authorize the investigators to release the information obtained in this study to scientific literature. I understand that I will not be identified by name.

4. I have been given Cathi Logan's and Traci Roon's telephone numbers. I have also been given Paul Huizenga's, Karen Ozga's, and Dr. Ellen Ballard's phone numbers. Paul Huizenga is the chairperson of the Human Subjects Review Board at Grand Valley State University, Karen is the chairperson of this research committee at Grand Valley State University, and Dr. Ballard is the chairperson of the MFB Human Subjects Review and Ethics Committee. I understand that I may contact Paul, Karen, Dr. Ballard or the investigators at any time if I have any questions.

5. I acknowledge that I have read and understand the above information, and that I agree to participate in this study.

__________________________________________  ________________________________
Participant's signature / Date                  Investigator's signature / Date

__________________________________________
Witness' signature / Date

I, __________________ am interested in receiving a summary of the study results.
(Participant's signature)

For questions or information regarding this research project, please feel free to contact:

**Cathi Logan**
student physical therapist / researcher
(616) 795-2301

**Traci Roon**
student physical therapist / researcher
(616) 795-4908

**Paul Huizenga**
Chairperson of Human Subjects Review Board
at Grand Valley State University
(616) 895-2472

**Karen Ozga M.M.Sc., P.T.**
Chairperson of research committee at GVSU
(616) 895-2679

**Ellen Ballard Ph.D.**
Chairperson of the MFB Human Subjects Review and Ethics Committee
(616) 242-9201
Appendix D

Vision Screen

A

S

Y

D

J

F

R

G
Appendix E

Initial Testing Instructions

Each subject was read the following instructions:

(1) Step on to the platform

(subject's feet were placed in the appropriate place)

(2) If it is more comfortable, you can move your toes out a little bit, but you need to keep your heels right where we put them.

(3) Do not move your feet now that they are set.

(4) Keep your hands at your side.

(5) Do not touch the walker unless absolutely necessary.

(6) You are the little blue person on the screen, and you control where it goes by shifting your weight.

(7) Try to move the little blue person as directly and as close to the target as possible.

(8) One at a time, each target will turn yellow to show you where to go, but you need to make sure you wait until it beeps before you begin. Then follow the circle to the target, hold it there until it beeps again, and then return to the center.
Appendix F

Graphical Representation of One Subject's Performance during the Random Limits of Stability Test