THE EFFECT OF BODY WEIGHT SUPPORT TREADMILL TRAINING ON PARETIC LEG CONTRIBUTION IN HEMIPARETIC WALKING IN PERSONS WITH CHRONIC STROKE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL

FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF SCIENCE

BY

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Elicia N. Ozimek

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DECLARATION

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

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Elicia N. Ozimek

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ABSTRACT

THESIS: The Effect of Body Weight Support Treadmill Training on Paretic Leg Contribuion in Hemiparetic Walking in Persons with Chronic Stroke

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The purpose of this study was to assess the effect of BWSTT on paretic limb function using the outcome measures of overground walking velocity, paretic leg propulsion, and the mechanical work produced by the hip, knee, and ankle of the paretic limb. Thirteen participants with chronic stroke, ranging in age from 40 to 80 years, completed 24 sessions of BWSTT over eight weeks. Overground walking velocity and bilateral kinematics and kinetics were collected prior to and following completion of the BWSTT intervention. All participants exhibited statistically significant increases in overground walking velocity post BWSTT. Neither the propulsive impulse of the paretic limb, relative to total propulsive impulse, nor the relative contribution of the paretic hip, knee, and ankle to total positive work significantly changed post BWSTT. The results suggest that paretic limb function remains unchanged following BWSTT, despite improvements in overground walking velocity.

TABLE OF CONTENTS

LIST OF TABLES

‡Tables from research article, Chapter 4. Number sequencing from beginning of Chapter 4.

LIST OF FIGURES

‡Figures from research article, Chapter 4. Number sequencing from beginning of Chapter 4.

NOMENCLATURE

BWSTT – body weight support treadmill training

BWS – body weight support

TM - treadmill

GRF – ground reaction force

A-P – anterior-posterior

CHAPTER 1

DEVELOPMENT OF THE PROBLEM

Introduction

Cerebrovascular accident, or stroke, is the third leading cause of death and the primary cause of long-term disability in the United States (Rosamond, Flegal et al. 2008). Following stroke, many individuals experience residual neurological and functional deficits, resulting in a multitude of impairments. These impairments include, but are not limited to decreased muscle coordination, strength, balance, and sensation. Hemiparesis, weakness on one side of the body, resulting from damage to motor neurons and their pathways, is one of the most debilitating impairments post-stroke. This traumatic insult to the brain often leads to diminished strength, particularly in the muscles used for locomotion, thereby impairing an individual's ability to walk (Olney and Richards 1996). Interventions used for the rehabilitation of gait for individuals post-stroke have aimed to reduce these impairments; however, most of the positive results reported are limited to improvements in walking speed. While increases in walking speed for patients with stroke are important for improving community access (Schmid, Duncan et al. 2007), the contribution of the paretic and non-paretic limbs to walking may provide more useful information.

Many studies have focused on post-stroke locomotion because of the reduction in independent mobility (Brandstater, de Bruin et al. 1983; Morita, Yamamoto et al. 1995; Turnbull, Charteris et al. 1995; Roth, Merbitz et al. 1997; Brown and Kautz 1999; Kim and Eng 2003; Kim and Eng 2004; Chen, Patten et al. 2005; Lamontagne, Stephenson et al. 2007). Researchers have employed a number of assessment tools in order to evaluate and quantify the gait asymmetries characteristic of hemiparetic gait. The gait of individuals with post-stroke hemiparesis is characterized by reduced walking speed (Brandstater, de Bruin et al. 1983; Turnbull, Charteris et al. 1995), disproportionate timing of the gait cycle (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005; Lamontagne, Stephenson et al. 2007), uncoordinated movement patterns (Wagenarr and van Emmerik 1994; Barela, Whitall et al. 2000), and decreased force output by the paretic limb (Morita, Yamamoto et al. 1995; Kim and Eng 2003; Bowden, Balasubramanian et al. 2006).

Spatio-temporal parameters are the easiest to obtain and therefore are the most widely used assessment tools for evaluating hemiparetic gait (Brandstater, de Bruin et al. 1983; Wall and Turnbull 1986; Roth, Merbitz et al. 1997). Some of the most common measurements performed include walking speed, walking velocity, and stance and swing duration, among others. Brandstater et al. performed an analysis of temporal variables of hemiparetic gait, comparing the results to those of healthy subjects (Brandstater, de Bruin et al. 1983). In this study, the patients with stroke walked significantly slower, with decreased cadence and stride length (Brandstater, de Bruin et al. 1983). Similarly, Turnbull et al. compared the range of walking speeds, from the slowest speed to the fastest speed the subjects were able to walk, between subjects with hemiparesis and healthy, age-matched controls, examining the effects of walking velocity on stride time and stride length (Turnbull, Charteris et al. 1995). Results indicated that the subjects with hemiparesis walked significantly slower, with a shorter stride length, across the entire range of walking speeds compared to the healthy subjects. Additionally, although both groups displayed a similar decrease in stride time with increased walking speed, the group of subjects with hemiparesis still demonstrated slower stride times overall (Turnbull, Charteris et al. 1995).

In addition to slower gait speeds, individuals with hemiparesis also display asymmetrical swing and stance phases, when compared to healthy subjects walking at a comfortable, self-selected speed. Even when healthy, age-matched subjects walk at slower speeds to match those of individuals with post-stroke hemiparesis, the proportion of time spent in stance versus swing remains uneven in the paretic and non-paretic limbs. On average, the swing phase tends to be shorter for the non-paretic limb, whereas it is increased for the paretic limb (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005). Therefore, a longer proportion of time is spent in stance phase on the non-paretic limb versus a shorter amount of time in stance phase on the paretic limb (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005).

While a majority of gait studies involving individuals with post-stroke hemiparesis have examined spatio-temporal variables, some have also examined the kinematic gait profiles associated with post-stroke hemiparetic gait (Kuan, Tsou et al. 1999; Kim and Eng 2004; Chen, Patten et al. 2005). Within non-disabled individuals, the gait profiles are generally very similar to one another and the basic patterns are easily recognizable. However, the gait patterns of individuals with post-stroke hemiparesis have been found to be more variable than those of healthy individuals (Kim and Eng 2004). Relative to non-disabled individuals walking at their self-selected speed, decreases in peak sagittal joint displacements at the hip, knee, and ankle have been reported bilaterally in individuals with hemiparesis, with a greater reduction on the paretic side (Olney, Griffin et al. 1991; Chen, Chen et al. 2003). Increased ankle plantarflexion at initial contact (Kim and Eng 2004), occasional knee hyperextension at weight acceptance (Kim and Eng 2004), and decreased knee flexion and ankle dorsiflexion during swing (Kuan, Tsou et al. 1999) are some of the common kinematic deviations of the paretic limb in the sagittal plane. In the frontal plane, the paretic hip occasionally displays a prolonged abduction pattern in swing (Kuan, Tsou et al. 1999; Kim and Eng 2004), while the paretic ankle shows signs of increased inversion (Kuan, Tsou et al. 1999). The kinematic gait patterns of the paretic limb in the transverse plane have been shown to be highly variable across subjects and studies (Kuan, Tsou et al. 1999; Kim and Eng 2004).

Chen et al. compared lower limb kinematics between subjects with stroke and healthy individuals walking at matched speeds (Chen, Patten et al. 2005). Significant decreases in knee flexion at toe-off and peak knee flexion during swing, as well as reduced peak hip extension were reported in the paretic limb (Chen, Patten et al. 2005). However, peak hip extension and knee flexion values in the non-paretic limb were not significantly different from the values in the healthy individuals (Chen, Patten et al. 2005). Considering that the healthy subjects were walking at decreased speeds to match those of the subjects with hemiparesis, the results suggest that the observed kinematic deviations are not entirely attributable to slower walking speed. Instead, the reduced gait speed of individuals with post-stroke hemiparesis may be the result of the altered kinematic profiles of the paretic limb.

Analysis of kinetic variables, particularly ground reaction forces (GRF), is another method used for evaluating post-stroke hemiparetic gait. Morita et al. examined the relationship between the GRFs of the paretic and non-paretic limbs and the degree of motor recovery in persons with stroke (Morita, Yamamoto et al. 1995). The results of the study suggested that the GRF profiles of hemiparetic gait are highly correlated with the gait ability of individuals with post-stroke hemiparesis with respect to degree of motor recovery (Morita, Yamamoto et al. 1995). Further analysis, for the purpose of identifying the differences between the paretic and non-paretic limbs, has led some researchers to investigate an isolated component of the GRF. For example, Bowden et al. quantified the contribution of the paretic limb to forward progression of walking by analyzing the anterior-posterior (A-P) component of the GRF (Bowden, Balasubramanian et al. 2006). Specifically, the measures derived from the A-P GRF impulse, for both the paretic and non-paretic limbs, were studied. The results of this study suggested that the contribution of the paretic leg to forward propulsion was sensitive to hemiparetic severity. That is, the paretic leg of individuals with severe hemiparesis contributed minimally to forward progression, whereas the contribution of the paretic leg of individuals with mild hemiparesis was almost equal to that of the non-paretic leg. Additionally, walking speed progressively decreased with the reduction of paretic propulsion as hemiparetic severity advanced from mild to severe (Bowden, Balasubramanian et al. 2006).

While the A-P GRF impulse provides an overall indication of the paretic limb's contribution to forward progression, it does not allow for the examination of individual joint contributions. Therefore, a few studies have assessed the mechanical work produced by the hip, knee, and ankle of the paretic and non-paretic limbs to provide more insight into the nature of the deficit of the paretic limb (Olney, Griffin et al. 1991; Chen and Patten 2008). Olney et al. examined the relationship between the mechanical work produced by the hip, knee, and ankle during gait for both limbs and self-selected walking speed of subjects with hemiparesis (Olney, Griffin et al. 1991). In the paretic limb, the more decreased walking speeds corresponded with decreased work values at all three joints, particularly in the ankle. In the non-paretic limb, the most notable difference with declining speed was the decrease in positive work by the ankle (Olney, Griffin et al. 1991). Together, the measurement of the mechanical work by the individual joints and the A-P GRF impulse provide a more complete assessment of the function of the paretic limb to hemiparetic walking. Understanding the initial contributions of the paretic limb to hemiparetic walking would allow for a better assessment of the effectiveness of rehabilitation interventions aimed at retraining walking for patients with hemiparesis.

Gait re-education is often considered an essential part of the rehabilitation process following stroke because of its importance to functional independence. Current concepts of motor learning favor a task-specific, repetitive training approach, thereby indicating that the best way to improve in an activity is to practice that activity (Carr and Shepherd 1998). A prime example of this concept is provided in a study by Winstein and colleagues, who reported that standing balance training could improve standing balance but not gait symmetry in patients with hemiparesis (Winstein, Gardner et al. 1989). Furthermore, a pilot study conducted by Richards et al. examined the effects of early, intensive, gait-focused physical therapy on ambulatory ability in patients with stroke (Richards, Malouin et al. 1993). The results of the study, comparing an intensive, gait-specific approach to a more conventional approach of physical therapy, suggested that the increased time spent concentrated on gait-specific activities was responsible for the more rapid improvement of locomotor function in patients with stroke (Richards, Malouin et al. 1993). Strong support for this specificity of training concept has led to a more task-oriented approach for promoting locomotor recovery after stroke.

Treadmill (TM) training is considered a useful intervention for gait rehabilitation in the stroke population because it incorporates motor learning concepts of repetitive "forced-use" of the paretic limb while continuously practicing complete gait cycles (Harris-Love, Forrester et al. 2001; Ada, Dean et al. 2003). In addition, TM training programs have resulted in significant improvements in gait cycle symmetry, increased over-ground walking speed, and increased step length for both the paretic and non-paretic limbs in subjects with chronic hemiparesis (Harris-Love, Forrester et al. 2001; Ada, Dean et al. 2003). Recently within the rehabilitation community, a considerable amount of attention has been directed towards body weight supported treadmill training (BWSTT) as a means to improve gait for people post-stroke (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Hesse, Konrad et al. 1999; Sullivan, Knowlton et al. 2002; Barbeau and Visintin 2003; Hesse, Werner et al. 2003; Chen, Patten et al. 2005; Chen and Patten 2006). BWSTT implements the use of an overhead suspension and harness system to support a percentage of a patient's body weight as the patient walks on a treadmill. The harness system unloads weight from the lower extremities, promoting an increased ease of stepping and a more vertically erect walking posture, thus allowing the patient to practice walking without the risk of falling.

BWSTT has been found to lead to a more successful recovery of ambulation for patients with stroke with respect to overground walking speed, endurance, functional balance, and lower limb motor recovery (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Barbeau and Visintin 2003). When compared to a more conventional Bobath approach (Bobath 1990), BWSTT has been shown to be more effective at restoring gait function, with positive effects on overground walking speed and physical assistance required to walk (Malouin, Potvin et al. 1992; Hesse, Bertelt et al. 1995). Similar results were seen in another study investigating the effectiveness of BWSTT in retraining gait, as compared to TM training with no body weight support (BWS) (Visintin, Barbeau et al. 1998). After a 6-week training period, the group receiving BWSTT scored significantly higher in overground walking speed and endurance, functional balance, and lower-limb motor recovery than the group bearing full weight during TM training. Follow-up evaluation at 3 months post-training revealed that the BWSTT group continued to have significantly higher scores for overground walking speed and lower-limb motor recovery

(Visintin, Barbeau et al. 1998). Despite the overall positive results achieved in overground walking speed with this intervention strategy, BWSTT is not yet widely used in clinical settings (Jette, Latham et al. 2005).

The improvement in overall gait speed following BWSTT is well-documented within the literature (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Barbeau and Visintin 2003). However, the specific effects of BWSTT on non-paretic and paretic limb function in individuals with post-stroke hemiparesis have not been researched in great depth. The percentage swing time of the non-paretic limb has been found to increase during BWSTT (Chen, Patten et al. 2005), although there are no reports of this carrying over to overground walking. Changes in the kinematic gait profiles of patients with stroke have not been reported following BWSTT. Preliminary results have suggested that changes do occur in the A-P GRFs of the paretic and non-paretic limbs following BWSTT, however these results were based on a small test population and were variable between subjects (Plummer, Behrman et al. 2007). Therefore, it is difficult to adequately assess how individuals with post-stroke hemiparesis are improving their overground walking speed.

Many studies have evaluated the pathologic nature of hemiparetic gait utilizing a number of different assessment tools. There is minimal contention within the literature that individuals with chronic stroke walk slower and more asymmetrically when compared to healthy individuals. The measureable asymmetry between the paretic and non-paretic limbs in individuals with post-stroke hemiparesis is relative to the function of the paretic limb during gait. Efforts have been made in the rehabilitation process to improve post-stroke walking function. Improvements in walking speed and endurance following rehabilitation, particularly BWSTT, have come to be expected, however it is unclear how these improvements are achieved. Further analysis is required to more fully understand the effects of BWSTT on paretic limb function during gait, which may provide more insight into the efficacy of BWSTT as a viable treatment option for individuals with post-stroke hemiparesis.

Purpose

The purpose of this study is to assess the effect of BWSTT on paretic limb function in individuals with chronic post-stroke hemiparesis using outcome measures of walking velocity, paretic leg propulsion, and mechanical work produced by the hip, knee, and ankle of the paretic limb.

Significance

It is well established in the literature that BWSTT improves the walking speed of patients with post-stroke hemiparesis. The increases in walking speed are important for improvements in community access. However, it is unclear how these improvements in walking speed are being achieved. Additionally, the effects of BWSTT on paretic limb function have not been extensively researched. The information gained from this study may be used by physical therapists to better assess the effectiveness of BWSTT as a treatment option for retraining gait in patients with stroke.

Methods

Participants

Fifteen individuals presenting with chronic stroke aged 40-80 years were recruited for this study from local stroke support groups, rehabilitation centers, and clinicians who treat people with stroke. Participants were required to have only had a single stroke at least 6 months prior to study, not currently receiving physical therapy, and be ambulatory with a self-selected gait speed between 0.4 m/s and 0.8 m/s. Fifteen non-disabled individuals were recruited from local universities to serve as a non-equivalent comparison group.

The participants with chronic stroke were assessed prior to and following completion of the BWSTT intervention program. The non-disabled participants were only assessed once. The basic demographic information and data collected from the non-disabled participants were only used as a reference point for comparison of the data collected from the stroke participants. Written informed consent, approved by the Ball State University Institutional Review Board, was obtained from all participants prior to study involvement.

Intervention Procedure

The participants with chronic stroke were required to complete an exercise intervention program comprised of 24 sessions of BWSTT over eight weeks under the supervision of a physical therapist. Each training session consisted of 20 minutes of total walking time. Rest breaks were permitted as needed according to the participant’s tolerance, but were not included in the overall walking time.

Training was initiated at 30% body weight support (BWS) at the fastest possible walking pace the participant could achieve within the first two minutes of the intervention. Manual assistance was provided, as needed, throughout the intervention to promote an improved walking pattern. Handrail holding was not permitted during training in order to encourage typical arm swing.

On each subsequent treatment day, the treadmill speed was increased by 0.2 mph until the minimum age and gender norms for community walking speed or the maximum participant tolerance was met. In order to progress the BWSTT protocol, the subject could take no more than one rest break per 20 minutes of total walking time. In addition, the subject had to achieve specific quality requirements without therapist assistance. These requirements included symmetrical step length and stance time, upright trunk alignment, and consistent heel strike bilaterally with adequate limb loading. The subject had to maintain these quality requirements for at least five minutes of the 20 minute treatment time to progress the BWSTT protocol. The progression of the BWSTT protocol was dependent on the subject meeting the parameter requirements for speed, time, and quality. BWS was decreased to 15% or 0%, accordingly. The BWS protocol was followed for the duration of the 24 intervention sessions. These protocol progression guidelines are similar to protocols carried out in other published studies (Visintin, Barbeau et al. 1998; Sullivan, Knowlton et al. 2002; Chen and Patten 2006; Plummer, Behrman et al. 2007).

Data Acquisition

Overground gait velocity was assessed using the comfortable 10-meter walk test (CWT) (Flansbjer, Holmback et al. 2005). The CWT was conducted in an open room, along a 14-meter walkway and the participants were timed for the middle 10 meters (Flansbjer, Holmback et al. 2005) using electronic timing gates (Fitness Technologies, Adelaide, Australia). The participants were instructed to walk at a comfortable, self-selected pace. Each participant completed the CWT three times and the average of the three trials was used for subsequent analysis.

Bilateral kinematics and kinetics were captured with a VICON F-series motion capture system (Vicon, Lake Forest, CA, USA). Thirty-nine retro-reflective markers were attached to the participants at specific anatomical landmarks based on the Plug-In-Gait (PiG) model used in the VICON software. GRF data was acquired using two AMTI force plates (Model BP600900-6-1000, Advanced Medical Technology, Inc., Watertown, MA, USA) embedded in the laboratory walkway.

Data was collected while each participant walked at their self-selected speed along a 6-meter walkway equipped with the embedded force plates. The participants of the non-equivalent comparison group were requested to complete a few trials walking at their self-selected speed and few trials walking at a slower speed, similar to the speed of the participants with stroke. GRFs were measured throughout the stance phase for both the paretic and non-paretic legs of the chronic stroke participants, and the right and left legs of the non-disabled participants. Participants were allowed to use their usual AFOs for walking during the entirety of the testing sessions. They were closely supervised by a researcher during all walking trials. Participants were requested to wear the same shoes and AFOs, if applicable, for all testing sessions, both pre and post.

The kinematic and kinetic data was initially processed using VICON Workstation software (Vicon, Lake Forest, CA, USA). Customized MATLAB 7.5 (Mathworks, Boston, MA) programs were written to calculate the A-P GRF impulse and the mechanical work produced by the hip, knee, and ankle of the paretic and non-paretic limbs.

The A-P GRF impulse was subdivided into the propulsive impulse, braking impulse, and net impulse (sum of the propulsive impulse plus braking impulse) for each leg. The mechanical work produced by the hip, knee, and ankle was subdivided into positive, negative, and total work (sum of the positive plus negative work) at each individual joint for each leg.

Statistical Analysis

Paired t-tests were used to analyze the differences in the mean values of gait velocity and percentage contribution of the paretic limb to total propulsive impulse. Repeated measures ANOVA were used to analyze the differences in the mean values of the relative contribution of the paretic hip, knee, and ankle to total positive work. Statistical significance was accepted at an alpha level of 0.05.

Limitations

The participants with stroke were not classified by hemiparetic severity. The only control for time since stroke was a minimum of six months. The physical activity level of the participants prior to inclusion in the study was not controlled. Therefore, the differing degrees of motor recovery, large range of time since stroke, and variable activity levels of the participants may skew the results with respect to percent contribution to total propulsion of the paretic limb and percent contribution to total positive work of the paretic hip, knee, and ankle.

Delimitations

Trials used for analysis were only accepted if the whole foot and no part of the contralateral foot landed on the force plate during the stride. All participants involved in this research study were from the Midwestern United States and reflect the demographics of that area.

Summary

BWSTT is a rehabilitation intervention aimed at improving the gait of individuals with post-stroke hemiparesis. A majority of the positive results reported for this intervention are limited to improvements in walking speed. Information regarding the contribution of the paretic limb to walking may provide more useful information. The percent contribution of the paretic limb to total propulsion and the percent contribution of the paretic hip, knee, and ankle to total positive work were assessed prior to and following completion of a BWSTT intervention program in an effort to understand if any changes in paretic limb function occur. The information gained from this study may be considered useful to physical therapists treating patients with post-stroke hemiparesis.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Each year in the United States over 700,000 people experience a cerebrovascular accident or stroke, approximately 600,000 of these being first time attacks (Rosamond, Flegal et al. 2008). With a survivor cohort of approximately 5.8 million persons, stroke is the primary cause of long term disability and the third leading cause of death in the United States (Rosamond, Flegal et al. 2008). For this reason, a great deal of literature over the years has been focused on the effects of stroke and the outcomes of rehabilitation.

Stroke is a form of cardiovascular disease that affects the arterial blood supply leading to and within the brain. It is caused by a hemorrhage or thrombus of the blood vessels carrying oxygenated blood to the brain, usually of one side, resulting in damage to motor neurons and their pathways. This damage to the central nervous system often leads to residual neurological deficits, which vary depending on the location of the clot or rupture and the amount of brain tissue affected.

The brain is an exceptionally complex organ that controls many various body functions. Therefore, there is a wide range of neurological deficits that may arise following a stroke. Some of the most common neurological deficits include problems with vision, speech, memory loss and balance. Additionally, diminished strength, decreased muscle coordination, and decreased sensation often occur on the contralateral side of the body from the side of the brain affected. For example, if an obstruction occurs on the left side of the brain, the right side of the body is affected. The resulting hemiparesis, weakness on one side of the body, particularly affects the muscles used for locomotion, thereby significantly impairing walking ability.

Effects of Stroke on Gait Function

Initially following stroke, only 30% to 37% of stroke patients are able to walk independently (Skilbeck, Wade et al. 1983; Jorgensen, Nakayama et al. 1995), whereas 64% to 80% of stroke patients are able to walk independently at discharge from the hospital (Dean and Mackey 1992; Jorgensen, Nakayama et al. 1995). Despite the positive increases in independent walking ability, changes in overall gait function are often evident by observation and well established in clinical literature. Post-stroke hemiparetic gait is characterized by reduced walking speed (Brandstater, de Bruin et al. 1983; Turnbull, Charteris et al. 1995), asymmetry of the gait cycle (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005; Lamontagne, Stephenson et al. 2007), uncoordinated movement patterns (Wagenarr and van Emmerik 1994; Barela, Whitall et al. 2000), and altered kinetic gait profiles (Olney, Griffin et al. 1991; Morita, Yamamoto et al. 1995; Bowden, Balasubramanian et al. 2006).

The average walking speed for patients with stroke, reported in literature, ranges from 0.16 meters per second to 0.76 meters per second (Brandstater, de Bruin et al. 1983; Wall and Turnbull 1986; Turnbull, Charteris et al. 1995; von Schroeder, Coutts et al. 1995; Goldie, Matyas et al. 1996). This wide range in walking speeds has been suggested to be related to the patients' degree of motor recovery, with more severe motor deficits being linked to slower walking speeds (Brandstater, de Bruin et al. 1983). However, regardless of the degree of motor recovery, compared to healthy, age-matched individuals, patients with stroke consistently walk at slower gait speeds (Brandstater, de Bruin et al. 1983; Turnbull, Charteris et al. 1995; Goldie, Matyas et al. 1996). Goldie et al. performed a study comparing the walking speeds of patients with stroke to healthy, age and sex matched individuals, in order to quantify the initial deficit and change in gait velocity following rehabilitation for stroke (Goldie, Matyas et al. 1996). Results indicated that on average, prior to rehabilitation, the patients with stroke walked at 38.6% of the speed of the healthy individuals. Following eight weeks of physical therapy, the walking speed of the patients with stroke improved to 55.1%, however it was still significantly slower compared to the healthy individuals (Goldie, Matyas et al. 1996). These reductions in gait speed in patients with stroke are associated with decreases in cadence and shorter stride lengths (Brandstater, de Bruin et al. 1983; Roth, Merbitz et al.

1997). Additionally contributing to the slower walking speeds are changes in the gait cycle.

For healthy individuals, walking at a comfortable, self-selected speed, the proportion of time spent in stance phase versus swing phase is symmetrical between the right and left sides, however for individuals with post-stroke hemiparesis this proportion is altered (Brandstater, de Bruin et al. 1983; Chen, Chen et al. 2003). Stance phase tends to be longer for both the paretic and non-paretic limbs, although the non-paretic limb spends a greater proportion of time in stance overall (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005). This corresponds with a longer swing phase for the paretic limb and a shortened swing phase for the non-paretic limb (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005). Even when compared to healthy, age-matched individuals walking at slow speeds, similar to those of individuals with post-stroke hemiparesis, the proportion of time spent in stance versus swing remains uneven between the paretic and non-paretic limbs (Chen, Patten et al. 2005).

Accompanying these asymmetries present in the gait cycle of individuals with post-stroke hemiparesis are changes in their kinematic and kinetic gait profiles. The kinematic gait profiles of healthy individuals are usually very similar to one another and the same pattern of joint excursions can be identified for each joint across all planes of motion. However, unlike healthy individuals, variation exists in the kinematic gait profiles of individuals with hemiparesis (Kim and Eng 2004). In some cases, the gait patterns exhibited by individuals with stroke are very similar to those found in healthy individuals, whereas in other cases different or additional gait patterns emerge (Kim and Eng 2004). Bilateral decreases in peak sagittal joint displacements at the hip, knee, and ankle have been linked to slower walking speeds displayed by individuals with post-stroke hemiparesis, with greater reductions occurring in the paretic limb (Olney, Griffin et al. 1991; Chen, Chen et al. 2003). Many of the kinematic deviations found in individuals with stroke are observed in the paretic limb at specific instances of the gait cycle. Some common deviations of the paretic limb in the sagittal plane include increased ankle plantarflexion at initial contact (Kim and Eng 2004), occasional knee hyperextension at weight acceptance (Kim and Eng 2004), and decreased knee flexion and ankle dorsiflexion during swing (Kuan, Tsou et al. 1999). In the frontal plane, prolonged hip abduction is occasionally seen in the paretic hip during swing (Kuan, Tsou et al. 1999; Kim and Eng 2004), while the paretic ankle shows signs of increased inversion (Kuan, Tsou et al. 1999). There is a high degree of variation across individuals with stroke regarding the kinematic gait patterns of the paretic limb in the transverse plane (Kuan, Tsou et al. 1999; Kim and Eng 2004).

The kinematic gait patterns exhibited during walking are a direct result of the moments generated at the joints. Therefore, it is not surprising that post-stroke individuals also exhibit changes in their kinetic gait profiles. Just as the kinematic gait profiles of healthy individuals are similar across individuals, similarities are also present in their kinetic gait profiles. However, more than one form of kinetic gait pattern has been identified in individuals with stroke across all planes (Kim and Eng 2004). In the frontal plane, in addition to the patterns displayed in healthy gait (Eng and Winter 1995), an additional hip abductor moment at toe-off in the paretic limb and an additional knee adductor moment just prior to toe-off in both the paretic and non-paretic limbs, have been found in post-stroke individuals (Kim and Eng 2004). In the sagittal plane, some post-stroke individuals display the standard extensor-flexor-extensor moment pattern at the paretic knee, typically seen in healthy gait (Eng and Winter 1995), whereas others display a flexor moment pattern (Kim and Eng 2004). The kinetic gait patterns in the transverse plane, particularly at the paretic knee and ankle, have been found to be highly variable across post-stroke individuals (Kim and Eng 2004). At the knee, some post-stroke individuals display an internal rotator moment throughout stance, while others display an external rotator moment for the first half of stance followed by an internal rotator moment for the second half of stance (Kim and Eng 2004). At the ankle, several patterns have been identified, although the most prevalent pattern has been an abductor moment occurring through a majority of stance (Kim and Eng 2004). Even with the variation in kinetic gait patterns, when compared to healthy individuals, most of the moments of post-stroke individuals are of smaller amplitude, especially in the paretic limb (Olney, Griffin et al. 1991).

The effects of stroke on gait function have been the focus of study for many researchers throughout the years because of the impact it has on an individual's functional independence (Olney and Richards 1996; Lamontagne, Stephenson et al. 2007). The identification and quantification of the gait disturbances that characterize post-stroke hemiparetic gait are important to understanding the underlying pathology of stroke. Additionally, the development of effective rehabilitation interventions, aimed at retraining walking, is dependent on understanding the characteristics typically seen in post-stroke gait.

Rehabilitation

Gait re-education is an essential part of the rehabilitation process following stroke because of its importance to functional independence. One of the early, more conventional approaches sometimes used by physical therapists to achieve this goal emphasizes the control of solitary components of gait prior to resuming full ambulation (Dewald 1987; Bobath 1990). The application of this approach ranges from strictly functional strengthening exercises and practice of single movements to more complex neurofacilitation techniques and neurodevelopmental therapy (NDT, Bobath) (Dewald 1987; Bobath 1990). In regards to gait improvement, NDT (Bobath) focuses on balance, weight-bearing, and weight-shifting activities (Bobath 1990). Despite the overall goal of restoring gait, this conventional approach does not stress gait practice. Hesse et al. evaluated gait performance, measuring maximal walking speed and endurance, as well as gait symmetry in 148 chronic hemiparetic stroke patients before and after a 4-week comprehensive NDT rehabilitation program (Hesse, Jahnke et al. 1994). The lack of substantial improvement in either gait performance or symmetry following the NDT rehabilitation program provided little support for the efficacy of NDT as a primary treatment option for restoring gait function (Hesse, Jahnke et al. 1994).

Current concepts of motor learning favor a task-specific, repetitive training approach, thereby indicating that the best way to improve in an activity is to practice that activity (Carr and Shepherd 1998). A prime example of this concept is provided in a study by Winstein and colleagues, who examined the effects of a balance retraining program on both standing balance and gait symmetry in a group of chronic hemiparetic stroke patients (Winstein, Gardner et al. 1989). The standing balance program used in this study utilized visual feedback to encourage the patients with stroke to symmetrically distribute their weight over both limbs and to transfer more weight onto the paretic limb while practicing weight shifting. It was believed that following completion of this standing balance program, patients with stroke would demonstrate a more symmetrical weight distribution during quiet standing, as well as an improvement in the amount of weight shifted onto the paretic limb during walking. However, the results of this study suggested that although standing balance training does improve standing balance, its effects on gait symmetry are minimal in patients with post-stroke hemiparesis (Winstein, Gardner et al. 1989). Therefore, the natural suggestion for improvements in gait function of patients with stroke would require participation in rehabilitation therapies that emphasize gait practice. Richards et al. conducted a pilot study examining the effects of early, intensive, gait-focused physical therapy on ambulatory ability in patients with stroke (Richards, Malouin et al. 1993). A comparison was made between the gait function outcomes of patients with stroke that completed a gait-specific physical therapy approach to those patients that completed a more conventional physical therapy approach. Results indicated that the increased time spent concentrated on gait-specific activities was responsible for a more rapid improvement of gait function in patients with stroke (Richards, Malouin et al. 1993). The outcome of this study further supports the concept of specificity of training, which has led to the development of more task-oriented approaches for promoting locomotor recovery for patients with stroke.

Treadmill (TM) training is an intervention used in the rehabilitation of gait for patients with stroke that incorporates motor learning concepts of training specificity and repetition. The repetitive ‘forced-use’ of the paretic limb and the repetitive practice of complete gait cycles are some key features of this intervention that are believed to induce greater improvements in the gait of patients with stroke (Harris-Love, Forrester et al. 2001; Ada, Dean et al. 2003). Compared to overground (OG) walking, patients with stroke have demonstrated improved gait symmetry when walking on a TM (Harris-Love, Forrester et al. 2001). The relative stance time of the paretic limb increases, while it decreases in the non-paretic limb, indicating greater stance-time symmetry (Harris-Love, Forrester et al. 2001). Additionally, single leg stance time increases in the paretic limb and decreases in the non-paretic limb, which corresponds with an increase in swing time for the non-paretic limb and a decrease in swing time for the paretic limb (Harris-Love, Forrester et al. 2001).

While improvements in gait symmetry for patients with stroke are a significant effect of TM training, more important are the improvements that transfer to OG walking. Ada et al. assessed the effects of a TM and OG walking program at reducing walking disability in patients with chronic stroke (Ada, Dean et al. 2003). The aim of the TM training was to increase walking speed and step length, while the OG walking following the TM was used to reinforce any gains achieved on the TM. Following completion of this program, patients with stroke exhibited significant increases in walking speed, step length for both the paretic and non-paretic limbs, and walking capacity. Walking capacity was measured by the distance a patient was able to walk in six minutes. These improvements were maintained by patients with stroke for at least three months after cessation of the program (Ada, Dean et al. 2003).

TM training has proven to be a useful intervention for gait rehabilitation in the stroke population because of the positive effects it has on walking ability. Modifications to this training technique have been suggested to further advance these positive outcomes. One such modification, receiving a considerable amount of attention in the rehabilitation community, involves the use of body weight support (BWS) during TM training (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Hesse, Konrad et al. 1999; Sullivan, Knowlton et al. 2002; Barbeau and Visintin 2003; Hesse, Werner et al. 2003; Chen, Patten et al. 2005; Chen and Patten 2006). Body weight support treadmill training (BWSTT) implements the use of an overhead suspension and harness system to support a percentage of a patient's body weight as the patient walks on a treadmill. The harness system unloads weight from the lower extremities, promoting an increased ease of stepping and a more vertically erect walking posture (Visintin, Barbeau et al. 1998; Hesse, Werner et al. 2003). In many cases, as a patient's walking ability improves, the percentage of weight being supported is progressively decreased.

In comparison to initial methods used for gait rehabilitation for patients with stroke, BWSTT has been found to lead to a more successful recovery of ambulation with respect to overground walking speed, endurance, functional balance, and lower limb motor recovery (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Barbeau and Visintin 2003). Hesse et al compared BWSTT to a more conventional Bobath approach for non-ambulatory patients with chronic stroke (Hesse, Bertelt et al. 1995). Results indicated BWSTT was superior at restoring gait function, with respect to improvements in overground walking speed and physical assistance required to walk (Hesse, Bertelt et al. 1995). Similarly, Visintin and colleagues compared the effects of gait training with BWSTT to TM training with no BWS for patients with stroke (Visintin, Barbeau et al. 1998). After a six-week training period, the patients receiving BWSTT scored significantly higher in overground walking speed and endurance, functional balance, and lower-limb motor recovery than the patients bearing full weight during TM training. Follow-up evaluation at three months post-training revealed that the BWSTT group continued to have significantly higher scores for overground walking speed and lower-limb motor recovery (Visintin, Barbeau et al. 1998). Despite the overall positive results achieved with BWSTT, it is not widely used in clinical settings (Jette, Latham et al. 2005).

For patients with stroke, improvement in overground walking speed following BWSTT is one of the most significant and well-documented results in the literature (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Sullivan, Knowlton et al. 2002; Barbeau and Visintin 2003). While these increases in walking speed are important for improving community access (Schmid, Duncan et al. 2007), there is little documentation on the effects of BWSTT on non-paretic and paretic limb function for individuals with post-stroke hemiparesis. Gait symmetry and gait kinematics have been suggested to improve during BWSTT (Hesse, Konrad et al. 1999; Chen, Patten et al. 2005), however it remains unclear whether these improvements are sustained and transferred to overground walking. The lack of substantial evidence regarding the limb function of individuals with hemiparesis following BWSTT make it difficult to adequately assess how improvements in overground walking speed are being achieved. Therefore, it is important to quantify the differences in non-paretic and paretic limb function prior to and following completion of BWSTT to further assess the effectiveness of this intervention for retraining gait in patients with post-stroke hemiparesis.

Variables used to assess gait function in patients with stroke

Over the years, researchers have employed many different assessment tools to evaluate and quantify the gait asymmetries characteristic of hemiparetic gait. Spatio-temporal parameters are the easiest to obtain and therefore are the most widely used assessment tools for evaluating the gait of individuals with post-stroke hemiparesis (Brandstater, de Bruin et al. 1983; Wall and Turnbull 1986; Roth, Merbitz et al. 1997). Walking speed, stance and swing duration, cadence and stride length are some of the more common measurements performed. As mentioned earlier, the results of research studies examining these parameters indicate that patients with stroke walk significantly slower than their healthy counterparts, with decreased cadence and stride length (Brandstater, de Bruin et al. 1983; Turnbull, Charteris et al. 1995). Additionally, individuals with hemiparesis also display asymmetrical swing and stance phases compared to healthy individuals (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005). The gait performance of individuals with stroke, as measured by these spatio-temporal parameters, particularly walking speed, has been suggested to be related to their degree of motor recovery (Brandstater, de Bruin et al. 1983; Chen, Chen et al. 2003). Therefore, not surprisingly, walking speed is often considered a valuable measure of patient status. Further support for the use of walking speed as a primary measure of status is provided by Brandstater et al, who found that increases in walking speed paralleled improvements in the paretic limb (Brandstater, de Bruin et al. 1983). This relationship between walking speed and paretic limb function, as measured by stance and swing duration, has led to walking speed being used as a measure of treatment efficacy for physical therapy interventions, such as TM training (Hesse, Bertelt et al. 1995;

Visintin, Barbeau et al. 1998; Sullivan, Knowlton et al. 2002; Ada, Dean et al. 2003; Barbeau and Visintin 2003). Although walking speed has been found to be correlated with many other temporal parameters, such as cadence, stance duration of the non-paretic and paretic limbs, and double support duration, it has not been found to be an adequate singular indicator of gait status for patients with stroke (Roth, Merbitz et al. 1997). Improvements in walking speed can be the result of many different factors, such as increased cadence, increased step/stride length, or a combination of factors. Therefore, although walking speed is a useful overall gait measure, it should be assessed in conjunction with other variables used to characterize the gait of patients with stroke to better understand gait function.

In addition to spatio-temporal variables, some researchers have examined the kinematic gait profiles associated with post-stroke hemiparetic gait, particularly examining the magnitude and shape of the joint angles of the lower limbs (Kuan, Tsou et al. 1999; Kim and Eng 2004; Chen, Patten et al. 2005). Although the magnitude of the joint angles of the lower limbs for patients with stroke are generally decreased for both limbs compared to non-disabled individuals, the reductions observed in the paretic limb are often more significant (Olney and Richards 1996; Chen, Chen et al. 2003; Chen, Patten et al. 2005). Results suggest that the magnitude of these kinematic gait profiles are related to walking speed (Kim and Eng 2004). When compared to healthy individuals purposefully walking at slower gait speeds to match those of individuals with post-stroke hemiparesis, the individuals with hemiparesis continue to display significant reductions in the joint angle excursions of the paretic limb (Chen, Patten et al. 2005). Based on these results, it may be suggested that the slower walking speeds seen in individuals post-stroke are the result of altered kinematic gait profiles, especially of the paretic limb. However, patients with stroke that walk at faster walking speeds do not always exhibit kinematic gait profiles more similar to those exhibited by healthy individuals (Kim and Eng 2004). For example, Kim and Eng found that a number of their patients with stroke that walked at a faster walking speed displayed prolonged hip abduction during swing on the paretic limb (Kim and Eng 2004). This extended frontal plane hip pattern is not typically seen in healthy individuals, therefore it was believed to be a compensatory mechanism utilized by the patients with stroke to make up for the lack of hip and knee flexion and ankle dorsiflexion necessary to clear the ground, thereby allowing for the increases in walking speed (Kim and Eng 2004). Furthermore, more than one kinematic gait pattern has been identified across patients with stroke, indicating that different strategies may be utilized to accomplish the same goal of walking (Kim and Eng 2004). The kinematic gait profiles, for both the paretic and non-paretic limbs, for patients with stroke, relative to walking speed, are not consistent across patients. Therefore, the relationship between walking speed and joint angle excursion for the paretic and non-paretic limbs cannot be generalized to all patients with stroke. Further analysis is required to fully appreciate hemiparetic gait function.

The analysis of kinetic variables, particularly ground reaction forces (GRF), has been used to evaluate post-stroke hemiparetic gait, in order to more fully understand the function of the paretic and non-paretic limbs. Morita et al examined the relationship between the GRFs of the paretic and non-paretic limbs and the degree of motor recovery in persons with stroke (Morita, Yamamoto et al. 1995). The results of the study suggested that the GRF profiles of hemiparetic gait are highly correlated with the gait ability of post-stroke hemiparetic individuals with respect to degree of motor recovery (Morita, Yamamoto et al. 1995). Further analysis, for the purpose of identifying the differences between the paretic and non-paretic limbs, has led some researchers to investigate an isolated component of the GRF. For example, Bowden et al. quantified the contribution of the paretic limb to forward progression of walking by analyzing the anterior-posterior (A-P) component of the GRF (Bowden, Balasubramanian et al. 2006). Specifically, the measures derived from the A-P GRF impulse, for both the paretic and non-paretic limbs, were studied. The results of this study suggested that the contribution of the paretic leg to forward propulsion was sensitive to hemiparetic severity. That is, the paretic leg of individuals with severe hemiparesis contributed minimally to forward progression, whereas the contribution of the paretic leg of individuals with mild hemiparesis was almost equal to that of the non-paretic leg. Additionally, walking speed progressively decreased with the reduction of paretic propulsion as hemiparetic severity advanced from mild to severe (Bowden, Balasubramanian et al. 2006).

While the A-P GRF impulse provides an overall indication of the paretic limb's contribution to forward progression, it does not allow for the examination of individual joint contributions. Therefore, a few studies have assessed the mechanical work produced by the hip, knee, and ankle of the paretic and non-paretic limbs to provide more insight into the nature of the deficit of the paretic limb (Olney, Griffin et al. 1991; Chen and Patten 2008). Olney et al. examined the relationship between the mechanical work produced by the hip, knee, and ankle during gait for both limbs and self-selected speed of subjects with hemiparesis (Olney, Griffin et al. 1991). In the paretic limb, the subjects that walked at decreased walking speeds had decreased work values at all three joints also, particularly in the ankle. In the non-paretic limb, the most notable difference with declining speed was the decrease in positive work by the ankle (Olney, Griffin et al. 1991). Together, the measurement of the mechanical work by the individual joints and the A-P GRF impulse provide a more complete assessment of the function of the paretic limb to hemiparetic walking.

Summary

Patients with stroke often have significantly impaired walking ability resulting from weakness on one side of the body (hemiparesis). The gait of individuals with post-stroke hemiparesis is characterized by reduced walking speed (Brandstater, de Bruin et al. 1983; Turnbull, Charteris et al. 1995), asymmetry of the gait cycle (Brandstater, de Bruin et al. 1983; Chen, Patten et al. 2005; Lamontagne, Stephenson et al. 2007), uncoordinated movement patterns (Wagenarr and van Emmerik 1994; Barela, Whitall et al. 2000), and altered kinetic gait profiles (Olney, Griffin et al. 1991; Morita, Yamamoto et al. 1995; Bowden, Balasubramanian et al. 2006). Rehabilitation techniques used for the re-education of gait for patients with stroke aim to restore gait function. Improvements in walking speed following rehabilitation, especially for BWSTT, have been well documented in the literature. However, despite these improvements in walking speed, it remains unclear how increases walking speed are being achieved. Many variables have been used to assess gait function in patients with stroke. Of all the variables used, the measurement of mechanical work of the individual joints and the A-P GRF impulse seem to provide the most complete assessment of the function of the non-paretic and paretic limbs to hemiparetic walking.

CHAPTER 3

METHODS

Participants

Fifteen individuals presenting with chronic stroke were recruited for this study from local stroke support groups, rehabilitation centers, and clinicians who treat people with stroke. Two subjects were unable to complete the testing protocol without the use of their assistive walkers. Therefore, only the data from the remaining thirteen individuals with chronic stroke were used for subsequent analyses (11 female; 2 male; 60.5 ± 11.3 years of age; time since stroke (years) = 3.5 ± 2.8; affected side left = 3; right = 10). Inclusion criteria for participation included (1) between 40 and 80 years of age, (2) a single stroke at least 6 months prior to study, (3) ability to walk independently overground with or without the use of an assistive device or ankle foot orthosis (AFO), (4) a self-selected gait speed between 0.4 m/s and 0.8 m/s, and (5) ability to ambulate 14 meters without the use of an assistive device with supervision. Exclusion criteria included (1) currently receiving physical therapy services, (2) any co-morbidities or pre-existing cardiovascular conditions that would prohibit gait training and exercise, (3) any preexisting neurological or current musculoskeletal conditions that would limit gait ability separate from the effects of stroke, and (4) complications from other health conditions that could influence walking. All participants with chronic stroke were also required to provide a physician release confirming medical stability and approval to enter an exercise program.

Fifteen non-disabled individuals (8 female; 7 male; 58.1 ± 6.6 years of age) were recruited from local universities to serve as a non-equivalent comparison group. Inclusion criteria were (1) between 40 and 80 years of age and (2) ability to walk independently during home and community activities. Exclusion criteria were (1) any known neurological condition or neurological deficit, (2) any current musculoskeletal condition, outside of typical age-related changes, (3) any recent orthopaedic surgeries within 6 months of the study, and (4) complications from other health conditions that could influence walking.

The participants with chronic stroke were assessed prior to and following completion of the BWSTT intervention program. The non-disabled participants were assessed on a single occasion. The basic demographic information and data collected from the non-disabled participants were only used as a reference point for comparison of the data collected from the stroke participants. Written informed consent, approved by the Ball State University Institutional Review Board, was obtained from all participants prior to study involvement.

Intervention Procedure

The participants with chronic stroke completed an exercise intervention program comprised of 24 sessions of BWSTT over eight weeks under the supervision of a physical therapist. Each training session consisted of 20 minutes of total walking time. Rest breaks were permitted as needed according to the participant's tolerance, but were not included in the overall walking time. Participants' heart rates and blood pressure were monitored before each session began, at all rest breaks, and after completion of each session to ensure that they could safely continue training. The ACSM Guidelines for Exercise Testing and Prescription was used as guide regarding decisions about termination of an intervention session (American College of Sports Medicine., Whaley et al. 2006).

Participants were fitted in a harness that connected to an overhead suspension system (Litegait®) positioned over the treadmill (3106 Gaitkeeper®, Mobility Research, Tempe, AZ, USA). The suspension system had a flexible yolk and Bisym scale to measure the amount of weight on the system. Training was initiated at 30% body weight support (BWS) at the fastest possible walking pace the participant could achieve within the first two minutes of the intervention on the first day of training. Verbal and manual assistance was provided, as needed, throughout the intervention to promote an improved walking pattern. Handrail holding was not permitted during training in order to encourage typical arm swing.

On each subsequent treatment day, the treadmill speed was increased by 0.2 mph until the minimum age and gender norms for community walking speed (Oberg, Karsznia et al. 1993) or the maximum participant tolerance was met. In order to progress the BWSTT protocol, the subject could take no more than one rest break per 20 minutes of total walking time. In addition, the subject had to achieve specific quality requirements without therapist assistance. These requirements included symmetrical step length and stance time, upright trunk alignment, and consistent heel strike bilaterally with adequate limb loading. The subject had to maintain these quality requirements for at least five minutes of the 20 minute treatment time to progress the BWSTT protocol. The achievement of these quality requirements was based on the subjective assessment of the supervising physical therapist. Progression of the BWSTT protocol was dependent on the subject meeting the parameter requirements for speed, time, and quality. If the subject met all of the requirements within one treatment day, then BWS was decreased on the next treatment day. BWS was decreased to 15% or 0%, accordingly. The BWS protocol was followed for the duration of the 24 intervention sessions. These protocol progression guidelines are similar to protocols carried out in other published studies (Visintin, Barbeau et al. 1998; Sullivan, Knowlton et al. 2002; Chen and Patten 2006; Plummer, Behrman et al. 2007).

Data Acquisition

Overground gait velocity was assessed using the comfortable 10-meter walk test (CWT) (Flansbjer, Holmback et al. 2005). The CWT was conducted in an open room, along a 14-meter walkway and the participants were timed for the middle 10 meters

(Flansbjer, Holmback et al. 2005) using electronic timing gates (Fitness Technologies, Adelaide, Australia). The participants were instructed to walk at a comfortable, self-selected pace. Each participant completed the CWT three times and the average of the three trials was used for subsequent analysis. Participants were permitted 30 seconds rest between each trial if necessary.

Bilateral kinematics and kinetics were captured at 60Hz with a 10 camera VICON F-series motion capture system (Vicon, Lake Forest, CA, USA). Thirty-nine retro-reflective markers were attached to the participants at specific anatomical landmarks based on the Plug-In-Gait (PiG) model used in the VICON software. GRF data was acquired at 1200Hz using two AMTI force plates (Model BP600900-6-1000, Advanced Medical Technology, Inc., Watertown, MA, USA) embedded in the laboratory walkway.

Data were collected while each participant with chronic stroke walked at their self-selected speed along a 6-meter walkway equipped with the embedded force plates. In the non-equivalent comparison group, data were collected for each non-disabled participant walking at their self-selected speed and at slower speeds, similar to those exhibited by the participants with chronic stroke. GRFs were measured throughout the stance phase for both the paretic and non-paretic legs of the chronic stroke participants, and the right and left legs of the non-disabled participants. A minimum of 10 trials were collected for each participant in order to obtain a minimum of three good trials for each leg. A trial was defined as good if the whole foot and no part of the contralateral foot landed on the force plate during the stride. Participants were allowed to use their usual AFOs for walking during the entirety of the testing sessions if necessary for safety. They were closely supervised by a researcher during all walking trials. Participants were requested to wear the same shoes and AFOs, if applicable, for both pre and post testing sessions.

The kinematic and kinetic data was initially processed using VICON Workstation software (Vicon, Lake Forest, CA, USA). Customized MATLAB 7.5 (Mathworks, Boston, MA) programs were written to calculate the A-P GRF impulse and the mechanical work produced by the hip, knee, and ankle of the paretic and non-paretic limbs. The GRF data, normalized by each participant's body weight, was filtered with a recursive low-pass fourth order Butterworth filter at 50Hz. The three good trials for each leg were averaged together for subsequent analysis.

Calculation of paretic propulsion

The A-P GRF impulse was subdivided into the propulsive impulse, braking impulse, and net impulse (sum of the propulsive impulse plus braking impulse) for each leg. The propulsive impulse is the time integral of the positive A-P GRF, whereas the braking impulse is the time integral of the negative A-P GRF. The percentage contribution of the paretic limb to total propulsive impulse, referred to as paretic propulsion (P_p), was calculated by dividing the propulsive impulse of the paretic limb (PPI) by the sum of the paretic and non-paretic propulsive impulses (NPPI) (see Equation 1) (Bowden, Balasubramanian et al. 2006).

<u>*Equation 1*</u>: $$P_p = \frac{PPI}{PPI+NPPI} \times 100\%$$

Calculation of relative contribution of each paretic joint to total positive work of the paretic limb

The mechanical work produced by the hip, knee, and ankle was subdivided into positive, negative, and total work (sum of the positive plus negative work) at each individual joint for each leg. Positive work was calculated by integrating the positive joint power with respect to time and negative work was calculated by integrating the negative joint power with respect to time. The power at a joint (P_j) (watts) at a particular instant in time is the product of the net moment of force at that joint (M_j) (newton-meters) and the joint angular velocity (ω_j) (radians/second) (see Equation 2) (Winter 1990). The total positive work (W) of the paretic leg was calculated by adding the positive work values for each respective joint together (Hip Work = HW, Knee Work = KW, Ankle Work = AW) (see equation 3). The relative contribution of the paretic hip, knee, and ankle to total positive work (RCW) was calculated by dividing the positive work of the respective joint (WRJ) by the total positive work of the paretic leg (see equation 4).

Equation 2: $$P_j = M_j \times \omega_j$$

Equation 3: $$W = HW + KW + AW$$

Equation 4: $$RCW = \frac{WRJ}{W} \times 100\%$$

Statistical Analysis

Paired t-tests were used to analyze the differences in the mean values of gait velocity and percentage contribution of the paretic limb to total propulsive impulse. Repeated measures ANOVA were used to analyze the differences in the mean values of the relative contribution of the paretic hip, knee, and ankle to total positive work.

Statistical significance was accepted at an alpha level of 0.05.

CHAPTER 4

RESEARCH ARTICLE

The following paper has been submitted to Gait and Posture for review.

THE EFFECT OF BODY WEIGHT SUPPORT TREADMILL TRAINING ON PARETIC LEG CONTRIBUTION IN HEMIPARETIC WALKING IN PERSONS WITH CHRONIC STROKE

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Abstract

Body weight support treadmill training (BWSTT) has proven to increase the walking speed of patients with stroke. However, there is minimal research on the effects of BWSTT on the function of the paretic and non-paretic limbs, relative to walking speed. The purpose of this study was to assess the effect of BWSTT on paretic limb function using the outcome measures of overground walking velocity, paretic leg propulsion, and mechanical work produced by the hip, knee, and ankle of the paretic limb. Thirteen participants with chronic stroke, ranging in age from 40 to 80 years, completed 24 sessions of BWSTT over eight weeks. Overground walking velocity and bilateral kinematics and kinetics were collected prior to and following completion of the BWSTT intervention. All participants exhibited statistically significant increases in overground walking velocity post BWSTT. Neither the propulsive impulse of the paretic limb, relative to total propulsive impulse, nor the relative contribution of the paretic hip, knee, and ankle to total positive work significantly changed post BWSTT. The results suggest that paretic limb function remains unchanged following BWSTT, despite improvements in overground walking velocity.

1. Introduction

Body weight support treadmill training (BWSTT) is a task-oriented therapy approach used for retraining walking in persons with post-stroke hemiparesis. Compared to other methods used for retraining gait, BWSTT has been suggested to be more effective at restoring ambulatory function in persons with stroke with respect to overground walking speed [1-4]. However, the mechanisms used by these persons to achieve such improvements in walking speed are unclear. The measurement of walking speed is easy to obtain, therefore it is one of the most widely used measures of performance. For individuals with stroke, increases in walking speed are important for improving community access [5]. However, functional walking speeds are achievable, despite poor coordination of the paretic limb and decreased symmetry between the paretic and non-paretic limbs [6, 7]. Therefore, a better understanding of the effects of BWSTT on the function of the paretic and non-paretic limbs is needed, in conjunction with the changes in walking speed.

Post-stroke hemiparesis results in a disrupted, asymmetrical walking pattern. The unilateral impairment of the paretic limb often leads to an increased dependency on the non-paretic limb for walking. The goal of BWSTT is to reduce the asymmetries present between the paretic and non-paretic limbs. Therefore, an important measure of paretic limb function is the contribution of the paretic limb to forward propulsion in hemiparetic walking. For non-disabled individuals, the propulsive impulse of the right and left limbs, relative to the total propulsive impulse, is almost symmetrical between limbs. However, for individuals with post-stroke hemiparesis, the propulsive impulse of the non-paretic and paretic limbs, relative to total propulsive impulse, is often asymmetrical, with a larger percentage of the total propulsive impulse being generated by the non-paretic limb [6]. This asymmetry is reduced with improved motor recovery [6].

The propulsive impulse of the paretic limb provides a gross measure of paretic limb function; however it does not provide any specific information on the contribution of the individual joints. The quantification of the mechanical work performed at each joint, relative to total work, can identify where the specific deficits are occurring in the paretic limb. Similar to the propulsive impulse of the paretic limb, it has been suggested that a smaller percentage of the total positive work is performed by the paretic limb compared to the non-paretic limb. Olney et al found that the non-paretic limb performed approximately 60% of the total positive work, compared to the 40% performed by the paretic limb, across all walking speeds [7]. Closer examination of the positive work performed at each individual joint of the paretic limb revealed differences, primarily between the hip and ankle, at different walking speeds. Overall, as walking speed increased the positive work performed at the hip decreased, while the positive work at the ankle increased [7]. For non-disabled individuals, a majority of the positive work, relative to the total positive work of the limb, is performed at the ankle. Therefore, a therapeutic intervention aimed at restoring normal gait function would suggest that an increase in the amount of positive work performed at the ankle in the paretic limb should be expected.

The purpose of this study was to determine the effects of a BWSTT intervention program on overground walking velocity, paretic propulsion, and mechanical work produced by the paretic hip, knee, and ankle in individuals with chronic stroke. It was hypothesized that the propulsive impulse generated by the paretic limb, relative to total propulsive impulse, would increase following BWSTT. It was also hypothesized that there would be a change in the relative contribution of the paretic hip, knee, and ankle to total positive work following BWSTT.

2. Methods

2.1 Subjects

Fifteen individuals with a single stroke and resultant hemiparesis were recruited from local stroke support groups, rehabilitation centers, and clinicians who treat people with stroke. Inclusion criteria for this study were (1) between 40 and 80 years of age, (2) a single stroke at least 6 months prior to study, (3) ability to walk independently with or without the use of an assistive device or ankle foot orthosis (AFO), (4) a self-selected gait speed between 0.4 m/s and 0.8 m/s, (5) not currently receiving physical therapy services, and (6) no pre-existing or current cardiovascular, neurological, musculoskeletal, or other health conditions, separate from the effects of stroke, that could influence walking. Fifteen non-disabled individuals were recruited to serve as a non-equivalent comparison group for the hemiparetic subjects. The non-disabled subjects were within the same age range, able to walk independently, and had no apparent gait abnormalities. Subject characteristics are presented in Table 1. All procedures were approved by the Ball State University Institutional Review Board.

2.2 BWSTT Protocol

Subjects with chronic stroke completed 24 sessions of BWSTT over eight weeks under the supervision of a licensed physical therapist. They wore a fitted harness that connected to an overhead suspension system (Litegait®) as they walked on a treadmill (3106 Gaitkeeper®, Mobility Research, Tempe, AZ, USA). Each session consisted of 20 minutes total walking time with rest breaks permitted as needed. Training was initiated at 30% body weight support (BWS) at the fastest possible pace the subject could achieve within the first two minutes of training on the first day. Verbal and manual assistance was provided, as needed throughout training to promote an improved walking pattern. Handrail holding was not permitted in order to encourage typical arm swing.

Progression of the BWSTT protocol was dependent on the subject meeting parameter requirements for speed, time, and quality. On each subsequent treatment day, the treadmill speed was increased by 0.2 mph until the minimum age and gender norms for community walking speed [8] or the maximum subject tolerance was met. Subjects could take no more than one rest break per 20 minutes of total walking time to progress the protocol. Quality requirements, without therapist assistance, included symmetrical step length and stance time, upright trunk alignment, and consistent heel strike bilaterally. Subjects had to maintain these requirements for a minimum of five minutes during the total 20 minutes. Successful achievement of these requirements was based on the subjective assessment of the supervising physical therapist. Once all parameter requirements were met, BWS was decreased to 15% or 0%, accordingly, at the next session. These protocol progression guidelines are similar to those carried out in previous studies [3, 4, 9, 10].

2.3 Testing Protocol

Overground gait velocity was assessed using a comfortable 10-meter walk test (CWT) [11], conducted in an open room, along a 14-meter walkway. Subjects were timed for the middle 10 meters using electronic timing gates (Fitness Technologies, Adelaide, Australia). The subjects were instructed to walk at a comfortable, self-selected pace. Each subject completed the CWT three times and an average of the three trials was used for subsequent analysis.

Bilateral kinematics and kinetics were captured with a 10 camera VICON F-series motion capture system (Vicon, Lake Forest, CA, USA) and two AMTI force plates (Model BP600900-6-1000, Advanced Medical Technology, Inc., Watertown, MA, USA), at 60Hz and 1200Hz, respectively. Thirty-nine retro-reflective markers were attached to the subjects based on the VICON Plug-In-Gait (PiG) model. Three good trials were collected for each limb during data collection of the subject walking at his/her self-selected speed along a 6-meter walkway equipped with embedded force plates. A trial was defined as good if the whole foot and no part of the contralateral food landed on the force plate during the stride.

The subjects with chronic stroke completed a testing session prior to and following completion of the BWSTT intervention program. The non-disabled subjects only completed one testing session.

2.4 Data reduction and analysis

The kinematic and kinetic data was initially processed using VICON Workstation software (Vicon, Lake Forest, CA, USA). Customized MATLAB 7.5 (Mathworks, Boston, MA) programs were written to calculate the anterior-posterior GRF (A-P GRF) impulse and the mechanical work produced by the hip, knee, and ankle of the paretic and non-paretic (right and left) limbs. The GRF data, normalized by each subject’s body weight, was filtered with a recursive low-pass fourth order Butterworth filter at 50Hz. The three trials for each limb were averaged together for subsequent analysis.

The propulsive impulse, defined as the time integral of the positive A-P GRF, for each limb was used for further calculations. The percentage contribution of the paretic limb to total propulsive impulse, referred to as paretic propulsion (P_p), was calculated by dividing the propulsive impulse of the paretic limb by the sum of the paretic and non-paretic propulsive impulses [6]. The percentage contribution of the right limb to total propulsive impulse for the non-disabled subjects was used for comparison.

The positive mechanical work produced by the hip, knee, and ankle of the paretic limb, defined as the integration of positive joint power with respect to time, was used for further calculations. The total positive work of the paretic limb was calculated by adding the positive work values for each respective joint together. The relative contribution of the paretic hip, knee, and ankle to total positive work was calculated by dividing the positive work of the respective joint by the total positive work of the paretic limb. For the non-disabled subjects, the relative contribution of the hip, knee, and ankle to total positive work was based on the right limb.

2.5 Statistics

The differences in the mean values of gait velocity and paretic propulsion before and after BWSTT were assessed using paired t-tests. Repeated measures ANOVA were used to analyze the differences in the mean values of the relative contribution of the paretic hip, knee, and ankle to total positive work. Statistical significance was accepted at $p < 0.05$. All statistical analyses were compiled using the Statistics Package for the Social Sciences (SPSS Inc., Chicago, IL).

The gait velocity, right limb propulsion, and relative contribution of the right hip, knee, and ankle to total positive work of the non-disabled subjects was used as a reference of comparison for the subjects with chronic stroke to determine if they moved more towards normal following BWSTT. No statistical analyses were run on these data.

3. Results

Two subjects were excluded from the study because they were unable to complete the testing protocol safely without the use of their assistive walkers. Table 2 presents the group means for overground gait velocity, P_p, and relative contribution of the paretic hip, knee, and ankle to total positive work. Overground gait velocity was significantly increased following the eight-week BWSTT intervention program ($p = .003$). The average P_p for all of the subjects with stroke remained unchanged post BWSTT ($p = .918$, Figure 1). Changes in P_p per subject did occur post BWSTT, though the direction of change was inconsistent across subjects. Changes in the average relative contribution of the paretic hip ($p = .821$), knee ($p = .930$), and ankle ($p = .919$) to total positive work post BWSTT were minimal (Figure 2). Similar to P_p, changes did occur in each joint per subject, however the direction of change was inconsistent across subjects.

4. Discussion

The purpose of this study was to assess the effect of BWSTT on paretic limb function in individuals with post-stroke hemiparesis using outcome measures of overground walking velocity, paretic leg propulsion, and mechanical work produced by the hip, knee, and ankle of the paretic limb. Overground walking velocity was found to significantly increase following 24 sessions of BWSTT. However, despite hypotheses that the percentage of total propulsive impulse generated by the paretic limb would increase following BWSTT, no significant differences were found. Additionally, expectations for the percent contribution to total positive work of the paretic hip, knee, and ankle following BWSTT to change, with more work being performed by the paretic ankle, were not supported by the results.

The increases in walking velocity following BWSTT are consistent with results from previous studies [1, 2, 4, 10]. During BWSTT, the individuals with hemiparesis were able to practice walking at faster treadmill speeds than their self-selected walking speed. Therefore, the increase in walking velocity following BWSTT may be the result of training at faster treadmill speeds. This implies that there is some carryover from supported treadmill training to overground walking for individuals with stroke.

Paretic propulsion has been suggested to provide a quantitative measure of the coordinated output of the paretic limb that is sensitive to hemiparetic severity and, as such, may be considered a valuable measure of the outcomes of a therapeutic walking intervention [6]. While our subjects were not separated by hemiparetic severity, the average P_p, both prior to and following BWSTT, exhibited by our subjects resembled the P_p seen by Bowden et al in individuals with moderate post-stroke hemiparesis (36%) [10]. When interpreting P_p per subject, our results were more similar to those of the pilot study by Plummer et al [10], where the P_p increased post-intervention for some subjects, whereas it was decreased or remained steady for others. It is possible that for those subjects who had an increase in P_p post-intervention, advancing more towards normal, there was some restitution of the motor coordination of the paretic limb. Comparatively, the decreases in P_p would suggest a more functional compensation by the non-paretic limb.

In addition to P_p, the changes in the relative contribution of the paretic hip, knee, and ankle to total positive work were examined to further our understanding of the contribution of the paretic limb to forward propulsion in hemiparetic walking. Olney et al suggested that the paretic limb performs approximately 40% of the mechanical work of walking across all walking speeds [7]. However, large discrepancies in the amount of work being performed by the paretic ankle and moderate differences in the amount of work being performed by the paretic hip were noted between different walking speeds. The subjects with stroke that exhibited a faster self-selected walking speed (0.63m/s) performed more work with the paretic ankle and slightly less work with the paretic hip, compared to those subjects that walked at a slower self-selected gait speed (0.25 m/s) [7]. Additionally, a major focus of BWSTT is the repetitive forced-use of the paretic limb and improved stepping with the paretic limb. Therefore, we expected to see an increase in the relative contribution of the paretic ankle to total positive work as walking speed increased post BWSTT. However, contrary to our expectations, there was no significant change in the relative contribution of any of the joints of the paretic limb to total positive work. In comparison to the results of Olney et al, the average relative contribution of the paretic hip was similar to those with faster self-selected walking speeds, although the average relative contributions of the paretic knee and ankle were more similar to those with slower self-selected walking speeds. These confounding results suggest that the relative contribution of the paretic hip, knee, and ankle to total positive work are not necessarily related to walking speed.

In conclusion, the lack of change in the P_p and the relative percent contribution of the paretic hip, knee, and ankle to total positive work suggest that patients with stroke are achieving increases in walking velocity, post BWSTT, by some other means than changes in paretic limb function. It is possible that the patients with stroke have already developed compensatory mechanisms to help them functionally achieve the goal of walking and BWSTT just strengthens an already existing compensatory pattern, allowing patients to attain faster walking velocities. Using P_p as an outcome measure of BWSTT, the average P_p results from this study would suggest that BWSTT is not a valuable intervention for improving paretic limb function. However, per subject P_p results may suggest otherwise. Further research is needed regarding the mechanisms that are responsible for the improved walking velocities following BWSTT.

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Table 1
Hemiparetic (n = 15) and non-disabled (n = 15) subject characteristics

	Hemiparetic	Non-disabled	Range
Age (years)	61.5 (11.4)	58.1 (6.6)	40 -79
Gender (M/F)	3/12	7/8	
Paretic side (right/left)	11/4		
Time since stroke (years)	3.4 (2.7)		0.75 - 7

Group means and standard deviations (in parentheses).

Table 2
Outcome Measures

	Pre BWSTT	Post BWSTT	p-value
CWT Walking Velocity (m/s)	0.62 (0.14)	0.73 (0.17)	0.003
Motion Capture Walking Velocity (m/s)	0.66 (0.19)	0.77 (0.22)	0.027
Paretic Propulsion (P_p) (%)	34 (19)	34 (17)	0.918
% Contribution to Total Positive Work			
Hip	43 (13)	42 (13)	0.821
Knee	27 (15)	27 (18)	0.930
Ankle	30 (15)	31 (14)	0.919

Group means and standard deviations (in parentheses). P_p and % contribution to total positive work values are representative of the paretic limb.

Figure 1

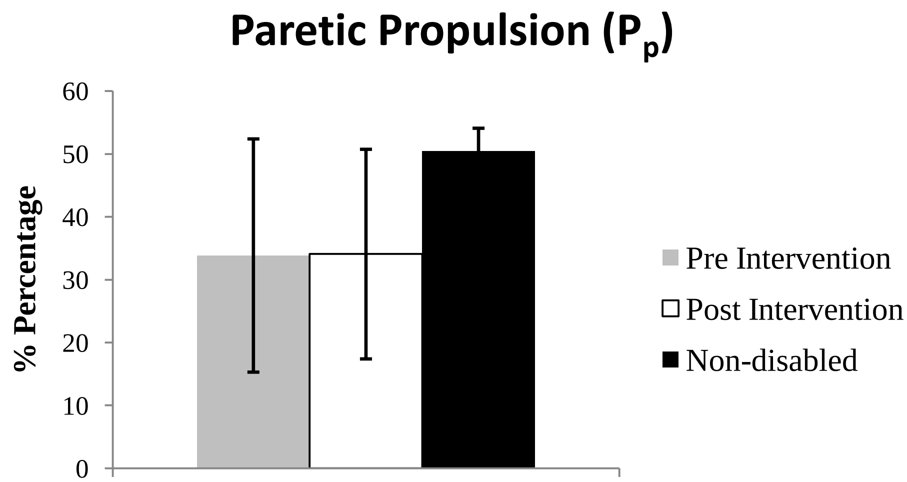
Paretic Propulsion (P_p)
% Percentage
60
50
40
30
20
10
0
Pre Intervention
Post Intervention
Non-disabled

Figure 2

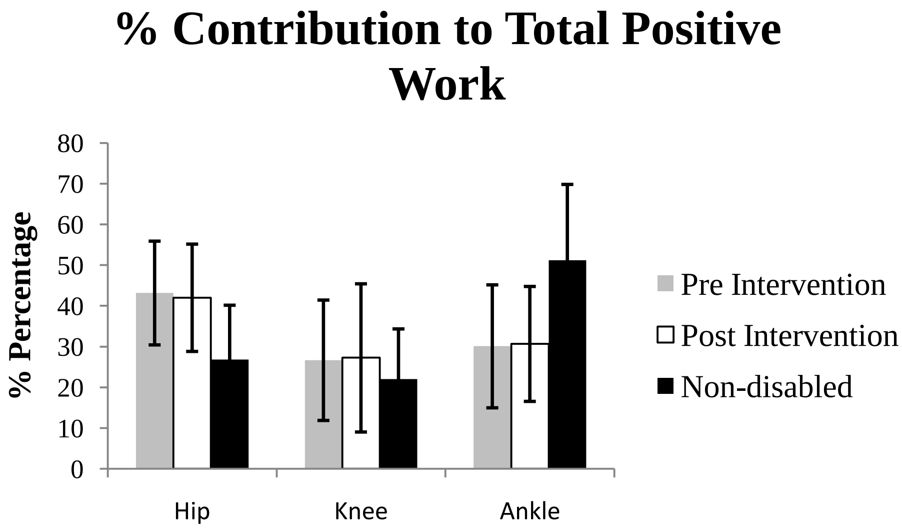
% Contribution to Total Positive Work
% Percentage
80
70
60
50
40
30
20
10
0
Hip
Knee
Ankle
Pre Intervention
Post Intervention
Non-disabled

Figure 1 Caption

Comparison of the average propulsion (expressed as a percentage of total propulsion) generated by the paretic limb (P_p) before (gray bars) and after (white bars) completion of BWSTT intervention for the hemiparetic subjects. The black bars represent the average propulsion of the right limb of the non-disabled subjects. There were no significant differences in the percent of P_p of the hemiparetic subjects between testing sessions. Error bars indicate SD.

Figure 2 Caption

Comparison of the average relative contribution of the paretic hip, knee, and ankle to total positive work (expressed as a percentage for each joint) before (gray bars) and after (white bars) completion of BWSTT intervention for the hemiparetic subjects. The black bars represent the average relative contribution of the right hip, knee, and ankle to total positive work. There were no significant differences in the relative contribution of the paretic hip, knee, and ankle of the hemiparetic subjects between testing sessions. Error bars indicate SD.

CHAPTER 5

SUMMARY AND CONCLUSIONS

Summary

The gait of individuals with post-stroke hemiparesis is characterized by reduced walking speed, disproportionate timing of the gait cycle, uncoordinated movement patterns, and decreased force output by the paretic limb. Gait retraining interventions, such as BWSTT, have aimed to improve these impairments, however the positive outcomes reported are limited to increases in walking speed. There is minimal research examining the changes in paretic and non-paretic limb function following rehabilitation utilizing BWSTT. The purpose of this study was to assess the effect of BWSTT on paretic limb function using the outcome measures of overground walking velocity, paretic leg propulsion, and the mechanical work produced by the hip, knee, and ankle of the paretic limb. Thirteen participants with chronic stroke, between the ages of 40 and 80 years, completed 24 sessions of BWSTT over eight weeks. Overground walking velocity and bilateral kinematics and kinetics were collected prior to and following completion of the BWSTT intervention.

Overground walking velocity significantly increased (p = 0.003) following completion of the BWSTT intervention, consistent with the findings from previous studies examining the use of BWSTT for retraining gait in patients with stroke (Hesse, Bertelt et al. 1995; Visintin, Barbeau et al. 1998; Sullivan, Knowlton et al. 2002; Barbeau and Visintin 2003). No significant differences were found between the pre-intervention and post-intervention values for the average percent contribution of propulsion generated by the paretic limb, or paretic propulsion (P_p) (p = .918). Changes were present in the P_p per subject post BWSTT, though the direction of change was inconsistent across subjects. There were also no significant differences in the average relative contribution of the paretic hip (p = .821), knee (p = .930), and ankle (p = .919) to total positive work pre to post BWSTT. Similar to P_p, changes were present at each joint per subject, however the direction of change was inconsistent across subjects.

Conclusions

Overground walking velocity improved following the eight weeks of BWSTT, indicating that BWSTT leads to a more successful recovery of walking function with respect to walking velocity. Increases in walking velocity are necessary for improving the community access of patients with stroke. However, the goal of BWSTT for retraining walking in patients with stroke is not limited to increases in walking velocity.

The aim of rehabilitation approaches used for retraining gait in patients with stroke, including BWSTT, is to restore the ‘normal’ patterns of gait, as exhibited by healthy, non-disabled individuals. Therefore, a major focus of BWSTT is on the deficits present in the paretic limb.

The contribution of the paretic limb to forward propulsion, as measured by paretic propulsion, has been suggested to provide a quantitative measure of the coordinated output of the paretic limb and as such, may be considered a valuable measure of the outcomes of therapeutic walking interventions. Based on the results of this study, BWSTT has no effect on the coordinated output of the paretic limb. Further supporting this assessment is the lack of change in the relative contribution of the paretic hip, knee, and ankle to total positive work. However, before quickly eliminating BWSTT as a possible option for retraining gait in persons with stroke, it is important to evaluate the individual results per subject. Some of the subjects in this study did exhibit increases in the amount of paretic propulsion post BWSTT, indicating that there was some change in the coordinated output of the paretic limb. Paretic propulsion has also been suggested to be sensitive to hemiparetic severity. For this study, our subjects were not separated by hemiparetic severity. Therefore, it is possible that for those subjects participating in this study that were able to increase their paretic propulsion, only had a moderate degree of hemiparetic severity.

Despite the lack of change in the overall paretic propulsion and relative contribution of the paretic hip, knee, and ankle to total positive work post BWSTT, overground walking velocity still increased. This may suggest that individuals with chronic stroke have already developed compensatory mechanisms to help them functionally achieve walking. The increases in walking velocity are a result of the BWSTT strengthening this already existing compensatory mechanism and making it more effective. If the goal of BWSTT is to achieve optimal functional performance for individuals with stroke, it is possible that the approach should be less focused on restoring 'normal' gait patterns and more focused on what is the new normal, most effective walking pattern for the individual.

Future Recommendations

The paretic propulsion and relative contribution of the paretic hip, knee, and ankle to total positive work did not change post BWSTT, indicating that BWSTT had no effect on paretic limb function. However, there was a moderate degree of variability in the results across subjects, indicating that changes in paretic limb function following BWSTT should not be applied broadly to all individuals with stroke, at least six months post. Rather, recommendations to repeat this study, recruiting a larger sample of individuals with stroke, across different time frames since stroke would be suggested. It would also be recommended to examine the effect of hemiparetic severity, physical activity levels prior to initiating BWSTT and outside of training, time since stroke, and age on the outcomes of BWSTT, particularly paretic propulsion and relative contribution of the paretic hip, knee, and ankle to total positive work.

CHAPTER 6

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