THE ACUTE EFFECT OF WHOLE-BODY VIBRATION ON GAIT PARAMETERS IN ADULTS WITH CEREBRAL PALSY

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF SCIENCE

BY

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DECEMBER 2011
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 whole or in part, for a degree at this or any other university.

X

Kathryn A. Faust
P.I.
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My patient friend who listened to me scream on the phone every night and knows how important it was for me to finish this project- for his constant support…

...Thank you
As more adults with cerebral palsy (CP) are surviving longer (1) an intervention is needed to help reduce spasticity and increase overall strength to improve mobility, and therefore life quality. Adults with CP are lacking a form of independent exercise that allows them to maintain or improve their ambulation skills (1, 2). A new approach to increase muscle strength and flexibility is called whole-body vibration (WBV). The goal of the current study was to determine the acute effects of using an individualized frequency (I-Freq) approach to WBV therapy on gait in adults with CP. In this study, eight adults with CP (age 20-51 years, six men, two women) participated in two sets of testing: the first set was used to determine their I-Freq and the second set to perform a 3D gait analysis before and after a WBV treatment. The WBV was administered in five sets of one minute of vibration followed by one minute of rest. The gait analyses included collection of kinematic and EMG data. Subjects experienced a significant increase in walking speed ($P=0.047$), stride length ($P=0.017$) and dynamic ankle range of motion ($P=0.042$) after the acute bout of WBV. These data show that WBV treatments at I-Freq could help adults with CP maintain their range of motion and overall mobility through an independent and cost effective means.
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Nomenclature

WBV- whole-body vibration
CP- cerebral palsy
ROM- range of motion
GRF- ground reaction force
AP- action potential
Chapter 1- Development of the Problem

Introduction

Cerebral palsy (CP) results from damage to the developing central nervous system while in utero, during delivery, or during the first two years of life (3). The most common signs of the disorder are spasticity, rigidity, muscle weakness, ataxia, and movement disorders (4). The extent of the disorder can depend on the scale, degree, and position of the damage that occurs in the spinal cord, brain stem, or brain. The motor skills of the children affected by cerebral palsy do improve as they age and grow; however, the skills never match those of typically developed individuals (3).

One of the biggest problems associated with movement for individuals diagnosed with CP is spasticity, which is defined as a velocity-dependent resistance of muscle to stretch (3). Damage occurring in the brain results in a loss of inhibitory input through the reticulospinal tract and other systems which cause an over excitability of the alpha and gamma motor neurons that ultimately result in muscle contractures or spasticity (3). The inability of the spastic muscle to change length like bone causes a decline in gait function for individuals with CP. The increased skeletal growth without the increase of the muscle growth leads to a relative muscle
tightness, contracture, and finally bony torsions (5). The result of this is an overall reduction in the quality and quantity of the motor skills available to these individuals. By reducing or eliminating spasticity through medication or surgery, affected individuals have been able to control the motor skills that they still possess more effectively.

CP physically manifests itself in one of three diagnoses, or clinical patterns of involvement, based on the limbs affected: diplegic, hemiplegic, or quadriplegic. Diplegia CP describes the condition when there is significant effect on the legs with a less severe impact on the arms; hemiplegic involves both the legs and the arms ipsilaterally; and quadriplegia involves all four limbs (3). There are also four different movement disorders of CP that can be defined based on motor patterns: spasticity, athetosis, ataxia, and mixed. Seventy percent of the CP population is classified at spastic, 20% as athetoid, and 5% ataxic (6). Movement disorders can coexist with the clinical patterns of involvement in a number of different combinations (3). Individuals with CP can also be classified based on their functional level. One functional classification system developed by the Cerebral Palsy-International Sport and Recreation Association (CP-ISRA) is the Functional Classification System (6).

As the overall life expectancy for individuals in developed countries increases, so too does the life expectancy of individuals with CP. This coupled with advances made in the medical field has resulted in a growing number of adults with CP (7). Although the life expectancy of individuals with CP has increased, the access and attention to the medical and rehabilitative needs of these individuals has been limited (7). It has been suggested that the lack of care for adults with CP is due in part to the special attention given to the children with CP by the physiotherapists who feel their effort may be better concentrated on this younger population (8). By decreasing the
amount of therapy received, adults begin to lose their range of motion, flexibility, and strength. (9).

Other than physical therapy, there are many treatment options for adults with CP including: physiotherapy, oral pharmacological intervention, and surgery. Physical examination and visual assessment traditionally have been the only options available for the evaluation of patients with CP. In recent years, however, the number of studies utilizing new technologies has increased (3, 10). One of those techniques used to identify and guide treatment plans is three dimensional gait analysis which provides temporal and spatial parameters, kinetic and kinematic data, and electromyographic (EMG) data (10). The most common gait abnormalities for individuals with CP include: toe walking, crouched gait, and hip adduction (3). Because there are many treatments options for individuals with CP, a gait analysis is especially important for prescription of orthotics and assistive devices, documentation, assessment, development of rehabilitation strategies and planning pre and postsurgical intervention (1, 11). A gait analysis allows surgeons to look at multiple neuromuscular problems and each joint involved with locomotion at one time allowing for a more complete and successful treatment plan (1, 12). Data from a 3D gait analysis quantifies the magnitude of deviation of gait from individuals without CP and helps to provide a qualitative explanation for these deviations (13).

A gait analysis is especially important for adults with CP because a number of studies have documented a progressive loss of function, specifically mobility with age. Although CP is due to static damage which does not progress with age, researchers have disputed this point over the years. Bottos et al. (7) found that independent walking or other forms of supported walking were lost by the time the subject reached adulthood. Forty-four percent of the population walked independently prior to 18 years of age, but only 22% were walking independently as
adults. In a study by Andersson et al. (14) it was determined that 79% of adults with spastic diplegic CP were able to walk with or without walking aids at one point in their lives, but 51% of those claimed that their walking ability had decreased during recent years with 9% having stopped walking completely. Explanations offered by the patients for the reduction in locomotion included deterioration of condition, reduced muscle strength, and impaired postural control (14).

The Andersson et al. study (14) made it clear that remaining independently mobile is a major objective for individuals living with CP. Higher survival rates have been found in adults with CP who have retained a higher functional level (2). Studies have reported that regular exercise improves functional status, decreases the level of required assistance, and reduces the incidence of secondary conditions in people with disability (15, 16). Seeing the positive effects that exercise can bring to adults with CP, it is obvious that these individuals are in need of an outside source of therapy or exercise beyond that provided by the care provider. One method shown to be effective in helping children with CP to improve body function and enhance abilities is through improving overall strength (17). Many authors have hypothesized that programs like these may prevent the decline in function often seen in adults diagnosed with CP (9). However, very few studies have been published to guide interventions to help improve the health and wellbeing of these individuals.

A method for increasing muscle strength and range of motion is a technique referred to as “whole-body vibration” (18-20). Whole-body vibration (WBV) can be characterized by a few key descriptors including: frequency (measured in Hz), amplitude (measured in mm), gravitational force, duration of the exercise, as well as the direction of the vibration. The frequency of the vibration usually ranges between 3 -50 Hz depending on the subject’s characteristics and the
desired outcome. The amplitude ranges from a few micrometers to many millimeters. The frequency and amplitude of vibration are very important when choosing a protocol since the interaction of these factors will determine the magnitude of the g-forces, or the acceleration experienced by an object due to gravitational pull, and therefore the intensity of the training (18, 21). Due to the wide range of frequency and amplitude combinations that could be combined, there are many WBV protocols to choose from for humans (22).

Vibration can be administered in two ways: directly to the muscle in question or through WBV (23). The main difference between the direct and indirect vibration is the magnitude of amplitude and frequency of the original vibration that reaches the target muscle (23). WBV treatments transmit vibrations to the subject’s entire body, which generates mechanical stresses to the muscle groups and soft tissues throughout the body (22). Vibrations stimulate the muscle spindles and the alpha-motor neurons, which initiates a muscle contraction (24). Vibration applied to skeletal muscle tend to induce a reflex response that involves both a sustained contraction of the muscle vibrated and simultaneous relaxation of its prime antagonists (25).

This new technique has been used in many different populations including: older healthy adults (26, 27), young healthy nonathletic adults (27-33), highly trained athletes (19, 34-36), individuals with spinal cord injury (37), adults with Parkinson’s (25), adults with cerebral palsy (24), and children with cerebral palsy (38, 39). Positive changes have come from each of the populations; however, even within the same population, the results were not consistent likely due to the many variations of protocols used in the studies. The typical vibration frequency used has ranged from 15 Hz (28) -120 Hz (40); with most studies using the range 20-45 Hz (23). The duration of the exercise is another factor that has varied between studies ranging from 0.1 min
(41) to 30 minutes (40). Many studies have used 60 seconds of WBV followed by 60 seconds of rest and then repeated as set protocol for acute WBV (28, 35, 36, 42, 43).

The studies mentioned above are either chronic, spanning a few weeks to a month, or acute with measurements of changes assessed immediately following the treatment. The acute effects of vibration are an interest to mainly physiologists and sport scientists, however, in the clinical setting, a chronic treatment seems more appropriate with three main therapeutic aims: increasing muscle strength, improving balance, and increasing bone mass (18). However, both types of studies, chronic and acute, have had positive and negative changes associated with them.

These contrasting results could be caused by a lack of uniformity among protocols, specifically the frequency chosen. As seen from previously stated research, WBV can act as great tool for intervention, however, unless individualized; optimal results may not be produced. Many researchers assume that the vibration frequency induced by a motor to the platform elicits a tonic vibration reflex similar to the direct or indirect application of vibration on muscle or tendons (44). Researchers also agree that several factors influence the effects of vibration and that the intensity of the load on the neuromuscular system is determined by the vibration frequency and amplitude. However, in a study by Martin and Park (45) they found that by administering a high-frequency vibration they may have actually decreased the harmonic synchronization of the motor units, which has a negative influence on neuromuscular performance. Di Giminiani et al. suggests that each individual has a different optimum frequency of vibration that elicits the greatest reflex response during WBV (44).
Since the individualized frequency technique has resulted in a positive outcome for many populations, it seems that adults with CP may benefit as well. By adding WBV at an individualized frequency to their exercise routines, adults with CP could potentially see the same positive changes that other populations have experienced. Since adults with CP are surviving longer than ever before in combination with a decrease in therapy and exercise, they are declining in their function and walking ability. They are in need an intervention to help increase their strength and maintain their level of daily activity without the aid of therapists and insurance coverage. Based on previously performed studies, WBV could aid in increasing strength, flexibility, and walking speed in adults with CP. No studies have been performed to date on the acute effects of whole-body vibration on gait in adults with cerebral palsy.

**Purpose**

The goal of the current study was to determine the acute effects of using an individualized frequency approach to WBV therapy on gait in adults with cerebral palsy. It was hypothesized that the subject’s would exhibit a greater range of motion in the knee and ankle allowing for an increased velocity, and increased step length during gait as a result of the WBV.

**Significance**

In the future, whole-body vibration could augment everyday physical therapy for adults with cerebral palsy by increasing range of motion and allowing them to improve their gait independently. The relative low cost of WBV and the ease of use make this technique a viable alternative to physical therapy. By improving strength and overall health, WBV could extend and increase the quality of life for adults with CP.
Limitations

Due to the size of the spastic diplegic cerebral palsy population, adults with hemiplegic cerebral palsy were added to the sample. In a study by Bottos et al. (7) they found that 53.7% of their sample had underwent orthopedic surgery. Most adults with CP will have undergone orthopedic surgery by the time they reach adulthood. This is a factor that was unable to be controlled for in this study especially since each individual with CP presents their disability differently; which means that the surgeries performed vary greatly from subject to subject. Due to the disabilities the subjects had, acute WBV was chosen to limit the amount of standing time for the subjects on the vibration plate.

Delimitations

The participants needed to be primarily diagnosed with spastic hemiplegic or diplegic cerebral palsy. They had to fall between the ages of 18 and 65 and could be male or female. They were rated between CP5-CP8 on the CP-IRSA Functional Classification System, which means that at the time of the study, they were independently mobile. They must not have received a baclofen or Botox injection for at least three months nor had surgery in the last two years prior to participating in the study. The subjects were asked to not attend physical therapy the day before or day of the testing. Due to the functional limitations of the subjects acute WBV was chosen to limit the amount of standing time on the vibration plate.

Summary

Adults with CP are lacking a form of independent exercise that allows them to maintain or enhance their ambulation skills. With age, they are increasing spasticity and tightness in their muscles which makes it increasingly difficult to continue being active which is a key factor to a
healthy lifestyle. WBV could act as a tool for these adults by increasing flexibility and muscle strength. One way to measure the changes from WBV on adults with CP is through a 3D gait analysis. This technique allows the researcher to quantify all of the gait deformities in one place at the same time as well as the changes that WBV can evoke in the gait pattern. The information gained from this study may be useful for adults with CP looking to improve their gait and mobility independently as well as for physical therapists looking for a new intervention for their patients.
Cerebral Palsy

Cerebral palsy results from damage to the developing central nervous system (CNS) while in utero, during delivery, or during the first two years of life (3). The most common signs of the disorder are spasticity, rigidity, muscle weakness, ataxia, and movement disorders (4). The extent of the disorder can depend on the scale, degree, and position of the damage that occurs in the spinal cord, brain stem, or brain. The motor skills of the children affected by cerebral palsy do improve as they age and grow; however, the skills never match those of typically developed individuals (3).

The biggest problem associated with movement for individuals diagnosed with spastic cerebral palsy is spasticity (3). Damage occurring in the brain stem results in a loss of inhibitory input through the reticulospinal tract and other systems which cause an over excitability of the alpha and gamma motor neurons that ultimately result in muscle contractures or spasticity (3). The result of this is an overall reduction in the quality and quantity of the motor skills available to these individuals. By reducing or eliminating spasticity, affected individuals are able to maintain the motor skills that they still possess more effectively (3).
This disorder physically manifests itself in one of three diagnoses based on the limbs affected: diplegic, hemiplegic, or quadriplegic. Diplegia cerebral palsy describes the condition when there is significant effect on the legs with a less severe impact on the arms; hemiplegic involves both the legs and the arms ipsilaterally; and quadriplegia involves all four limbs. A description of how these diagnoses affect certain limbs and body parts are below in Table 1. A mixture of characteristics can exist in these different classifications (3) such that four different clinical types of cerebral palsy can be defined based on motor patterns including spasticity, athetosis, ataxia, and a combination of the three (6). Seventy percent of the CP population is classified as spastic, 20% as athetoid, and 5% ataxic. Individuals with CP can also be classified based on their functional level. One such functional classification system developed by the Cerebral Palsy-International Sport and Recreation Association (CP-ISRA) is the Functional Classification System (Table 1). CP1-CP4 describes individuals who are unable to ambulate independently without the help of chairs, orthotics, or braces. Individuals classified as CP5-CP8 are less affected, more highly functioning individuals who can ambulate independently(6).
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<tr>
<td><strong>CP2: moderate to severe spastic or athetoid quadriplegia</strong></td>
</tr>
<tr>
<td><strong>CP3: moderate spastic quadriplegia or severe hemiplegia</strong></td>
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<tr>
<td><strong>CP4: moderate to severe spastic diplegia</strong></td>
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<tr>
<td><strong>CP5: moderate spastic diplegia</strong></td>
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<td><strong>CP6: moderate athetosis or ataxia</strong></td>
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<tr>
<td><strong>CP7: true ambulatory hemiplegia</strong></td>
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<tr>
<td><strong>CP8: minimally affected diplegia, hemiplegia, athetosis, or monoplegia</strong></td>
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Table 1: CP-IRSA Functional Classification System (6)

Cerebral Palsy (CP) is associated with a significant death rate in individuals between the ages of 15 and 35 years especially for individuals with severe motor, cognitive and visual disabilities (9). As the overall life expectancy for individuals in developed countries increases, so too does the life expectancy of individuals with CP. This coupled with advances made in the medical field has
resulted in a growing number of adults with CP (7). This increased population has noted a lack of attention to their disability needs (7). It has been suggested that the lack of care for adults with CP is due in part to the special attention given to the children by the physiotherapists who believe their effort may be better concentrated on this younger population (8).

As these individuals with CP age, they are growing physically increasing in size and possibly increasing life skills, however, they still experience physical fatigue. The strongest predictors associated with this fatigue are bodily pain, deterioration of functional skills, limitations in emotional and physical functions, and overall low life satisfaction (9). By decreasing the amount of therapy received by the individuals, these adults begin to lose their range of motion, flexibility, and strength. An additional factor associated with the increased levels of fatigue in this population is the degree of pain reported which tends to limit the amount of activity performed by adults with CP (9). To date however, very few studies have been published to guide interventions to help improve the health and wellbeing of these individuals.

It has been estimated that 20-30% of participants with CP, age 16-20 years old, encounter restrictions in daily activities such as mobility, self-care, and nutrition (46). Although CP is due to static damage and does not progress with age, researchers have disputed this point over the years. A number of studies have documented a progressive loss of function, especially mobility, in adults. Bottos et al. (7) found that independent walking or other forms of supported walking were lost by the time the subject reached adulthood. From Bottos’ et al. study, 44% of the population had walked independently prior to 18 years of age, but only 22% were walking independently as adults. In a study by Andersson et al. (14) it was determined that 79% of adults with spastic diplegia were able to walk with or without walking aids at one point in their lives, but 51% of those reported decreases in their walking ability during recent years with 9% having
stopped walking completely. Explanations from these patients regarding the reduction in locomotion included deterioration of condition, reduced muscle strength, and impaired postural control (14).

When designing interventions for adults with CP, the general goals of physical and occupational therapists have been those of inclusion and participation in major life areas. Specific goals have included minimizing impairments in body function and structure, preventing secondary conditions, and optimizing activities and participation (9). Not surprisingly, higher survival rates have been found in adults with CP who have retained a higher functional level (2). Studies have reported that regular exercise improves functional status, decreases the level of required assistance, and reduces the incidence of secondary conditions in people with disability (15). Other studies have demonstrated that participating in, and the frequency of, therapy or exercise often times depends on the attitude of the care provider. If the care provider values the importance of exercise for the individual with the disability, there was a higher degree of exercise performed (47). Seeing the positive effects that exercise can bring to adults with CP, it is obvious that these individuals are in need of an outside source of therapy or exercise beyond that provided by the care provider. One method shown to be effective in helping children with CP to improve body function and enhance abilities is through improving overall strength (17). Many authors have hypothesized that programs like these may also prevent the decline in function often seen in adults diagnosed with CP (9).

There are many management options available for patients with cerebral palsy including physiotherapy, oral pharmacological intervention, and surgery. Traditionally, physical examination and visual assessment traditionally have been the only options available for the evaluation of patients with cerebral palsy. From this gait analysis the most common gait
abnormalities noticed for individuals with CP includes toe walking, crouched gait, and hip adduction (3). In recent years, however, the number of studies utilizing new technologies has increased (10). One technique that has proven to be beneficial to the assessment of these individuals is three dimensional gait analysis which provides temporal and spatial parameters, kinetic and kinematic data, and electromyography (EMG) data (10). From this more sophisticated analysis clinicians and researchers are able to obtain a more accurate assessment of the gait of these individuals which can better help guide intervention strategies.

**Gait Analysis**

As defined by Gage (12), a gait analysis is the measurement of characteristics that describe a human’s locomotion. It describes how a person walks and outlines the patterns they follow. A gait analysis can be a very helpful tool for describing and diagnosing motor control problems specifically in locomotion. According to Gage, a gait analysis allows surgeons to look at all of the motor problems at one time allowing for a more complete and successful treatment plan (12).

Gait analysis is especially important for those diagnosed with cerebral palsy as a preoperative tool for documentation, assessment, and planning (11). The task of walking involves moving the human body from one point to another while minimizing energy expenditure for a motor skill requiring a high degree of control and coordination. Walking in a neurotypical individual is a highly efficient process that requires a constant monitoring of, and adjustment to, biomechanical measures in order to maintain its high level of efficiency. Abnormal gait in patients with cerebral palsy is often due to the extensive damage to the central nervous system including the loss of selective muscle control, abnormal muscle tone, relative imbalance between muscle agonists and antagonists across joints, and deficient equilibrium reactions (12).
Kinetics and Kinematics. The components measured in a typical gait analysis include: kinematics, kinetics, and electromyography data. Kinematics describes the spatial movement of a body without regard to the forces that cause the movement. The movements assessed in a kinematic analysis include linear and angular displacements, velocities, and accelerations. Using the three cardinal planes of motion, measures of joint angles for the hips, knees, and ankles are used to assess the overall quality of motion during gait. Kinetics describe the mechanisms that cause movement which includes ground-reaction forces, joint moments, and joint powers, requiring simultaneous acquisition of joint motion and force-plate data in order to be calculated. Electromyographic data are acquired from electrodes placed on the surface of the skin of the patient providing information regarding muscle activation timing and intensity (12).

During typical gait there are identifiable events that help to define its overall structure and include: swing phase, initial contact, stance phase, and toe-off. During typical walking, these events occur contralaterally since humans have two lower extremities moving in opposing directions. The measure of stride length is defined as the distance between two heel strikes of the same foot and can be a very informative tool when discussing tendon and muscle stiffness. If an individual is very tight or spastic, their stride length would be decreased due to their lack of range of motion. The measure of stance phase can be further separated into single or double limb support. Single support occurs when only one foot is in contact with the ground and double support describes the time when both feet are in contact with the ground. For individuals with a lack of balance or strength, a greater amount of time is spent in double support, wherein the individual is seeking a comfortable and controlled position. Double support can be decreased by increasing velocity which makes it a key factor in typical walking. One method used to describe the overall frequency of gait is through the number of strides during a length of time and is
defined as stride rate. If an individual is unbalanced or lacks muscular control, their double support time increases to support themselves resulting in a lower velocity or stride rate (48).

When analyzing an individual’s gait the overall gait cycle is measured which is defined as the movement of a single limb from heel-strike to heel-strike again of the same foot (12). The cycle, seen in Figure 1, begins with the heel or foot strike of the right leg, which begins the stance phase, followed by the loading response, with plantar flexion occurring at the ankle in order to get the entire foot in contact with the ground. Next is mid-stance where the body weight passes forward over the foot, acting as a fulcrum, as the ankle moves through dorsiflexion. Terminal stance then occurs with the heel leaving the ground as the foot plantar flexes to allow the toe to leave the ground in pre-swing and propel the body forward. The swing phase follows which accounts for 40% of the overall gait cycle during walking. It starts with the initial-swing in which muscles control cadence and foot clearance, and then mid-swing and finally terminal swing with the foot prepared for contact with the ground before the cycle begins again (12).

At initial contact, the knee should be close to full extension. If the knee is in a flexed position at contact, this may indicate hamstring spasticity or contracture (48). After contact, the knee should flex to approximately 20° in order to absorb the impact through an eccentric action produced by the quadriceps. Peak knee flexion occurs during the swing phase to allow foot clearance. Knee flexion continues past the flat foot phase and reaches its peak during stance phase at 10 to 20° and 15 to 20% of the gait cycle (49). Throughout midstance the knee has started to extend again. The contraction of the soleus slows down the forward motion of the tibia and the femur continues to move forward causing a flexion in the knee. The peak knee extension occurs near heel-off with the magnitude near zero or a couple of degrees of flexion. At toe-off the knee takes an angle of 40 to 50° (49).
Figure 1: The gait cycle (12)

Using specially designed computer software and hardware during a gait analysis, various joint angles are measured and quantified with joint angles calculated from the difference between adjacent segment angles. Typically, the range of motion of a joint are graphed to study the range of motion that joint goes through during a gait cycle. As seen in Figure 2, the knee goes through a series of flexion and extension throughout the gait cycle.

Figure 2: Knee flexion throughout the gait cycle (12)
The ankle also progresses through a range of motion illustrated by the plantar and dorsiflexion angles of the gait cycle as seen in Figure 3. These changes are called “rockers” and three rockers occur during a typical gait cycle. The first rocker occurs at initial contact until the entire foot is in contact with the ground. This rocker includes the controlling of the foot to the floor through eccentric actions of the dorsiflexors of the ankle (12). An over-activity of the plantarflexors, often seen in spastic cerebral palsy, can result in an abnormal first rocker since the gastrocnemius can be very tight causing an inability for the heel to contact the ground first (12). The second rocker occurs when the foot is flat and the tibia advances over the foot to allow for forward movement (12). The third rocker is the push-off that begins the swing phase. This first power generation comes from the ankle and is created by the concentric contraction of the gastrconemius and soleus. If weakness is a factor in the plantar flexors, it can lead to crouch gait seen commonly in individuals with CP (12).

Figure 3: Ankle angle throughout the gait cycle (12)

Another variable of interest in gait is the moment of force or the joint moment. A moment is created when the force is applied at a distance away from that joint or pivot point. The force that is opposite the external moment caused by the weight of the foot is the internal tension.
created by the Achilles tendon (48). If an individual were to have a tight or stiff Achilles tendon, this would be shown in the lack of dorsiflexion and therefore the decrease in movement about the ankle. This would also reflect the flexibility of the muscles inserted near the Achilles tendon: the gastrocnemius and the soleus muscles since a tendon is a passive structure and a muscle is the tissue generating the actual force (48).

These same principles of joint moment can be applied to the hip and knee joint in that the internal joint moment at each joint must be equal and opposite to the moment created by the ground reaction force (GRF) (48). When in quiet standing, the GRF passes very near both the hip and knee joints requiring very little force to equal the GRF. However, when an individual squats with knees bent, the direction of the GRF vector moves anterior to the knee and the hamstrings must become active to oppose this moment (48). The result of stiff or inflexible hamstrings may result in a decreased moment about the knee thereby limiting the force production capacity of the muscle causing movement at the joint.

The location and direction of the GRF, in addition to the joint moment, changes throughout the gait cycle. At heel contact, the GRF is posterior to the ankle which implies that the muscles on the opposite side (i.e., triceps surae) must be active to combat the force. At heel strike, the full body weight is not experienced yet resulting in a lower magnitude force required to overcome the GRF (48). The vertical force reaction has been thoroughly studied and is required to counteract the force of gravity. It must equal the force of the body’s weight in order to maintain the height of the center of mass above the ground (50). When the total vertical force is less than the force of the body weight the center of mass of the body is accelerating downward and similarly, the total vertical force is greater than the force of the body weight which indicates an acceleration upward (50).
Throughout the gait cycle, the graphical representation of the GRF resembles that of an “M” as seen in Figure 4 below (48). These oscillations of the center of mass during walking correlate with deviations of the vertical reaction force from body weight (50). Most graphs that display GRF normalize the data to the subject’s body weight, where 100% is equal to the subject’s weight. During the initial double support, the force rises as the weight is transferred from the opposite limb. In early stance, the force rises above the resting body weight, then during mid-stance the force falls below resting body weight and is followed by the late stance as the force again rises above the body weight (48). During the end of the double support phase, the force falls quickly as weight is transferred to the opposite limb (48). The force can be above the 100% body weight during the loading response due to the deceleration that is necessary to slow the body from moving forward. When the body weight is transferred from one foot to the other, the force is less than 100%. Lastly, when the subject begins the toe-off phase there is increased momentum to push the body forward causing a spike in the vertical force, possibly above 100% (50).

Figure 4: The vertical ground reaction force in typical walking (50)
Electromyography. With the human body there are three types of muscle: striated, smooth, and cardiac. Skeletal muscle is striated and is under direct voluntary control while cardiac and smooth muscle is controlled by the autonomic nervous system. Cerebral palsy damage occurs in the brain, but the lack of innervations from this damage affects the musculoskeletal system which primarily affects the longitudinal growth of skeletal muscle (51). Muscle performance can be determined by many factors including: irritability, contractibility, extensibility, and elasticity. There are many functions performed by skeletal muscle such as movement production, posture and position maintenance, and joint stability (52).

Groups of skeletal muscles are arranged so they can work independently or be combined to produce very small detailed movement or a very powerful, large movement, respectively. Motor units are functional groups of skeletal muscle fibers that are all innervated by the same motor neuron. An action potential (AP) is a signal for contraction that is originated in the central nervous system transmitted to the alpha motor neuron and passed down to the motor neuron. The AP from one motor neuron reaches the muscle fiber at the neuromuscular junction that lies near the center of the fiber. When the AP reaches the synapse a series of chemical reactions occur and acetylcholine (ACH) is released. ACH then diffuses across the synapse and causes an increase in permeability of the membrane (52).

The resting membrane potential inside the muscle is -70mV to -95mV in reference to the outside. The AP is characterized by a depolarization from the resting potential of the membrane so that the potential becomes positive, about +40mV, and continues climbing to a point of hyperpolarization before returning to the resting potential followed by the last phase which is called repolarization (52).
Electromyography is the technique used to record and analyze the electrical changes that occur in the fiber membranes during the contraction of skeletal muscle (52). Typically, EMG helps to measure the muscular performance, document training effects, and analyze sporting activities. When a muscle is in a relaxed state the recorded EMG signal is considered to be the baseline. The quality of the EMG signal can be affected by several external factors including: tissue characteristics, physiological cross talk, changes in geometry between muscle belly and electrode site, external noise, the electrodes and the amplifiers (52, 53). In order to obtain a clean signal, the skin above the muscle must be properly prepared by removing hair and dead skin (53).

**Whole-Body Vibration**

Muscle weakness is one of the largest contributors to gait problems experienced by children with cerebral palsy (18, 54). Increasing muscle strength and therefore improving gait and motor control is the number one goal for many physical therapists and patients (54). A method for increasing muscle strength and range of motion is a technique referred to as “whole-body vibration” (18-20).

Whole-body vibration can be characterized by a few key descriptors including: frequency (measured in Hz), amplitude (measured in mm), g force created, duration of the exercise, and in some instances the direction of the vibration. In most research studies the frequency of the vibration ranges between 25 Hz to 45 Hz depending on the subject’s characteristics and the desired outcome. The amplitude of the vibration ranges from a few micrometers to many millimeters. The g force, described as the acceleration experienced by an object due to gravitational pull, can reach 15g (where 1g is the acceleration due to the Earth’s gravitational field or 9.81 m/s²) (22, 55). The frequency and amplitude of vibration are very important when
choosing a protocol since the interaction of these factors will determine the magnitude of the g-forces and therefore the intensity of the training (18, 55). Due to the wide range of frequency and amplitude combinations that could be combined, there are many whole-body vibration protocols to choose from for humans (22).

Natural vibration stimulation occurs naturally in activities of everyday living (e.g. riding in a moving vehicle, skateboarding, and bike riding) and in various different sporting events. There can be impact shocks such as stride impact during running, where the soft tissue vibrates and continues to oscillate at its natural frequency during which the amplitude dampens within the tissue. There is also continuous vibration like that experienced across the arms during bike riding. During this type of vibration the input force matches the soft tissue vibration in frequency. This natural frequency is determined based on the subject’s stiffness and mass. Each bridge between the actin and myosin myofilaments in the skeletal muscle can contribute to the stiffness of the overall muscle; therefore, the overall stiffness of the tissue (i.e., the natural frequency) can increase with muscle activity (22).

Vibration can be administered in two ways: directly to a specific muscle belly by a vibration unit that can be hand-held or fixed to an exterior support or indirectly through whole-body vibration where the user stands on a plate or other device in a static position or while simultaneously performing dynamic stretches or movements (23). The main difference between the direct and indirect vibration is the magnitude of amplitude and frequency of the original vibration that reaches the target muscle (23). During direct vibration, the measured amplitude and frequency remains close to that of the original vibration characteristics at the source, while indirect vibration may be attenuated in a non-linear pattern because of the soft tissue it passes through during the transmission of the signal to the target muscle (23). WBV treatments transmit
vibrations to the subject’s entire body, which generates mechanical stresses to the muscle
groups and soft tissues throughout the body. Soft tissue acts as a wobbling mass, vibrating in a
dampened manner in response to mechanical excitation, the neuromuscular system acts to
dampen this soft tissue resonance that occurs in response to pulsed and continuous vibration
(22).

The response of the muscle depends on muscle-tension, muscle or segment-stiffness, in
addition to the amplitude and frequency of the mechanical vibration. It is very difficult to
accurately predict the amount of stress delivered to a specific muscle due to the complex
kinematics chain involved in this process. One way to assess muscular activity elicited through
vibrations is through surface electromyography. The software used to collect EMG signals
usually report RMS (root mean square) of the EMG signal. Many studies report an increase in
muscle EMG in the lower body during vibration training which suggests an increase in
neuromuscular activity, although specific WBV frequencies have been reported to produce a
higher EMG RMS signal than others (34, 56).

Vibration therapy is said to stimulate the body’s natural stretch reflex and cause muscle
contractions (57). More specifically, vibration of a muscle stimulates the primary endings of the
muscle spindles Ia afferent neuron, which synapses directly onto the alpha motor neurons,
causing contraction of homonymous motor units and results in a tonic contraction of the
muscle. EMG data have revealed that the tonic vibration reflex has both a monosynaptic and a
polysynaptic component (58). Whole-body vibration is known to stimulate type II (fast twitch)
motor units, which are typically recruited during high-intensity, explosive movements or
whenever type I (slow twitch) motor units have been maximally recruited (57).
Many different populations have been used in vibration studies including: older healthy adults (26, 27), young healthy nonathletic adults (27-33), highly trained athletes (19, 34-36), individuals with spinal cord injury (37), adults with Parkinson’s (25), adults with cerebral palsy (24), and children with cerebral palsy (38, 39). Positive changes have come from each of the populations; however, even within the same population, they did not have the same results due to the many variations of protocols used in the studies. Because of the many characteristics (frequency, amplitude, resultant g force, and static or dynamic positions) available with vibration therapy, the protocols vary greatly. The typical frequency is anywhere from 15 Hz (28) -120 Hz (40); with most studies using the range 20-45 Hz (23). The duration of the exercise is another factor that has varied between studies ranging from 0.1 min (41) to 30 minutes (40). Many studies have used 60 seconds of WBV followed by 60 seconds of rest and then repeated as set protocol for acute WBV (28, 35, 36, 42, 43).

Most vibration studies are either chronic, spanning a few weeks, or acute, with measurements immediately following the treatment. The acute effects of vibration are an interest to mainly physiologists and sport scientists, however, in the clinical setting, a chronic treatment seems more appropriate with three main therapeutic aims: increasing muscle strength, improving balance, and increasing bone mass (18). However, both types of studies have had positive and negative changes associated with them.

There are very few studies that have looked into the interaction of WBV and individuals with CP (18, 24, 38, 39). All of the studies mentioned are chronic studies that ranged from eight weeks (24) to six months (18, 38, 39). Similar methods were used for both a study by Ruck et al. (38) and Stark et al. (39). It included three minutes of vibration followed by three minutes of rest and then repeated three times for a total of nine minutes of WBV exposure. Both studies recruited
school-aged children diagnosed with CP. Ruck et al. discovered that, the children who had received the WBV increased their average walking speed in the ten meter walk test by a median of 0.18m/s (38). Stark et al. showed that the new program improved the bone mineral density, bone mineral content, muscle force and gross motor function (39).

With similar variables as Stark et al., but evaluating adults with cerebral palsy, Ahlborg et al. (24) performed a study evaluating the effects of WBV compared to resistance training. For eight weeks, adults diagnosed with CP performed either a resistance training program or a progressive WBV program with 11 different levels of intensity with a frequency of 25-40 Hz. The levels and frequencies were based on the subject’s perceived exertion with an overall duration of approximately six minutes (24). There was a significant decrease in spasticity in the knee extensors in the WBV group and a significant increase in gross motor function (24).

**Individualized Frequency.** As seen from previously stated research, WBV can act as valuable tool for intervention, however, unless individualized; optimal results may not be produced. Many researchers have assumed that the vibration frequency induced by a motor to the platform elicits a tonic vibration reflex similar to the direct or indirect application of vibration on muscle or tendons (44). Researchers agree that several factors influence the effects of vibration and that the intensity of the load on the neuromuscular system is determined by the vibration frequency and amplitude. However, in a study by Martin and Park (45) it was determined that by administering a high-frequency vibration there may have been a decrease in the harmonic synchronization of the motor units, which could have a negative influence on neuromuscular performance. Di Giminiani et al. suggests that each individual has a different optimum frequency of vibration that elicits the greatest reflex response during WBV (44).
Several investigations have reported a specific frequency that elicits the highest level of electromyographic activity. Both Cardinale et al. (34) and Di Giminiani et al. (44) compared a range of vibration frequencies and compared the EMG$_{RMS}$ response in healthy populations. As expected, the researchers discovered that all vibration conditions produced more EMG$_{RMS}$ activity than the no vibration condition. However, more importantly it was determined that vibration-induced muscle activity increases are dependent on the vibration frequency. Individual responses could be related to individual capabilities in damping external perturbations to avoid resonance effects. It was stated by Cardinale et al. that EMG recordings could present a means for individualizing training protocols for WBV (34). Using similar protocols two separate studies assessed the individualized frequency of subjects in a half squat position for a period of 60 seconds (34) (44). During the study the subjects performed a series of different vibrations each for 60 seconds. EMG data was collected and the root mean square calculated to compare the results. Additionally, one of the studies randomized the order of the frequencies and had a 4 minute pause between trials to reduce residual side-effects (44).

Side Effects of Whole-Body Vibration. Although vibration has been used for many years and in many different fields, there are still risks to be considered when it comes to vibration. Each individual’s biological reaction to the vibration therapy is unique, partly due to the differences between on the key descriptors (frequency, amplitude, duration). Some of the negative side effects of vibration have included damage to peripheral nerves, blood vessels, joints, and perceptual function, although typically through extended exposures (22). Additionally, changes in endocrine, cardiovascular, respiratory, central nervous system and metabolic functions have been noted in previous research performed with animals (58).
Acute effects noted in previous research have included increased oxygen consumption, muscle temperature (59), skin blood flow resulting in erythema (60, 61), muscle power, jumping height, and insulin-like growth factor1 and cortisol (18, 62). To date the only true side effect of chronic or long term vibration treatment has been increased bone mineral density (18, 57).

In a topic review of WBV completed by Cardinale et al. (22), it was noted that certain frequencies of vibration have been studied for their potentially dangerous effects on humans but only at specific frequencies and amplitudes. Despite all of the potential risks and side effects, more recent studies have shown that at low amplitudes and frequencies mechanical stimulation is a safe and an effective way to exercise for humans (27, 29, 35, 63). Further it is stated that vibration could be used as a beneficial form of exercise specifically for sedentary, injured, and elderly people with impaired muscle activation.

Posing WBV as a form of exercise, Ruck et al. performed a study with children diagnosed with cerebral palsy and found this intervention to be a safe form of exercise. Although the incidence rate was low there were reports of some redness of the feet or ankle in a few subjects; however it only occurred in the first few treatment sessions. Out of all the WBV sessions, 0.6% were interrupted because the child complained of fatigue and 0.5% were interrupted because the child complained of pain (stomach ache, headache, and back pain) (38).

In summary, adults with CP are surviving longer than ever before and are noting a lack of attention to their needs. Without therapy and exercise, they are declining in their function and walking ability. They are in need an intervention to help increase their strength and maintain their level of daily activity without the aid of therapists and insurance coverage. Whole-body
vibration is a new technique that has shown promise, both chronically and acutely, by increasing strength, flexibility, and walking speed in many varied populations. The individualized frequency technique has been reported to have even greater effects when used with the WBV. No studies have been performed to date on the acute effects of whole-body vibration on gait in adults with cerebral palsy.
THE ACUTE EFFECTS OF WHOLE-BODY VIBRATION ON

GAIT PARAMETERS IN ADULTS WITH CEREBRAL PALSY

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Abstract:

As more adults with cerebral palsy (CP) are surviving longer (1, 7), an intervention is needed to help reduce spasticity and increase overall strength to improve mobility, and therefore life quality. Adults with CP are lacking a form of independent exercise that allows them to maintain or improve their ambulation skills (1, 7). A new approach to increase muscle strength and flexibility is called whole-body vibration (WBV). The goal of the current study was to determine the acute effects of using an individualized frequency (I-Freq) approach to WBV therapy on gait in adults with CP. In this study, eight adults with CP (age 20-51 years, six men, two women) participated in two sets of testing: the first set was used to determine their I-Freq and the second set to perform a 3D gait analysis before and after a WBV treatment. The WBV was administered in five sets of one minute of vibration followed by one minute of rest. Following the acute exposure to WBV subjects experienced a significant increase in walking speed \((P=0.047)\), stride length \((P=0.017)\) and dynamic ankle range of motion \((P=0.042)\). These data show that WBV treatments at I-Freq could help adults with CP maintain their range of motion and overall mobility through an independent and cost effective means.

Keywords: whole-body vibration, gait, cerebral palsy, biomechanics, range of motion
Introduction:

Cerebral palsy (CP) results from damage to the developing central nervous system while in utero, during delivery, or during the first two years of life (3). The most common signs of the disorder are spasticity, rigidity, muscle weakness, ataxia, and movement disorders (4, 64). The extent of the disorder can depend on the scale, degree, and location of the damage that occurs in the spinal cord, brain stem, or brain (3). The motor skills of the children affected by cerebral palsy do improve as they age and grow; however, the skills never match those of neurotypically developed children (3). Due to advances made in neonatal technologies, more children diagnosed with cerebral palsy (CP) are experiencing longer life spans (2, 7). However, as a result of the increased life expectancy these individuals continue to experience the effect of CP but are limited in the availability of resources to effectively deal with the symptoms (7).

One of the biggest problems associated with movement for individuals diagnosed with cerebral palsy is spasticity because of the associated pain, contractures and subluxation (3, 64). Currently, there are many options for the treatment of spasticity including physical modalities, oral pharmacologic agents, peripheral injectables, intrathecal agents, and surgical interventions (65), although the basic and most common form of treatment is physical therapy (66). However, adults diagnosed with CP have reported a lack of attention and availability of care (7, 14). This may be in part to the beliefs of physiotherapists who feel that they can have a larger impact on younger patients with CP (7, 8) or to limitations in health care coverage (46). By decreasing the amount of therapy, these adults begin to lose their range of motion (ROM), flexibility, and strength (2, 9, 46).
As a result of the spasticity experienced by individuals with CP, impairments in gait are often manifested and identified as a problem (5). Gait analysis can be a very helpful tool for describing and diagnosing motor control problems specifically in locomotion (12). A gait analysis allows surgeons to look at many motor problems involved with locomotion concurrently allowing for a more complete and successful course of treatment (12). The components measured in a typical gait analysis include: kinematics, kinetics and electromyography data (12). Abnormal gait in patients with CP is often due to the extensive damage to the central nervous system including the loss of selective muscle control, abnormal muscle tone, relative imbalance between muscle agonists and antagonists across joints, and deficient equilibrium reactions (12). Because there are many treatment options for CP individuals, a gait analysis is especially important for documentation, assessment, and in planning pre and post interventions (11).

It is vital to keep adults with CP active and walking since higher survival rates have been found in those adults with increased functional levels (2). Rimmer et al. reported that regular exercise improves functional status, decreases the level of required assistance, and reduces the incidence of secondary conditions in adults with disabilities (15). For many therapists, maintaining or improving gait in adults with CP is one of the major goals (38, 66). Even though it is clear that a lot of emphasis is put on maintaining gait for adults with CP, they are still lacking a method to improve their ambulation skills independently.

Muscle weakness is another large contributor to gait problems experienced by adults with CP (18, 54). A new technique for increasing muscle strength and ROM is that of “whole-body vibration” (WBV) (18-20). Vibration therapy is said to stimulate the body’s natural stretch reflex and consequently causes muscle contractions (67). More specifically, vibration of a muscle is suggested to stimulate the primary endings of the muscle spindle (Ia afferent), which excites
alpha motor neurons, causing contraction of homonymous motor units which results in a tonic contraction of the muscle (57). Vibration has been shown to strengthen muscles (29, 36), increase jump height (33), increase flexibility (19) and increase power output (35, 36). Two studies in particular have used vibration as a long-term intervention for patients with CP and the results have shown a decrease in spasticity (24) and an increase in walking speed (38). However, the acute effects of WBV on adults with CP or the effect of WBV on 3D gait analysis have not been assessed.

While some studies have shown positive effects of vibration, others have shown a decrease in force production, rate of force development, and EMG activity (68-72). One possible reason for the equivocal findings may stem from each individual, and even each muscle, having an individualized vibration frequency to which it responds to most vigorously (34, 44). Applying the idea of individualized frequency to any population using WBV may show a more effective change in the variables being studied. By finding that WBV improves walking in adults with CP, a more feasible and cost effective therapy alternative may be available. With lack of support from insurance and therapy facilities, adults with CP would have the means to increase strength and decrease spasticity on their own.

Therefore, the goal of the current study was to determine the acute effects of using an individualized frequency approach to WBV on gait in adults with CP. It was hypothesized that the subject’s gait would have a greater ROM in the knee and ankle allowing for an increased velocity, and increased step length as a result of the WBV. In the future, whole-body vibration could augment everyday physical therapy for adults with CP to increase muscle strength and reduce spasticity thereby increasing ROM.
**Materials and Methods:**

*Subjects.* Eight individuals with CP participated in this study and were recruited from facilities that aid adults with special needs across the state of Indiana. Participants ranged in age from 20-51 years and were classified as a rank CP5-8 in the CP-IRSA Functional Classification System(6), indicating that they were independently mobile for a short distance without aids or assistive devices. All participants were diagnosed with primary spastic diplegic or hemiplegic CP and had not received a baclofen or botox injection in the past three months, nor had surgery in the past two years. A sample size estimation was performed to obtain an effect size of 0.05 (Beta = 0.2; alpha = 0.05) based on the 10m walk test results in a study by Ruck et al. (38).

*Insert Table 1*

*Treatment Protocol.* Subjects reported to a biomechanics Laboratory and answered a set of screening questions. All individuals were required to visit the laboratory on two separate visits which we conducted with a minimum of two hours between the first and second visit, but could be scheduled up to a week apart. Each visit lasted about one and a half to two hours during which time all procedures were explained to the subject. After the explanation, the subject was asked to sign a university approved informed consent document and fill out a health history questionnaire.

For individuals that completed the assessments on two separate days (two day protocol), the first visit entailed a short vibration exposure to determine each subject’s individualized frequency. This frequency coincides with the maximal activation of the lower body muscles, which was then used for the second portion of the study. The overall vibration exposure during the individualized frequency protocol was approximately 70 seconds (seven, ten second
exposures with a four minute rest interval between each exposure)\(^{(34, 44)}\). The second visit included a pre-gait analysis, the vibration treatment (detailed below), and a post-gait analysis. For individuals that completed the assessments on the same day (one day protocol), the pre-gait analysis was performed prior to the individualized vibration exposure to ensure there were no effects on the subject’s pre vibration gait assessed during the second visit. Once the pre-gait analysis was complete, the individualized frequency was determined, followed by a two hour break to reduce fatigue as well as residual vibration effects. Following the break, the vibration treatment was administered and the post-gait analysis was performed. Five subjects completed the two day protocol while three subjects performed the one day protocol.

*Individualized Frequency.* Prior to the vibration exposure and gait assessment, the subjects were prepped by shaving and lightly abrading with fine sandpaper, followed by cleaning the muscles of interest on both the right and left legs with alcohol (i.e., rectus femoris, medial hamstring, lateral hamstring, tibialis anterior, and gastrocnemius). Muscle activation was monitored using DelSys surface electrodes (Delsys DE-2.1 Single Differential EMG Electrode) (inter-electrode distance: 1cm) were placed centrally on the muscles of interest according to Cram’s recommendations \(^{(73)}\), and were attached using double stick tape. A reference electrode, in the form of a dispersive pad, was placed over the patella of the right knee. During the vibration exposure subjects stood with knees bent at 15 degrees on a 0.82 x 1.02 m Pneu-Vibe Pro vibrating platform (Pneumex, Sandpoint, ID). A goniometer was used to ensure 15 degrees of flexion between the thigh and shank segments and the position was monitored using a laser level to help maintain this position throughout the entire protocol. The vibration protocol consisted of a series of vibrations ranging from 20 Hz to 50 Hz in 5 Hz increments, with peak-to-peak amplitude of 2mm in a randomized order. To reduce the chance of residual effects, a four
minute resting period was used between the vibration sets (44). At each vibration level, a static trial was collected with no vibration for ten seconds followed by a ten second trial at the set vibration frequency. This data was collected and processed using a Butterworth notch filter +/- 2 Hz of the trial frequency. To determine muscle activation levels the root mean square of the signal was used to find the specific frequency that most excites the above mentioned muscles.

**Gait Analysis.** The data collection recorded kinetic, kinematic, and electromyography (EMG) data. Subject measurements were taken for height, weight, joint girths (ankle and knee), leg length and the distance between the anterior superior iliac spines. Following subject measurements, reflective markers were placed on the subject’s bony landmarks following the Plug-In-Gait Model (Vicon, Oxford, UK). Subjects performed ten gait trials by walking across a 10m walkway. The subjects were provided no other instructions other than to walk naturally across the platform at a self-selected pace. A 12 camera Vicon MX system was used to collect kinematic data during gait trials and was sampled at 60Hz.

**Whole-Body Vibration (WBV).** The WBV treatment protocol consisted of a series of one minute of vibration followed by one minute of rest, repeated five times, for a total of five minutes of vibration. During the vibration exposure subjects were required to maintain a semi-squat position at the set individualized frequency, with the knees flexed to approximately 15 degrees. This position was used to help increase activation of the hamstrings during WBV.

**Passive Range of Motion.** A passive ROM in flexion and extension was measured at the knee and ankle using a goniometer by a certified athletic trainer. The participant was tested in a supine relaxed position as described by Rothstein et al. (74). This measurement was taken both pre and post vibration treatment to assess ROM about each joint (75). By measuring both passive and
dynamic ROM during gait, a more thorough assessment of the effect of ROM both prior to and following vibration exposure can be discovered.

**Outcome Measures.** The variables that were measured included joint angle measures as well as temporal and spatial parameters. The dynamic ROM about the knee joint was measured between the thigh and shank segments such that full extension was zero and a positive value indicates flexion. The ankle angle was measured between the foot and shank segments where a positive value indicates dorsiflexion and a negative value indicates plantarflexion. Both angle measurements were taken at initial contact and at toe-off and reported in degrees. Step and stride time were calculated and measured in seconds. Due to the importance of initial contact and toe-off during the gait cycle, the knee and ankle angles were obtained at these specific points. Once the knee and ankle angles were graphed, the minimum and maximum angles were extracted and subtracted to find the absolute range of motion about that joint.

*Insert Figure 1*

The velocity of the subject was measured as the average horizontal speed of the body along the plane of movement (52) and was measured in meters/second. The cadence was defined as step frequency and was measured in steps/minute. The step length and stride length were obtained as well. The step length was defined as the distance from initial contact of one foot to initial contact of the opposite foot and the stride length was defined as the distance between initial contact of one foot to initial contact of that same foot (12).

With CP being an umbrella term and presenting itself differently in every affected individual, we compared the affected limb for subjects diagnosed with hemiplegic CP and took the average of
both limbs for subjects diagnosed with diplegic CP as had been similarly done in a previous study (76).

Statistical Analysis. Through SPSS (IBM, Somers, NY), the variables were compared using Repeated Measures Analyses of Variance to compare the data pre and post vibration. More specifically, the variables included walking speed, cadence, step length, stride length, step time, stride time, ankle angle and knee angle at initial contact and toe off, passive and dynamic ROM as a function of the independent variable of vibration status (i.e., no vibration, individualized frequency vibration). For all tests the alpha level was set at \( p \leq 0.05 \).

Results:

All eight subjects completed all visits and protocols and the results can be seen in Tables 2 and 3. The comparisons from pre to post WBV revealed significant changes in three of the main variables: walking speed \( (F_{1,7}=5.764, P=0.047; \eta^2=0.452) \), stride length \( (F_{1,7}=9.757, P=0.017, \eta^2=0.582) \) and dynamic ankle ROM \( (F_{1,7}=6.185, P=0.42; \eta^2=0.469) \). Although there were small changes in each of the other variables there were no other significant effects assessed in this study. There were small differences between the 1 Day and 2 Day Protocol results as seen in Figure 1 and Figure 2. There were no major differences between the subjects’ data using one or two day protocols as seen in Table 2.

Insert Figure 2 and 3, 4 and Table 2.

The average individualized frequency for all of the subjects was 38.13 \( \pm \) 8.52 Hz. The average time from the end of the vibration protocol to the beginning of the first trial gait was 66 seconds.
(range 45s to 100 seconds). The average time from end of vibration protocol to the end of the post-vibration gait collection was 392 seconds (range 243s to 483s).

Insert Table 3 and 4

Discussion:

The goal of this study was to determine the acute effects of whole-body vibration on gait velocity, cadence, step length, stride length, step time, stride time, ankle angle and knee angle at initial contact and toe-off, and joint ROM during gait in adults with CP. Dynamic ankle ROM, stride length and walking velocity were found to significantly increase following an acute bout of WBV. Hypothesized significant changes in knee ROM and step length were not found, however, there were increasing trends noticed.

From the joint angle results, it could be suggested that the WBV exposure resulted in an increased ROM at the ankle which could have been the results of changes in overall muscle length. The short bout of WBV used in this study may have caused the muscle to become more supple, allowing for a change in length to occur during gait. Although a change in passive ROM was not observed, an effect size (Cohen’s d= -0.11 for the knee and 0.23 for the ankle) was obtained indicating that a significant change might have been obtained if the overall sample size of the study was increased. There was a significant increase in the dynamic ankle ROM (21.63° ± 5.978°) which could have resulted from a relaxation of the triceps surae allowing the ankle to go through a greater range of dorsiflexion movement. This increased ROM about the ankle (following WBV) more closely resembles a typical and more energy efficient gait pattern (ankle ROM 25°). As mentioned, spasticity can lead to pain in joints and with an acute bout of WBV there was an increase in ROM which can be an indicator of a decrease in spasticity. It remains to
be seen if this increased ROM would result in a decrease in pain along with a faster more typical gait pattern. Future studies should look at intramuscular temperature to see if muscles are in fact becoming more pliable and easily stretched. Also determining if there is a physical change in the length of the muscle post WBV would help prove this hypothesis.

This increase in ROM in the knee and ankle occurred at both initial contact and toe-off. At both phases of the gait cycle, there was a decrease in knee angle indicating that the knee was closer to full extension. This suggests that the hamstring muscle in addition to the gastrocnemius could be more relaxed allowing for an increased ROM and greater degree of knee extension. Given that these muscles are often times spastic in individuals with CP the increased ROM following the acute bout of WBV appears to have resulted in more elongated muscle which could be the result of a reduction in overall spasticity. Future studies should assess the overall levels of spasticity in the muscles to determine the nature of the increased ROM following WBV.

With the increased ROM demonstrated with the individualized WBV exposure the individual is able to achieve greater degree of knee extension. As the individual moves closer to full extension the limb becomes more rigid allowing the body to propel itself over its base of support and forward. Without the full extension at initial contact, the pivotal action of the “heel rocker” is reduced which results in decreased momentum, reduced stride length and decreased velocity (50). With the trends experienced in both the ankle and knee ROM reaching closer to typical gait this could explain the significant increase in stride length.

Another result of the increased ROM is that the subjects were able to reach further during their strides. It is worth noting that there was not a significant change in the step length (\(P=0.905\)), which was determined based on the diagnosis of each subject, but there was the significant
change in stride length ($P=0.017$). For the subjects diagnosed as hemiplegic CP, the affected side’s step length was used for comparison. For those diagnosed diplegic CP the data from both the right and the left sides were averaged to get a value. Since stride length is measured using both the right and left step for all subjects, it seems that there was a compensatory action occurring. This change could be a result of an increase in step length of the unaffected side. This effect might also be explained through the averaging performed on the diplegic subjects’ data. These subjects could have had an imbalance between their affected sides but that it did not show due to the averaging of their data. In the future, it would be advisable to look at each side of a diplegic individual as separate to ensure the most thorough results.

This significant increase in stride length would directly result in an increase in walking velocity which was experienced in the subjects of this study. The increases in walking velocity following the acute WBV are consistent with results from a previous study (38). In a longitudinal study by Ruck et al. (38) similar changes in walking velocities were elicited using a vibration protocol similar to the one used in this study. Subjects in the previous study received nine minutes of vibration therapy per day over six months and increased their average walking velocity in the ten meter walk by a median of 0.18 m/s (38). These results, compared to the results of the current study, show that a longer duration of vibration may produce a greater magnitude of change in the subjects. After only five minutes of an individualized vibration exposure, the adults with CP were able to walk faster across the ten meter gait platform. In the previous study the changes gait parameters were not assessed, but the results from this study suggest that the increase in walking velocity following WBV may be the result of increased ROM throughout the knee and ankle. This implies that WBV could have allowed adults with CP to walk more effectively with an increase in velocity which could lead to adults with CP increasing their daily
exercise since mobility may become easier. It is important to note that the WBV protocol used in the current investigation was that of an individualized protocol, since the previous study utilized a (what were their parameters) protocol it would be interesting to determine if the effects are different based on the different vibration settings.

One additional measure that demonstrated an increase following the vibration exposure was cadence (average change=1.33 steps/min). Although this was not significant, it was noted in five of the eight subjects and resulted in an effect size of 0.54. As such, it result does warrant further investigation into the duration and amplitude parameters of the WBV intervention. It is possible that additional exposure to the WBV in the form of time or an increase in the amplitude of the plate, either higher or lower, could induce significant results in cadence in this population.

Summary:

The significant changes in walking velocity, stride length and dynamic ankle ROM demonstrated that WBV could be a viable and effective intervention for adults with CP. WBV could be performed daily at the patient’s own schedule since there would be no need for a therapist to be present during the WBV. This intervention is cost effective when compared to the rising cost of health insurance and physical therapy sessions. This also allows for adults with CP to be more independent and in control of improving or maintaining their ambulation skills. Physical therapists and orthopedists alike could also use this as a fairly inexpensive intervention that produces immediate results.

Acknowledgements:

Special thanks to the Ball State Biomechanics Laboratory and the ASpiRE Grant.
References:

37. Criswell E, Cram JR. Cram's introduction to surface electromyography. 2nd ed. Sudbury, MA: Jones and Bartlett; 2011.
Figure 1
Figure 2
Figure 3
Figure 4
### Tables

Table 1: Subject Characteristics, diplegic cerebral palsy, hemiplegic cerebral palsy, R= right side affected, L=left side affected

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Gender</th>
<th>Age</th>
<th>Diagnoses</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>I-Freq (Hz)</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>20</td>
<td>hemiplegic-L</td>
<td>160.78</td>
<td>96.7</td>
<td>40</td>
<td>2 day</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>28</td>
<td>diplegic</td>
<td>161</td>
<td>87.4</td>
<td>30</td>
<td>2 day</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>25</td>
<td>hemiplegic-R</td>
<td>182</td>
<td>81.1</td>
<td>50</td>
<td>1 day</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>26</td>
<td>diplegic</td>
<td>165.5</td>
<td>77.4</td>
<td>40</td>
<td>2 day</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>51</td>
<td>diplegic</td>
<td>168</td>
<td>68.9</td>
<td>30</td>
<td>2 day</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>22</td>
<td>hemiplegic-L</td>
<td>183.5</td>
<td>73.2</td>
<td>40</td>
<td>2 day</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>35</td>
<td>hemiplegic-L</td>
<td>156</td>
<td>61.6</td>
<td>35</td>
<td>1 day</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>35</td>
<td>diplegic</td>
<td>180</td>
<td>82.6</td>
<td>35</td>
<td>1 day</td>
</tr>
</tbody>
</table>
Table 2: Significant Variables compared using the One-Day and Two-Day Protocols

<table>
<thead>
<tr>
<th>Significant Variable</th>
<th>Group</th>
<th>1-Day Protocol</th>
<th>2-Day Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking Speed (m/s)*</td>
<td>0.03 (0.12)</td>
<td>0.01 (0.04)</td>
<td>0.04 (0.12)</td>
</tr>
<tr>
<td>Stride Length (m)*</td>
<td>0.02 (0.13)</td>
<td>0.01 (0.004)</td>
<td>0.03 (0.02)</td>
</tr>
<tr>
<td>Ankle ROM (deg)*</td>
<td>1.46 (6.36)</td>
<td>0.35 (-1.45)</td>
<td>2.13 (-0.87)</td>
</tr>
</tbody>
</table>

Numbers represent mean scores with values in parentheses indicating the standard deviation. The ROM is the total degrees of flexion and extension that a joint can go through passively. *Significant differences from pre to post (p<0.05).
Table 3: Mean values of the measures of interest for pre and post vibration intervention

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre Vibration</th>
<th>Post Vibration</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking Speed (m/s)*</td>
<td>0.961 (0.121)</td>
<td>0.993 (0.128)</td>
<td>0.256905967</td>
</tr>
<tr>
<td>Cadence (steps/min)</td>
<td>97.54375 (34.857)</td>
<td>111.375 (6.723)</td>
<td>0.547101683</td>
</tr>
<tr>
<td>Step Length (m)</td>
<td>0.526 (0.062)</td>
<td>0.526 (0.062)</td>
<td>0.010420436</td>
</tr>
<tr>
<td>Stride Length (m)*</td>
<td>1.045625 (0.130)</td>
<td>1.069375 (0.139)</td>
<td>0.181709363</td>
</tr>
<tr>
<td>Step Time(s)</td>
<td>0.559375 (0.0285)</td>
<td>0.554375 (0.0252)</td>
<td>-0.190866111</td>
</tr>
<tr>
<td>Stride Time(s)</td>
<td>1.09625 (0.0746)</td>
<td>1.08125 (0.0637)</td>
<td>-1.413828998</td>
</tr>
<tr>
<td>Knee Angle @ IC</td>
<td>19.669 (9.511)</td>
<td>18.522 (9.053)</td>
<td>-0.12767449</td>
</tr>
<tr>
<td>Ankle Angle @ IC</td>
<td>-5.7036 (2.822)</td>
<td>-6.179 (2.144)</td>
<td>-0.062625174</td>
</tr>
<tr>
<td>Knee Angle @ TO</td>
<td>41.9336 (9.151)</td>
<td>41.400 (8.459)</td>
<td>-0.195350561</td>
</tr>
<tr>
<td>Ankle Angle @TO</td>
<td>-6.317 (4.750)</td>
<td>-6.813 (4.967)</td>
<td>-0.105306263</td>
</tr>
</tbody>
</table>

Numbers represent mean scores with values in parentheses indicating the standard deviation. Angles are measured in degrees. For the knee, full extension =0 deg and for the ankle, positive values indicate dorsiflexion and negative values indicate plantarflexion. *Significant differences from pre to post (p<0.05).
Table 4: The mean values of the range of motion about the knee and ankle pre and post vibration intervention

<table>
<thead>
<tr>
<th>ROM</th>
<th>Pre Vibration</th>
<th>Post Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passive</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee ROM</td>
<td>128.21 (18.17)</td>
<td>126.07 (15.82)</td>
</tr>
<tr>
<td>Ankle ROM</td>
<td>55.286 (10.22)</td>
<td>57.07 (8.62)</td>
</tr>
<tr>
<td><strong>Dynamic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee ROM</td>
<td>39.545 (14.402)</td>
<td>36.858 (14.169)</td>
</tr>
<tr>
<td>Ankle ROM</td>
<td>20.170 (7.044)</td>
<td>21.631 (5.978)*</td>
</tr>
</tbody>
</table>

Numbers represent mean scores with values in parentheses indicating the standard deviation. The ROM is the total degrees of flexion and extension that a joint can go through passively. *Significant differences from pre to post (p<0.05).
Figure Legends

Figure 1: A screen shot of the graph depicting the knee angle across the gait cycle. The maximum and minimum angles were abstracted to calculate the absolute knee range of motion in deg.

Figure 2: Comparison of Walking Speed (m/s) between subject’s means for the One-Day Protocol and the Two-Day Protocol

Figure 3: Comparison of Dynamic Ankle Range of Motion (deg) between subject’s means for the One-Day Protocol and the Two-Day Protocol

Figure 4: Comparison of Stride Length (m) between subject’s means for the One-Day Protocol and the Two-Day Protocol
Chapter 4- Summary and Conclusions

Summary

Due to an increase in life expectancy and an overwhelming direction of attention to the younger population, adults with cerebral palsy (CP) are noticing a decrease in care and attention as they age. There are an estimated 500,000 adults with CP in the United States and as they grow older, they are experiencing an increase in spasticity and underlying muscle weakness which is leading to a decrease in mobility and range of motion. A new technique used to increase muscle strength and flexibility called whole-body vibration (WBV) has been shown to have positive effects on many different variables and in many different populations. There has been very little research on the effects of WBV on adults with CP, and no research to date on the effects of WBV on specific gait parameters of adults with CP. The purpose of this study was to determine the acute effects of WBV on gait parameters in adults with CP. Eight adults diagnosed with spastic diplegic or hemiplegic CP, between the ages of 20 and 51, completed a 3D gait analysis before and after an acute bout of WBV.
As a result of an acute WBV exposure of only five minutes, walking speed increased significantly from pre to post. Significant improvements were also demonstrated for ankle dynamic range of motion following the WBV exposure. A positive change in stride length was also detected after just a few minutes of WBV. There were no significant differences found in the cadence, step length, step time, stride time, knee and ankle angles at initial contact, knee and ankle angle at toe-off, or the passive range of motion about the knee and ankle. Though the results were not significant, there was an increasing trend in step length and an increase in knee extension angle at initial contact and toe off. These results indicate that WBV may elicit changes in gait patterns that more closely represent typical walking.

Conclusions

Typical walking patterns are the most energy efficient through many optimizations; therefore any deviation of these patterns can result in energy wasted and excessive fatigue. The changes seen in this study are moving towards a more typical gait pattern. The decrease in the knee and ankle angles at initial contact and toe-off are indicators that the normally spastic gastrocnemius and hamstrings have relaxed allowing for a more typical ROM. This increase in ROM has also been noted in the length of each stride of the subjects. This stride increase directly results in an increased walking speed that is closer to that of normal adult walking which again has been shown to be more efficient.

From these results it seems that WBV elicited a relaxation or stretch in the spastic muscles of the subjects. This reduction could allow the subjects to control the motor skills they still possess more effectively. This decrease in tightness or increase in relaxation could be an indicator of a decrease in spasticity which would lead to a decrease in pain. Without the associated pain, adults with CP could be more willing to exercise, which would allow them to maintain a healthy
lifestyle independently. Increasing the amount of exercise performed, like WBV, could improve functional status and therefore increase survival rates.

**Future Recommendations**

The largest challenge for this study was the recruitment aspect. Finding adults with CP who qualified by meeting the inclusion and exclusion criteria was very difficult. By choosing to include adults diagnosed both hemiplegic and diplegic CP, we were able to get a larger sample size, but the population was no longer as homogenized as originally intended. Since the diagnosis of CP is a somewhat general term, obtaining a truly homogeneous sample becomes difficult since each subject presents the disability differently. However, since the purpose of this study was to determine the effect of WBV on kinematic parameters related to gait in individuals with CP, the decision to include both hemiplegic and diplegic diagnoses was not as critical. Future studies may wish to isolate the intervention to one specific diagnosis to determine if there is a differential effect between these groups.

It is still unknown how the muscles of adults with CP, both diplegic and hemiplegic, respond to an individualized frequency WBV. Individualized frequency was used in this study because it has proven to elicit a higher magnitude response in a variety of populations and on a range of variables (31, 44). In this study, 20-50 Hz was used to find the individualized frequency for each subject. In the future, it may be advisable to compare the individualized frequency results to baseline frequency results, typically 30 Hz, to ensure that this technique works with each specific population.

Another key variable involved with the vibration plate is amplitude. The vibration plate used for this study was the Pnemex Vibe Pro. This plate has a low and high setting referring to the
amplitude of the vibration exposure. In this study, we used the low setting as a starting point. Even on the low setting we were able to attain significant results; therefore, it could be possible that at the high amplitude setting, the magnitude of the results may increase.

The duration of exposure to the vibration is yet another factor that could have an effect on the results. For this study, subjects were exposed to five, one-minute vibrations with a one minute break in between each bout and all subjects tolerated the vibration well. A study that supports the findings of the current study was performed with children diagnosed with CP using a longitudinal study design (38). Ruck et al. utilized a nine minute vibration to which subjects increased their average walking speed in the 10m walk over the course of six months (38). These results, compared to the results of the current study, show that a longer duration of vibration may produce a greater magnitude of change in the subjects. However, by more closely studying the gait patterns using three dimensional gait analysis, the current study was also able to track the ankle ROM, which did increase significantly, and may have been a major factor to the increase in walking speed.

In the future, intramuscular temperature could be measured to determine if the WBV is acting as a warm-up exercise prior to the gait analysis. This warm up would allow the muscles to become more supple and result the ability to lengthen further. In order to positively and accurately say that WBV has changed the length of the muscles, an ultra sound machine could be used to measure the length of the muscle pre and post the WBV intervention. This would allow researchers to be able to collect conclusive data showing the relationship between muscle length and WBV.
Another variable worth studying is the ground reaction forces. Only kinematic data was processed and studied here in this study, however with the significant changes in the kinematic data would likely lead to changes in the kinetic and EMG data as well. Obtaining the kinetic data would allow for moment calculations about the joints which would also provide further descriptors about the muscles and joints involved during gait.

With WBV being a new field, there are many variables that can change within the current protocol that need to be studied further. Individualized frequency has been proven to produce greater results than a standard frequency in many populations, but further standardization is needed to identify the appropriate muscles to be used for the given protocol. With vibration being such a new topic, there are many protocols and techniques being used which can elicit a different response. In the future, it would be advisable for future studies to look at the longitudinal effects of WBV on gait parameters in adults with CP to see if the effects experienced in this study could be sustained over a longer period of time. A study to look at individualized frequency results compared to baseline frequency results should also be performed to prove that this new technique is effective for adults with CP. With CP being such a broad diagnoses, it may also be beneficial to study a very specific diagnoses (ex: spastic diplegic CP) to see how they are affected.
73. Criswell E, Cram JR. Cram's introduction to surface electromyography. 2nd ed. Sudbury, MA: Jones and Bartlett; 2011.