ABSTRACT

EFFECTIVENESS OF WHOLE BODY VIBRATION WITH PHYSICAL THERAPY FOR SPASTICITY AND GAIT IN CHILDREN WITH CEREBRAL PALSY: A META-ANALYSIS

Whole body vibration has been and intervention that has been gaining popularity as a physical therapy intervention. Children with cerebral palsy can have multiple limitation due to spasticity leading to secondary impairments. Articles within this meta-analysis were used to determine if whole body vibration with physical therapy intervention could decrease spasticity in the lower extremities in children with cerebral palsy. Additional articles were also reviewed to determine if a decrease in spasticity occurred, gait speed would improve. Based on the combined effects of 6 articles, spasticity was decreased in general amongst lower extremity musculature however gait speed was not improved. Spasticity reduction in knee extensors and plantar flexors were not found to be significant. Although findings determining if WBV with PT intervention can decrease spasticity in children with CP were not significant, all combined effects favored that of WBV with PT intervention. Other factors such as frequency that participants are exposed to as well as the total length of exposed time to WBV may be additional factors that can influence spasticity.

Janelyn Jade Young
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EFFECTIVENESS OF WHOLE BODY VIBRATION WITH PHYSICAL THERAPY FOR SPASTICITY AND GAIT IN CHILDREN WITH CEREBRAL PALSY: A META-ANALYSIS

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Janelyn Jade Young

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For the Department of Physical Therapy:

We, the undersigned, certify that the project of the following student meets the required standards of scholarship, format, and style of the university and the student's graduate degree program for the awarding of the doctoral degree.

Janelyn Jade Young
Project Author

Monica Rivera (Chair) Physical Therapy

Na Hyeon Ko Physical Therapy

For the University Graduate Committee:

Dean, Division of Graduate Studies

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INTRODUCTION

Cerebral Palsy is a non-progressive condition that is the leading cause of childhood disability.[1] In the United States, 2 out of every 1,000 live births are diagnosed with CP.[2] Of those diagnosed, spastic CP is the most prevalent, yielding about 77% prevalence among all children with CP.[3] Cerebral palsy is defined as non-progressive brain damage early in life with primary problems of movement and posture.[4] Muscular pathology is caused by weakness and spasticity which paired with physical growth causes leads to functional limitations.[4] Therefore, it is vital to provide interventions to prevent muscular changes from occurring by decreasing the effects of spasticity to maintain or improve independence.

There are currently multiple interventions for the muscular pathology in children with CP, such as surgical, pharmacological, and conservative therapies.[5] These current interventions may require lengthy recovery times or address the muscular and or spasticity temporarily.[6,7] Recently, studies have shown that whole body vibration (WBV), a conservative treatment, has been used to address muscular weakness and spasticity caused by early brain damage.[8-10] However, most studies have looked at the effects of WBV alone and not in conjunction with additional conservative treatment such as physical therapy (PT).[8,11,12]

By combining the use of WBV with PT interventions, children with CP may have the potential to slow the effects of spasticity to further address secondary motor performance deficiencies.[13] This meta-analysis can identify the effects of the 2 interventions combined to potentially contribute new knowledge of best practice for children with CP. Therefore, the purpose of this meta-analysis and systematic review is to determine if WBV with physical therapy can reduce spasticity and improve gait speed in children with CP.

BACKGROUND

Etiology

Cerebral palsy is the result of an abnormal development or defect to the brain that occurs preterm, at birth, or up to the age of 3 years old with those born before 28 weeks of gestation at highest risk.[14] Prior to birth, maternal infection/sickness, cystic lesions creating malformations, or improper wiring mechanisms can cause abnormal development of the fetal brain.[15] In a preterm birth, there is the risk of an intraventricular hemorrhage or periventricular leukomalacia.[16] During the perinatal period, an anoxic event or hypoxic ischemic encephalopathy causes widespread brain damage.[16] After birth and up to 2 years of age, acquired CP can occur when the child experiences event such as a cerebrovascular accident, head trauma, meningitis, or other incidents that damage the brain.[15] Any of the previously mentioned mechanisms can lead to, and later become diagnosed with CP.

Clinical Presentation of CP

Damage or an upper motor neuron (UMN) lesion can occur at various locations within the brain that lead to different presentations of CP.[17] Movement presentations are categorized into spastic (damage to the motor cortex), dyskinetic (damage to the basal ganglia), ataxic (damage to the cerebellum) and affect 1 or all limbs.[18] Due to the variability of CP, the Gross Motor Function Classification System (GMFCS) led to the categorization of children's capability to participate in movement-based activities on a scale of I-V (I is no limitations and V is severely limited and wheelchair bound).[18] The primary impairments are muscular weakness and spasticity which can lead to muscular abnormalities and eventually progress to skeletal abnormalities.[18] The combination of impairments can then affect motor performance such as dysfunction in motor control and poor balance/postural control.[4,18] However, UMN lesions can also impair vision, hearing, speech, cognition, and even result in seizures.[4,15,18] Although the presentations of CP can vary between children, for the purposes of this meta-analysis, spastic CP will be the primary focus due to spasticity being a major limitation.

Pathophysiology of Spasticity

Spasticity is defined as an increase in muscular tone that occurs after a passive quick stretch of muscle.[17,19,20] To provide the pathophysiology of spasticity, first an understanding of a simple stretch reflex will be discussed. Normally, when a quick stretch is provided to a muscle, the muscle spindle activates with s a change in length and velocity, which produces a stretch reflex response.[21] This creates a sensory signal from the spindle via the primary Ia afferent nerve to the α-motor neuron in the spinal cord.[21] From there, the α-motor neuron sends a signal to the agonist muscle that causes a reflex response.[21] Additionally, the afferent projects a collateral to an inhibitory neuron which inhibits the antagonist muscle.[21] In terms of spasticity, damage or a lesion in the various descending pathways: vestibulospinal, reticulospinal, or the corticospinal tracts creates deficits in the regulation of inhibitory influences on the spinal cord and the alpha motor neuron.[21] As a result, the reflex system receives increase excitation of the reflex arc.[21] Thus, unregulated excitation from the brain to the spinal cord produces an increase in muscle tone.[21]

Limitations in Children with CP

Although spasticity is a commonly seen presentation for most children with CP, it is only 1 facet in a multitude of contributing factors that lead to functional limitations. Spasticity causes the hypersensitivity of the muscle spindle which in turn contributes to hypertonia within a muscle.[21] This muscular change along with the combination of muscular weakness, development of contractures, and a loss of type II muscle fibers lead to changes in muscle architecture.[17] As such, muscle pulls become irregular, reduced, and with lack of proper lower extremity loading, eventually lead to skeletal deformities.[17] Skeletal deformities continue to worsen due to the child's progressive growth over their lifespan.[22] For example, bony deformities such as femoral anteversion, coxa valga, and subluxations can occur within the lower extremities.[22] These lower extremity deformities lead to gait deviations seen in children with CP such as equinus, crouch, jump, and scissoring gait.[23,24] The presence of skeletal deformities in children with CP increases the barriers in the progression of functional mobility .[25] At this time, interventions to improve functional mobility have primarily focused on exercise and task based approaches to improve muscular weakness.[26] However, evidence shows that exercise alone to address 1 deficit has had a small effect.[26] Therefore, it is important to address spasticity as it is an additional primary factor that contributes to the functional limitations in CP. Early recognition and intervention to address spasticity and avoid secondary impairments in children with CP is vital to maintain and improve functional mobility.

Interventions to Address Spasticity

Management of spasticity can be difficult and incorporate multiple treatment interventions depending on the severity of the effects of spasticity. Due to the variable approaches to manage spasticity, there is no standardized approach as interventions can incorporate multiple facets.[27] Primary interventions to address spasticity and its secondary effects are often surgical, pharmacological, or non-surgical.[19]

Mechanism of Surgical Intervention

Surgical approaches to address spasticity vary, but within the CP population procedures such as selective dorsal rhizotomy, orthopedic procedures, and intrathecal baclofen pumps are common.[27] Selective dorsal rhizotomies (SDR) specifically sever dorsal nerve rootlets to decrease aberrant sensory input to the spinal cord which in turn reduces spasticity in a specific muscle.[28] Although there are promising outcomes with SDRs surgical recovery can be extensive and the rehabilitation that follows can last up to a year.[29]

Orthopedic procedures do not address spasticity directly but instead address the secondary effects pertaining to deformities of muscle, tendon, or bone. This surgical procedure is called a single event multi-level surgery, also known as SEML.[27,30] This procedure is performed on the lower extremities such as the hips, knees, ankles or feet and is used to correct multiple soft tissue or bone deformations such as contractures that require muscle lengthening.[30] The SEMLS can improve gait function and specifically improve knee ROM.[31] However, significant complications following SEMLS include children who could not ambulate, required wheelchair dependency, and contracted regional pain syndrome following the surgical procedure.[32]

Intrathecal baclofen pumps are an effective treatment for spasticity reduction.[33] Pumps are reserved for severe spasticity and muscular spasms. As with the previous pharmacological interventions, intrathecal baclofen pumps have negative effects. The related device complications include device failure and issues with device placement.[34] While the effects of pharmacological use to treat spasticity are effective, there are multiple complications and consequences that require consideration.

Mechanism of Pharmacological Approach

The common pharmacological approaches to treat spasticity are through oral medications and botulinum toxin injections.[27] Oral medications are useful in treating spasticity.[35] However, oral medications have systemic effects throughout the body and no specificity to where the effects of the medication occur. This can increase the risk of a child experiencing side effects such as ataxia, weakness, confusion, and physical dependence in which the child must consistently intake the medication (due to tolerance) or physical withdrawal symptoms will be experieinces.[36,37]

Botulinum toxin injections are an additional intervention to treat spasticity, however the effects only last between 3 to 4 months.[38] The injection is used for focal spasticity and directly affects the neurotransmitters in the synaptic junction without the effects of sedation.[34] Although it is effective, botulinum toxin injections have side effects of pain at the site of injection, extensive muscle weakness at and surrounding the injection site, and decreased effectiveness after 3 months.[39]

Mechanism of Conservative Treatments

Lastly, physical therapy plays a vital role in the management of spasticity.[40] It can address function, movement, and maintain physical well-being.[40] When compared to surgical and pharmacological treatments, which can be costly and potentially impair mobility beyond the spasticity, physical therapy is an alternative intervention.[41] Physical therapy is "facilitating the participation needs of the child with CP and reducing the physical impairments of the symptoms".[26]

Physical therapy methods of treating spasticity through distinct interventions such as strength training, serial casting, and orthotics.[27] These methods with a combination of goal-oriented intervention and activity based tasks are beneficial in improving overall function.[26] Physical therapy is an ideal treatment option because it is non-invasive and can promote neuroplastic change.[13] However, current studies on physical therapy interventions to treat spasticity, (such as prolonged stretching, cryotherapy, and hydrotherapy) show minimal change in measured outcomes.[26,42]

Interventions Combined

In the United States, the lifetime cost for a person living with CP has been estimated to be 11.5 billion dollars.[43] Since CP is a costly disease, it is important for health care providers to offer treatment that is effective and efficient to reduce overall expenses paid by a patient. As previously stated, addressing spasticity or muscular weakness individually has had a small effect on the overall function in those with CP. Therefore, a combination of interventions that focus on both decreasing spasticity and increasing muscular strength to improve functional mobility can reduce the overall cost for patients with CP.[8] Physical therapy can help improve physical independence by decreasing the effects of CP during childhood through a functional goal oriented approach.[26] Recently, studies have shown that whole body vibration (WBV) can provide neuromuscular changes in a passive and time efficient method.[5,44] Physical therapy in conjunction with WBV can provide the quick, passive, efficient intervention needed in the CP population during childhood to reduce cost and improve function throughout the lifespan.

Whole Body Vibration

History

Whole body vibration is an intervention that began in the 1800s.[45] In Germany during 1996 was when the first side alternating WBV platform was created and was available for public use.[45] The use of WBV has been used for a wide variety for reasons and different populations such as astronauts to the athletic population.[46,47] This intervention is a passive treatment where the user statically stands or performs dynamic exercises on a vibrating platform.[44] The WBV platform provides vertical sinusoidal oscillations or side alternating movements consisting of low frequency and low amplitude waves that enter the body through the user's feet.[5,8,48,49] Exposure to vibration has been used to promote strength, balance, and improve bone mineral density.[50] Recently, studies have shown that WBV induces positive changes as a non-invasive intervention to address facets of muscular function in CP[51-53]

Settings

Vibrations are provided throughout the body by varying amplitudes, frequencies, and foot placements, and duration.[49] The amplitude is the amount of vertical displacement that the body receives and is measured in millimeters (mm).[54] Amplitude normally ranges between 0.5 mm to 10 mm.[54] The frequency determines the amount of vibration that the body receives through the number of cycles completed per second and is measured in Hertz (Hz).[55] Frequencies for WBV are commonly range from 6 Hz to 26 Hz.[56] The platform oscillates in a side to side and the point at which this occurs is called the fulcrum.[45] Foot placement based on the fulcrum can change the amount of oscillations that is received throughout the body.[45] The foot placements range from 0 to 4, where 0 receives little to no vibrations and 4 (10 mm) receives the largest amount of lateral amplitude.[45] Lastly, the optimal amount of exposure that occurs per session of WBV is recently being investigated, but at this time there have been no specific ranges that have been found to be most beneficial.

Physiological Effects of WBV

Research has documented that WBV stimulates muscle spindles which in turn increases the excitability of the muscles.[8] By providing a stimulus to the muscle spindle, the Ia sensory stimulus facilitates presynaptic inhibition.[8] Through presynaptic inhibition, less neurotransmitters are being delivered from the Ia afferent to the overexcited motor neuron.[8] This decreased signal therefore decreases the overactivity (caused by lack of inhibition from the brain) to the muscles and decreases spasticity.[8] Not only does WBV help decrease spasticity, but it also promotes a more normal interaction between flexors and extensors through reciprocal and supraspinal inhibition.[8] With proper activity following WBV, the nervous system can undergo activation of the agonist and inhibition of the antagonist.[44] Ongoing WBV and functional activity can slowly promote neuroplasticity.[8,57,58] This intervention is also beneficial because it is an intervention that requires little energy use for a short period of time.[59] Whole body vibration can address multiple impairments at 1 time, has been shown to be safe to use in children with CP, and it caters to the limitations of the disorder making it an ideal treatment.[59]

Current Literature on WBV

Recently, Ritzmann et al. published a meta-analysis examining the effects of vibration therapy in those with cerebral palsy.[54] The results of this meta-analysis showed that 1 session of vibration therapy had an effect on decreasing spasticity and improving coordination deficits.[54] The review found that the short term effects of vibration therapy can last up to 1 to 2 hours and long term effects which indicates chronic changes such as reduced spasticity and improved gait speed.[54] These findings indicate that with WBV and the reduced effect of spasticity, other treatments such as gait training to improve gait speed can be applied with a higher likelihood of positive outcomes.[54]

Tupimai et al.[60] had performed WBV and passive stretching on 12 children with spastic CP. The study found that with one-time exposure to WBV, showed a decrease in spasticity within the plantar flexor on the weaker leg.[60] However, with 6 weeks of exposure to WBV and passive stretching, it was found that spasticity was significantly decreased in all muscle groups excepts for the hip adductors on the weak side.[60] As the study performed a cross over design, it is difficult to determine if the change in spasticity is solely from the addition of WBV.[60] Since passive stretching is only 1 component of a physical therapy program, it is necessary to examine a comprehensive study with the inclusion of additional components to determine if the effects of WBV can be further implemented in future rehabilitation plans.

Purpose

Currently there are different findings that support[39,40] or refute[41] the use of WBV to decrease spasticity and improve functional mobility in CP. However, there is a gap in the literature, showing that systematic reviews and meta analyses compare WBV alone and not as an adjunct therapy[44,48,49,51,54] Studies have shown that WBV[34] combined with physical therapy[40] have been effective in improving functional mobility. Furthermore, the review will address the need for using multi-modal equipment in combination with physical therapy. This meta-analysis is based on the hypothesis that WBV with PT interventions combined should decrease the effects of spasticity allowing for improved functional mobility through gait parameters. Therefore, the null hypothesis would be that the use of WBV with physical therapy will not influence spasticity and will not improve gait parameters, such as gait speed. However, based on previous studies it is expected that there will be a positive change with WBV combined with PT intervention.

METHODS

Search Strategy

The primary literature search protocol and study design was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Search began August 2019 to December 2019. Databases searched include PubMed, Science Direct, Sport Discus, CINAHL Plus, Academic Search Ultimate, Sports Medicine and Education Index ProQuest, and Web of Science. Search terms include whole body vibration and cerebral palsy. Duplicates were removed and articles were then limited to peer reviewed articles, those written in the English language, and those published within the last 10 years. Articles were then screened and excluded based on title relevance and abstract. A consort describing elimination process of articles is presented in Figure 1 of the appendix.

Eligibility Criteria

Articles that were obtained after the literature search were then screened for inclusion/exclusion conditions: To be included in the meta- analysis, the subjects within the gathered studies had to meet the following criteria: (1) children diagnosed with CP, (2) ages between 5-12 years old, (3) able to weight bear with or without an assistive device; and (4) include whole body vibration. Articles that were included must also include the Modified Ashworth Scale (MAS) and/or gait speed as one of their outcome measures used. The studies were excluded if they included the following: (1) recent surgery within the last 6 months and (2) wheelchair bound.

Definitions

Data on the effects of WBV with PT compared to PT alone on spasticity and gait were analyzed. In this meta-analysis, PT intervention will be operationally defined as interventions that incorporate any of the following components: strengthening, therapeutic exercises, motor control, gait training, or passive stretching.

Outcome Measures

Modified Ashworth Scale

The MAS is a commonly used outcome measure to assess spasticity and is used within the studies collected for this meta-analysis. It is a modification of the Ashworth Scale and includes rankings 0, 1, 1+, 2, 3, and 4. The rater subjectively rates the quality of spasticity, or resistance, felt at a joint with a quick passive stretch. The scale ranks the amount of resistance felt from 0 to 4. At zero, there is no resistance felt with the quick stretch. At 4, the limb is rigid in either a flexed or extended position. The MAS measure has moderate to good interrater reliability (ICC: 0.61-0.87) and poor to good test re-test result (ICC: 0.36-0.83).[61] However, a systematic review compared multiple tools to assess spasticity in children with CP (tools such as MAS, myotonometer, Wartenberg pendulum test, and tonic stretch reflex testing to name a few) determined that there was no tool that had satisfactory reliability or validity due to lack evidence available.[62] Regardless of these findings, MAS is the most well-known and commonly used tool to rate spasticity due to its ease of use.[63] Within all the studies assessed, the MAS was converted to a 0-5 point scale for the purpose of data analysis.

Gait Speed

Gait speed is easily administered, time efficient, and is low cost. Gait speed examined via the 10-meter walk test (10MWT) has also been shown to be a positive predictor of functional ability.[64,65] In children with CP, the 10MWT also has a high interrater reliability (ICC: 0.99) and test-retest reliability (ICC: 0.98) and high intercorrelation (ICC: 0.63) with gross motor function.[66] Patients are instructed to walk at a normal walking pace for a distance of 10 meters in which their time is recorded using a stopwatch.[67]

Quality Appraisal

The PEDro scale is an 11-point scale used to identify the quality of the studies used in this meta-analysis. The scale identifies any internal validity flaws within a study. One point is given for each condition met. Since the first criteria addresses external validity, it will not be included within this meta-analysis and therefore scores will be out of a total of 10. The scale ranges from poor quality (≤3 points), fair quality (4-5 points), and high quality (6-10 points).[68] The quality of the obtained studies were reviewed and results are listed in Table 2.

Data Collection

Data involving the use of MAS or gait speed were collected from the results section of the included articles. Data extracted from articles include number of participants, pre- and post-test means, standard deviations, interquartile ranges, medians, and sample sizes. Medians and interquartile ranges were converted into means and standard deviations using a published conversion formula of converting the mean into the median and the standard deviation into the follow: SD= IQR/1.35.[69] The converted data was then used to calculate posttest values. Statistical analysis was then performed with the use of number of participants, means and standard deviations. The data analyzed provided information on the use of either the fixed or random model, homogeneity or heterogeneity, and statistical significance.

Statistical Analysis

Objective spasticity measures and gait speed data from participants were extracted from the obtained studies for statistical analysis. Number of participants, means and standard deviations were gathered from each study and analyzed to determine individual and combined grand effect size and confidence interval. Each intervention group and outcome measure had analyzed effect sizes to quantify the treatment effect. Based on Cohen's conventional values, effect sizes are characterized as small (<0.30), medium (<0.30-0.80), and large (>0.80).[70] Cohen's Q value determined if data between studies had statistical homogeneity or heterogeneity. The p value was determined to differentiate between the implementation of a fixed effect or random effect model. For visual representation of the included studies results along with the grand effect size, a forest plot is provided within the results section. Results were considered significant if the confidence intervals did not cross zero. Sub-analyses were created to observe the effects of WBV with PT on spasticity in knee extensors and plantar flexors.

RESULTS

Study Selection

An initial search using Academic Search Ultimate, CINAHL Plus, PubMed, ScienceDirect, Sport Discus, Sports Medicine and Education Index ProQuest, and Web of Science which provided a total of 497 citations using the term "whole body vibration and cerebral palsy". Articles were selected as shown in Figure 1. Duplicates were then removed, and 447 articles remained. The titles were then screened to determine each titles inclusion of this meta-analysis's PICO regarding diagnosis of CP. This then led to 56 articles remaining in which abstracts were then screened to determine the inclusion of children only within the study. Afterwards, 35 articles remained. Each article was screened for inclusion and exclusion criteria. The remaining 6 articles were chosen and reviewed for data comparison in this meta-analysis. These articles were then assessed for strengths and weaknesses using the PEDro scale. The results are listed in Table 1. The various studies ranged from 3-7 out of 10 on the PEDro scale. All the studies did not meet the criteria of blinding subjects and therapists.

Study Characteristics

The 6 articles that were included in this meta-analysis focused on WBV and children with CP. All articles meet the requirements of this PICO and specific details about each individual article is listed in Table 2.

A total of 3 studies were used to compare WBV with PT versus PT alone and its effect on decreasing spasticity in children with CP. A compilation of the studies included 62 total participants. The participants varied in functional levels. All the studies included WBV with PT as an intervention. Two of the studies looked at spasticity in various muscle groups and 1 study look at spasticity in the knee extensors only. One study had examined the immediate effects of WBV with PT in the reduction of spasticity via the MAS. Ages of participants ranged from 6 to 18 years old. Total exposure to WBV varied between 110-324 minutes for each study. Whole body vibration settings varied for each factor; frequency ranged from 12-20 Hz and the mode that WBV was received varied between a standing plate and a supine plate. Each of the studies that examined spasticity and used the MAS as an outcome measure scored between 3-4 on the PEDro scale where blinding of the subjects, therapists and assessors were not completed. All 3 studies included point estimate values.

A total of 3 studies were used to compare WBV with PT versus PT alone and its effect on gait speed via the 10 MWT. A compilation of the studies included 70 participants with GMFCS levels ranging from I to IV. All studies included WBV with PT as an intervention and compared results to participants that had PT only. Ages of the participants ranged from 5 to 12 years old. The studies had WBV exposure ranging from 54-1080 minutes. Whole body vibration settings varied between studies; frequency was between 5 and 25 Hz, amplitude ranged between 1 to 9 mm displacement, and all vibration was provided via a standing platform. The studies PEDro scores ranged from 4-7. The articles did not have blinding of subjects or therapists and did not include an intention to treat analysis. All 3 articles did include a random allocation of participants, between group comparison, and point estimate values.

Effects of WBV with PT Versus PT Alone on Spasticity

Lower Extremities

Ibrahim et al[71], Tupimai et al[60], and Dudoniene et al[72] had compared the effects of WBV on various lower extremity muscle groups. A total of 14 data points was used to compare effect sizes of each study. Four data points reviewed the knee extensors, 3 data points examined the hip adductors, 3 the plantar flexors, and 2 examined the knee flexors. Studies comparing the effect of WBV with PT to PT alone resulted in a Q value of 32.64 (p=0.001) indicating heterogeneity amongst the studies. The studies result in a moderate effect size (ES=-0.46, CI=-0.85, -0.07) favoring WBV with PT over PT alone in reducing spasticity via the MAS in the lower extremities of children with CP. Majority of studies either favored WBV with PT in reducing spasticity or it had no effect. One group by Tupimai et al[60] favored PT alone. The effect size of each individual study as well as the grand effect size is seen in Figure 2.

Knee Extensors

Ibrahim et al[71], Tupimai et al[60], and Dudoinene et al[72] were used in this sub analysis to determine the effects of WBV with PT versus PT alone in decreasing spasticity via the MAS in the knee extensors. These studies produced 6 data points that determined each individual effect size as well as a grand total effect. These studies produced a Q value of 19.59 (p=.0006) indicating heterogeneity amongst studies. Using the random effects model, there was an overall small effect size (ES= -0.20, CI=-1.05, 0.64) favoring WBV with PT compared to PT alone. However, since the confidence interval crosses zero, the effect of WBV with PT is not significant. Since the confidence interval crosses zero, the effect of WBV with PT is not significant. The results of the knee extensors favored WBV with PT except for Tupimai et al[60], which favored PT intervention alone. Figure 3 shows each individual effect size as well as the grand effect size.

Plantar Flexors

Ibrahim et al[71] and Tupimai et al[60] were used to create this sub analysis that identified the effects of WBV with PT versus PT alone in decrease spasticity via the MAS in the plantar flexors. The compilation of studies produced 4 data points that identified effect size of each study along with the grand effect of the studies combined. The 2 studies yielded a Q value of 0.63 (p=0.73) signifying homogeneity amongst the studies. With use of the random effects model, the studies combined had a moderate effect (ES=-0.21, CI=-0.66, 0.23) favoring WBV with PT over PT alone in reducing spasticity via the MAS in plantar flexors. However, the grand effect of all the studies had a confidence interval that crossed zero indicating that the effect was not significant. Majority of studies favored WBV with PT, however the effect size was not significant as the studies crossed zero. The grand effect and each study's individual effect are shown in Figure 4.

Effects of WBV with PT Versus PT Alone on Gait Speed

Ruck et al[9], Lee and Chon[10], and Ko et al[73] analyzed the effects of WBV with PT verses PT alone on gait speed and were utilized for this meta-analysis. Four data points were produced to determine the overall effect of increasing gait speed via 10 MWT in children with CP. Heterogeneity comparing WBV with PT to PT alone resulted in a Q value of 15.81 (p= 0.00036) signifying a high heterogeneity between the studies. The studies had a small combined effect size using the random effects model (ES=0.33, CI=-1.10, 1.75) favoring WBV with PT and showing that gait speed increased with this treatment. Although WBV with PT was favored in increasing gait speed, it is not significant due to the CI crossing 0. One study favored WBV with PT, 1 favored PT alone, and 1 study slightly favored WBV with PT. Figure 5 displays each study's effect size as well as the combined grand effect size

DISCUSSION

Purpose of Study

The purpose of this meta-analysis was to determine the effects of WBV with PT interventions versus PT usual plan of care in children with CP in decreasing spasticity implementing the MAS. Additionally, to ascertain if there are similar findings in the increase in gait speed via the 10 MWT. The hypothesis stated that WBV with PT interventions would be favorable over PT usual plan of care in decreasing spasticity and increasing gait speed. The null hypothesis was that there would be no effect favoring WBV with PT compared to PT alone in children with CP.

The hypothesis of WBV with PT decreasing spasticity greater than PT alone in the lower extremities was accepted. The main ES of -0.46 showed a moderate decrease in spasticity in the lower extremity musculature and favored WBV with PT. The meta-analysis implemented the random effects model as the studies were heterogeneous. In a further sub analyses of specific musculature, the knee extensors and plantar flexors showed a decrease in spasticity. However, the null hypothesis was accepted, as the confidence interval crossed zero in the scenarios. Furthermore, decreased spasticity in the knee extensors had a small effect size with WBV and PT and all studies were homogenous with each other. Lastly, the effect size of decreasing spasticity in the plantar flexors via WBV with PT was moderate and the studies were homogenous as well.

As for gait speed, the hypothesis was rejected, and the null hypothesis was accepted. Whole body vibration with PT compared to PT alone was not more effective in increasing gait speed. Although the null hypothesis was accepted, WBV with PT intervention was moderately effective, with an ES of 0.33 and CI

(-1.10, 1.75); but since the confidence intervals cross zero, the effects were not significant. The studies used to synthesize the data were also heterogeneous meaning that the data compiled may include should be interpreted with caution.

Findings and Significance

WBV with PT in Decreasing Spasticity via MAS Score in the Lower Extremities

Decreases in spasticity has been attributed to synaptic changes within the stretch reflex. This occurs in 2 ways. The first is via the mechanism in the stretch reflex. In spastic CP, the inhibitory supraspinal influences within the stretch reflex creates overexcitation in the reflex arc.[21] However, input from WBV provides frequency, amplitude, and velocity to the muscle spindle/muscle spindle primary and secondary endings, thus leading to an increase in muscle activation.[44] By maintaining balance on the vibration plate, voluntary muscle contractions to maintain appropriate position on the vibration plate allows for reciprocal inhibition to occur.[44] Furthermore, via WBV input, a decrease in muscle spindle responsiveness to more normalized levels results in a less hyperactive stretch response thereby creating presynaptic inhibition.[44]

Tupimai et al[60] had examined spasticity with 1 exposure to WBV, totaling 5 minutes, as well as being exposed to WBV for over 100 minutes. Participants that were only exposed to the initial 5-minute bout of WBV had a variability in spasticity responses. Some muscle groups had favored PT intervention alone. However, studies with WBV over 100 minutes of total exposure time to the intervention showed a greater effect on spasticity ES -0.66 CI (-0.33, -0.99) compared to other studies that had less exposure time within this meta-analysis. This can potentially indicate that with more overall total exposure to WBV with

PT can lead to adaptations at the muscle spindle. This in combination with voluntary muscle contractions when maintaining postural control on the vibration plate may allow for better muscular control and overall a creation of new motor movements.

Additionally, another factor that could have explained the decrease in spasticity is the frequency that the participants were exposed to. In a recent study looking at the effects of frequency, it was determined that WBV frequencies that are less than 20 Hz have a greater effect on muscular adaptations than higher frequencies.[11] Studies that used less than 20 Hz[71,72] favored WBV with PT intervention greater than the studies that used greater than 20 Hz.[60] It was determined in normal adults the average firing rate within muscle unit recruitment was between 25-31 Hz and that adults with CP had an average firing rate of 13-16 Hz.[74] This can explain why having a lower frequency was more beneficial since the normal firing rates in those with CP were lower.[74] Also, a study determined that there could have been more muscular fatigue occurring in frequencies higher than 20 Hz which could have a negative effect on spasticity.[11]

WBV with PT in Decreasing Spasticity via MAS Score in the Knee Extensors

The sub analysis investigating the effects of WBV with PT in decreasing spasticity when compared to PT alone in the knee extensors determined that WBV with PT was more effective, however the null hypothesis was accepted due to the CI crossing 0. Some factors to consider were the variability of WBV duration, position, and the intensity that was provided to the participants. In Dudoniene et al[72], the participants had vibration therapy provided in a supine position, whereas the additional studies used the standard standing position. Since the method used in Dudoniene et al[72] required the participants to lie supine, the participants did not actively engage the lower extremities, which potentially effects the reduction in spasticity, since the muscle fiber is not active throughout the treatment session. Furthermore, a larger frequency was administered compared to other studies. Frequency and position are potential factors, which impact spasticity results and caused WBV with PT to have a non-significant effect.

WBV with PT in Decreasing Spasticity via MAS Score in the Plantar Flexors

The effects of WBV with PT versus PT alone in decreasing spasticity via the MAS within the plantar flexors of children with CP had also accepted the null hypothesis, however, there was a minimal effect size of -0.21 and CI= (-0.66, 0.23) favoring WBV with PT. All studies either favored WBV with PT or were equally favoring both WBV with PT or PT alone. This could be due to the fact that the plantar flexors are among the first muscles affected by spasticity.[17] Depending on the child's age, if the child has already experienced a change in growth, it may be more difficult for spasticity to decrease in the plantar flexors if a contracture has already occurred.[75]

WBV with PT Effects on Increasing Gait Speed via 10MWT in Children with CP

When examining which intervention is more effective in improving gait speed between WBV with PT versus PT alone, the results show a moderate ES of 0.33. For the generation of functional gait mechanics, proper coordination between agonist and antagonist muscles are necessary. However, because of the lesion, there is uncoordinated agonist and antagonist muscle activation in the lower extremities, therefore diminishing gait properties which include gait speed.

Through WBV and resultant reciprocal inhibition, there is a decrease co-contraction in the agonist and antagonist muscle groups.[44,76] Supplemented with task based interventions, voluntary movement of the lower extremities is more obtainable.[55]Another cause of increased gait speed is the use of more motor units. With the increase in frequency of WBV, imposes an increase rate of muscle fibers activation.[55] With the variations in amplitude and frequency, muscle and spindle are exposed to variable changes.[77] This stimulates the activation of various muscle fibers that are not normally used during normal activities that the child may partake in.[55]

With WBV, Henneman's size principle can occur where small muscle fibers are stimulated faster than larger muscle fibers.[78,79] This indicates that normally, slow muscle fibers are recruited first and last to be recruited are the fast-fatigable type II muscle fibers.[80] However, with the prolonged exposure to WBV and the constant change in muscle activation, eventually larger fast-fatigable muscle fibers are activated.[78,79] Also, it has been found that adults with CP normally have an average firing rate of 13-16 Hz.[74] By initiating the use of frequencies between 12 and 18 Hz recruitment of type II fibers may potentially occur, potentially improving force production of the muscle.[11,81] An increase in force production ultimately improves the strength and functionality of the lower extremity muscle.[82] Therefore, the combination of an improvement in muscle fiber recruitment potentially leads to improved force production and in combination with lower frequencies can explain the effects that favored WBV with PT versus PT alone in improving gait speed.[11,82]

In the analysis of gait speed, Ko et al had a control group that was at a higher functional mobility level when compared to the experimental group. This occurred in which pre-intervention Gross Motor Function Measure score was significantly higher in the control group than in the WBV group due to 2 participants dropping out of the study from the WBV group. Therefore, data collected may not accurately reflect the effects of WBV with PT on gait speed in children with CP. Interventions within each study focused on different aspects that may affect gait differently. Focusing solely on increasing strength to musculature involved in gait may be more beneficial than that of a generalized PT intervention for children with CP.83 However, WBV exposure times varied between 54-914 minutes, each study had varying frequencies of WBV, and intervention prescription times that also revealed heterogeneity amongst the studies. Studies that focused on WBV with PT interventions >100 minutes did have a positive effect on gait speed.9 ,10 This indicated that prolonged exposure to WBV with PT may be key in improving gait parameters.

Current Literature in Relation to Findings

Spasticity

In Ahlborg et al[51], WBV was used and compared to resistance training in determining which intervention was more beneficial in decreasing spasticity. The study found similar results in that spasticity was reduced in the knee extensor muscle group.[51] Ahlborg et al. had a significant decrease in spasticity within the knee extensors, but not within other muscle groups.[51]

Park et al[84] had identified immediate effects of WBV in decreasing spasticity within the plantar flexors. The results of this studied determined that WBV can decrease spasticity in the plantar flexors for up to 1 hour after immediate exposure.[84]

Gait Speed

Other studies support WBV's positive effect on gait speed. However, there were several differences from this meta-analysis. Pin et al[55] study included a wider variability of age groups as well as ataxic and dyskinetic type CP. In an additional WBV study, Han et al[11] determined that increased gait speeds using WBV had the most significant changes between 12-18 Hz.

Limitations in This Meta-Analysis

Internal Validity Threats

There were several limitations within this meta-analysis. The first limitation includes those that threaten internal validity. The first internal validity threat occurs during data collection. First and foremost, there was only 1 researcher compiling data for this meta-analysis and although efforts were made to include all studies that met the inclusion criteria, human error during data collection could have occurred. Additionally, articles were excluded if they were not written in the English langue or if they were written before the year 2009. There may be additional and vital articles that could have been included that applied to the exclusion criteria, however the exclusion criteria was in place to include recent and current evidence.

The second limitation is that this meta-analysis includes articles with low validity scores based on the PEDro scale. Due to the limited number of studies that met inclusion and exclusion criteria within this population as well as a lack of evidence looking at the effects of WBV in combination with PT, any article that met the criteria was included. Therefore, the findings from this meta-analysis should been considered with caution and instead should help guide treatment ideas. A component of the PEDro that was not met by any of the studies included was the blinding of the subjects or the therapist. Although this may prove to be complicated due to the nature of the intervention requiring careful guarding of patients, future studies should incorporate ways to prevent any bias between the therapist or subject. Lee and Chon scored the highest on the PEDro scale with a score of 7/10 and was able to blind the assessors.[10]

An additional threat to validity that occurred within this study is the conversion of qualitative data into quantitative data when identifying the amount of spasticity in the lower extremities. Since the MAS has good to moderate inter rater reliability but poor to good test re-test validity, the outcome measure itself has potential flaws.[61] Nevertheless, the MAS is currently the most used outcome measure to address spasticity clinically. Since the outcome measure relies on the assessor to subjectively identify the quality of spasticity felt within a joint, the test is subject to user discrepancy. In order to convert non-parametric data into parametric data, medians and interquartile ranges were converted to means and standard deviations.[69] However, the equation used to convert non-parametric data into parametric data is normally used for a larger sample sizes.[69]

<u>External Validity Threats</u>

There were multiple external validity threats within this study. An evident threat to the external validity of this study lies within the population used. First, a small sample size was used. The sample sizes ranged from 12 to 30 participants. Due to this limited number of subjects, generalizing the findings from this meta-analysis to the population of children with CP should be done with caution. Effects that occur within the limited number of participants may not translate to a larger population.

Second, the population used had varying levels of functional capabilities. Participants that were included varied from GMFCS level I to level IV. Findings from this study may not affect those in different function levels the same as this study since the study encompasses a broad spectrum of functional capabilities. With further investigation, there was also a limited number of participants with GMFCS IV, so data may not encompass changes within this group.

Third, the subjects used within the studies include ages that are prior to adulthood. The age ranges vary however in physical growth of the participant. Functional limitations for those who are 5 years of age can vary between the functional capabilities of those who are 12. The time between ages incorporate a difference in physical size of the individual as well a difference in function. Whole body vibration can potentially diminish the effects of skeletal deformities and improve or maintain functional mobility. However, if the study includes children who are undergoing skeletal growth during the time of the intervention, there may be a drastic change in the functional capabilities of the individual.

Fourth, medications to reduce and treat spasticity prior to intervention, such as botulinum injections, were not excluded. Studies also could not control if subjects had additional treatment outside of their respective studies. Therefore, the effects of reduced spasticity cannot solely be contributed to the effects of WBV with PT.

Implications for Practice

The results of this study show that WBV with PT intervention can be beneficial in reducing spasticity within the lower extremities with the possibility of improving gait speed. This in turn can indicate the use of WBV in concurrence with PT to permit time effective and efficient interventions that target multiple deficits seen within CP. By decreasing the effects of spasticity, with the addition of physical therapy interventions, there is the possibility of reducing the risk or progression of muscular abnormalities. Once normal muscular function is attained, the patient can then focus intervention on their individual deficits.

In a clinical setting, WBV can be provided prior to intervention to decrease spasticity momentarily and promote task-based intervention to occur. Physical therapy interventions can then address any secondary effects of decreased motor performance such as poor balance, poor postural control, and uncoordinated gait. Implementing task-based intervention in addition to WBV may induce neuroplasticity to retrain the neuromuscular system.

In conjunction to WBV, functional mobility potentially be addressed. Since WBV with PT has had a small effect on increasing gait speed, it is vital to address other factors that can improve functions of gait. In this meta-analysis, interventions that focused on improved strength in musculature used for gait as well as interventions and WBV exposure times greater than 100 minutes may be beneficial for improving gait speed.[9,10,73] Gait speed is a positive predictor of functional ability so maintaining ambulatory abilities and continually focusing on improving gait speed, a child with CP can potentially preserve their independency.

Future Research

Future research should identify optimal dosing of WBV to address different impairments of CP. A study by Han et al[11] examines the immediate effects of WBV and different frequencies on gait speed. The results from this study determined that at 12 Hz and 18 Hz gait speed had a statistically significant improvement in gait speed.[11] Even though the study identifies optimal frequencies, the subject size was limited and further investigation is needed. Additionally, other

WBV settings such as amplitude, exposure time, and foot placement should be further researched.

In addition to optimal dosing, future research should also identify the effects of WBV with PT in children younger than 5 years old. In Stark et al[85], WBV and PT were provided to children between the ages of 1 to 2 years old. This study gave insight on the feasibility of providing early intervention to children diagnosed with CP. While a child is still developing, their nervous system is very malleable. Changes to promote improved motor functions can still be implemented while poor motor skills and adverse secondary effects of motor impairment can be avoided. Findings from this study indicate that WBV is safe to use in younger children and implementation of an appropriate functioning neuromuscular system can benefit children throughout their lifespan. Furthermore, WBV can be provided throughout the child's lifetime to identify any long-term effects of WBV with PT interventions and determine if any permanent changes occur.

Lastly, a promising area for investigation would be to identify the combined effects of multiple treatments to address impairments seen in CP. These include combining the effects of any of the following interventions: WBV, PT, surgery, pharmacological intervention, electrical stimulation, and any additional modality or treatment that has been used within this population. More studies looking at the effects of different combinations of treatments may provide insight on ideal treatments to address different impairments seen within CP.

Conclusion

This meta-analysis has determined that WBV with PT can be beneficial in decreasing spasticity within the lower extremities and can improve gait speed. Although findings may not be significant, WBV with PT was preferred in decreasing spasticity and improving gait speed. Whole body vibration is an intervention that has been shown to use presynaptic inhibition to create new motor pathways via neuroplasticity and bypassing improper signals coming from the brain.[78] However, due to the limited amount of literature available that examines the effects of combined therapy, health care providers should use best judgement and consider patients unique individual needs when creating a treatment that is effective and time efficient. Determining the effects of this study could improve the efficacy of physical therapy sessions for children with CP by combining interventions to produce increased functional outcomes. Sessions could be more useful by decreasing the effects of spasticity while contributing to task specific interventions and limit the secondary causes of motor impairments from this disability. WBV in combination with PT should be an option when treating children with CP in order to reduce costly interventions later in life. In conclusion, additional high-quality studies with larger population sizes should be performed to identify the effects of WBV with PT and determine the true efficacy of this intervention on children with CP.

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TABLES

Table 1. PEDro Scale of Selected Articles

Study	Random Allocation	Concealed Allocation	Baseline Comparability	Blind Subjects	Blind Therapist	Blind Assessors	Adequate Follow-Up	Intention to Treat Analysis	Between Group Comparison	Point Estimate Value	Total
Ibrahim et al. 2014	✓		✓						✓	✓	4
Tupimai et al. 2015	✓		✓						✓	✓	4
Dudoniene et al. 2017	✓							✓		✓	3
Ruck et al. 2010	✓	✓	✓						✓	✓	5
Lee and Chon 2013	✓	✓	✓			✓	✓		✓	✓	7
Ko et al 2016	✓						✓		✓	✓	4

Table 2. Article Protocol Summary

Study	Study Design	Subjects (n, age, GMFCS)	WBV Settings (Type, frequency, amplitude)	WBV Schedule (Frequency, Protocol)	WBV Training Exposure Time	Outcome Measures
Ibrahim et al. 2014	RCT	n=30, 8-12yo, GMFCS NA	Side to side, 12-18Hz 2-6mm	3x/wk for 12wks, 3 sets of 3 minutes (varying frequency)	324 minutes	MAS
Tupimai et al. 2016	Single Group Cross-Over	n=12, 6-18 yo, GMFCS I-III	Oscillation, 20Hz, N/A	5x/wk for 6wks	150 minutes	MAS
Dudoniene et al. 2017	RCT	n=20, 7-10yo, GMFCS N/A	Supine side alternating, 15Hz, 2-6mm	14 sessions over 3wk span, 6 sessions for 5 minutes, 8 sessions for 10 minutes	110 minutes	MAS
Ruck et al. 2010	RCT	n=16, 5-12yo, GMFCS II-IV	Side to side, 12-18Hz, 4mm	5x/wk for 24wks, 9 minutes	1080 minutes	10 MWT
Lee and Chon 2013	Blocked RCT	n=30, 8-12yo, GMFCS I-III	Side to side, 5-25Hz, 1-9mm	3x/wk for 8wks, 6 sets of 3 minutes (varying frequency)	432 minutes	10 MWT
Ko et al. 2016	RCT	n=14, 8-12yo, GMFCS I-III	Side to side, 20-24Hz, 1-4mm	2x/wk for 3wks, 9 minutes	54 minutes	10 MWT

FIGURES

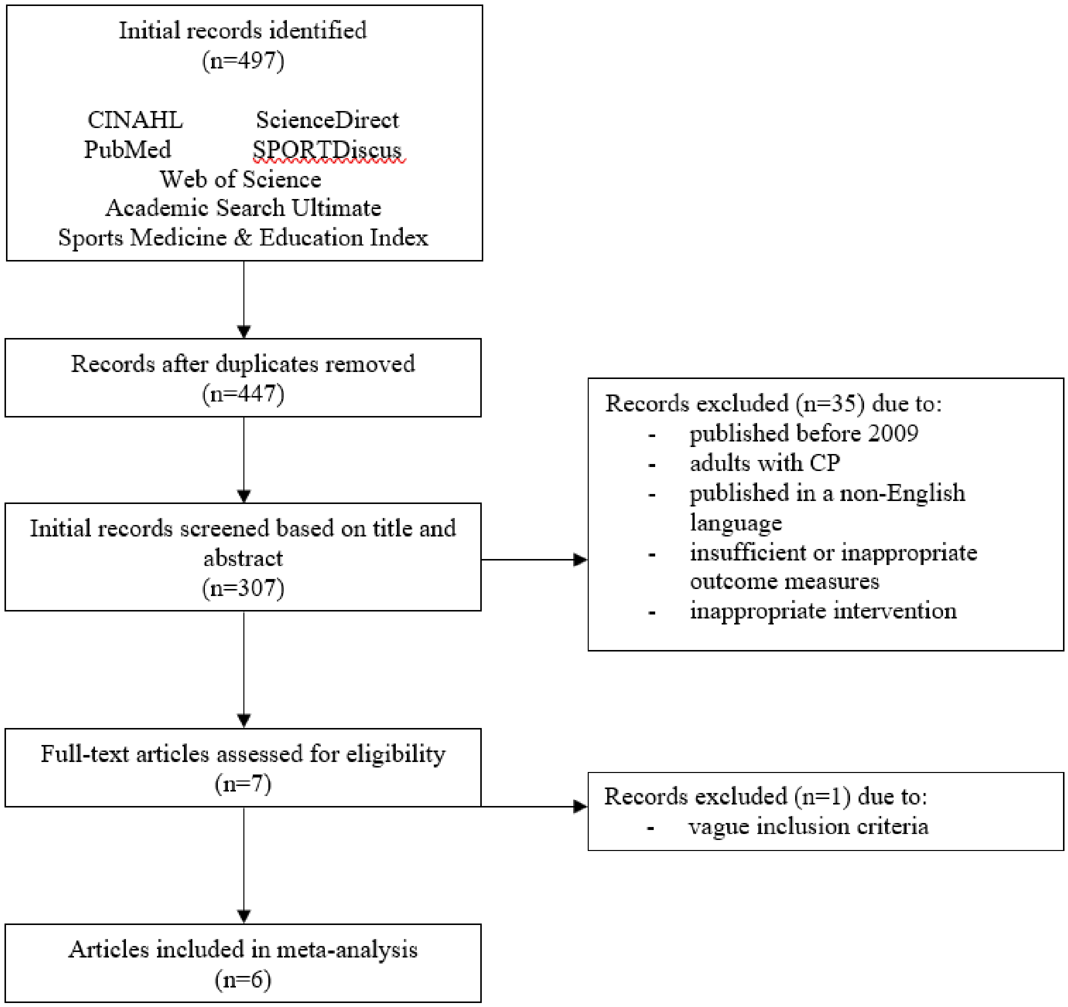

Figure 1. Article selection process.

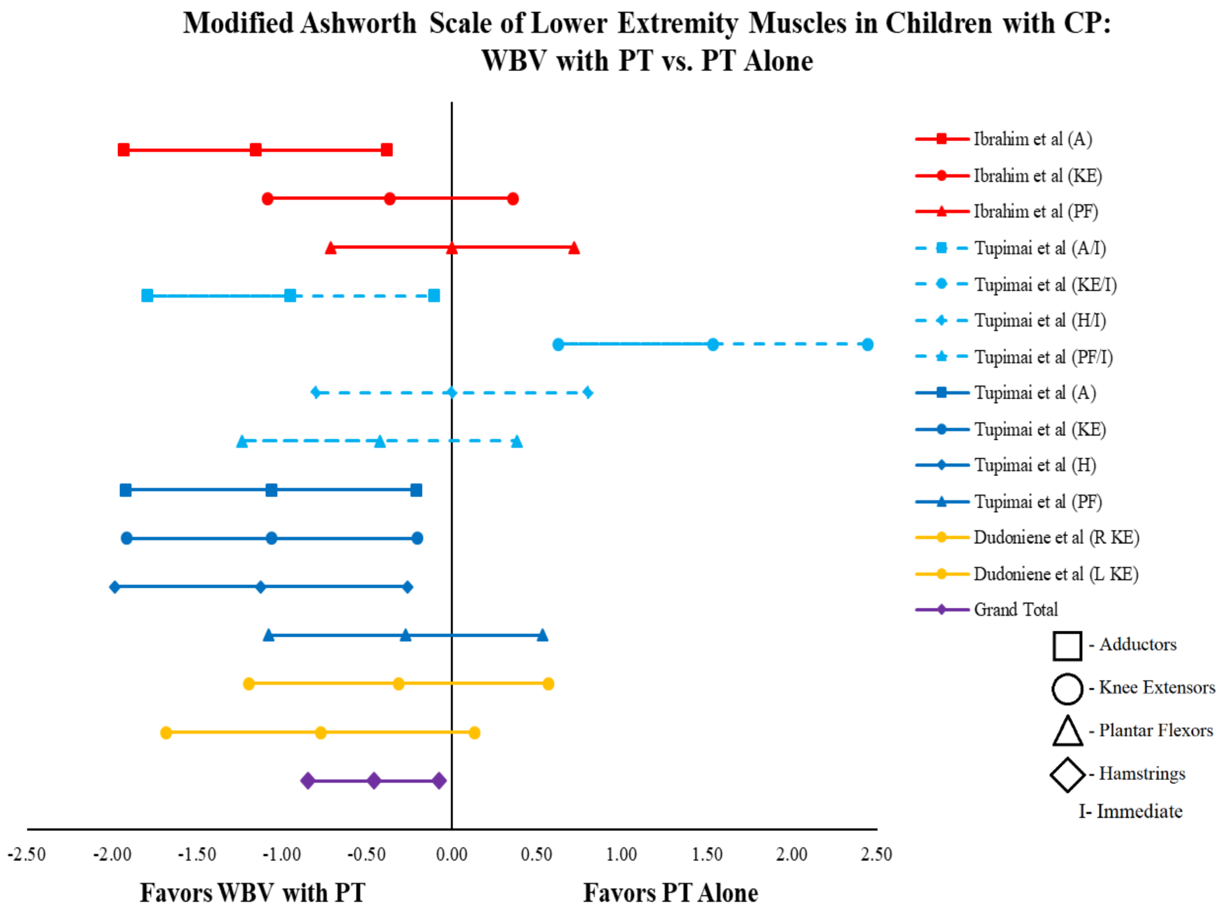

Figure 2. WBV with PT intervention versus PT intervention alone in reducing spasticity in the lower extremities.

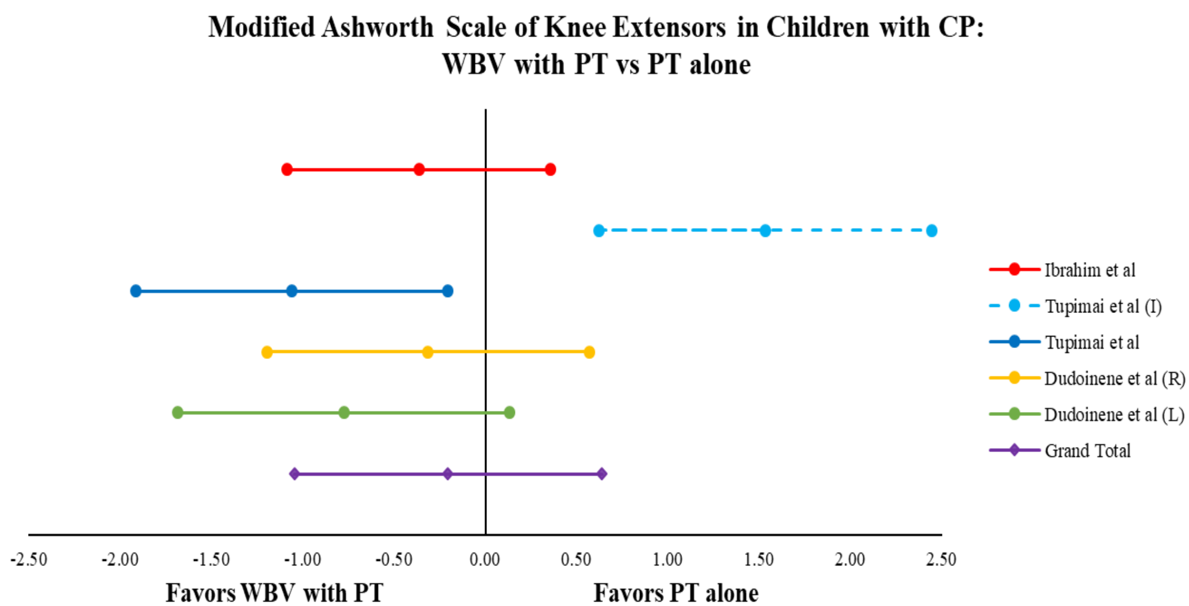

Figure 3. WBV with PT intervention versus PT intervention alone in reducing spasticity in the knee extensors.

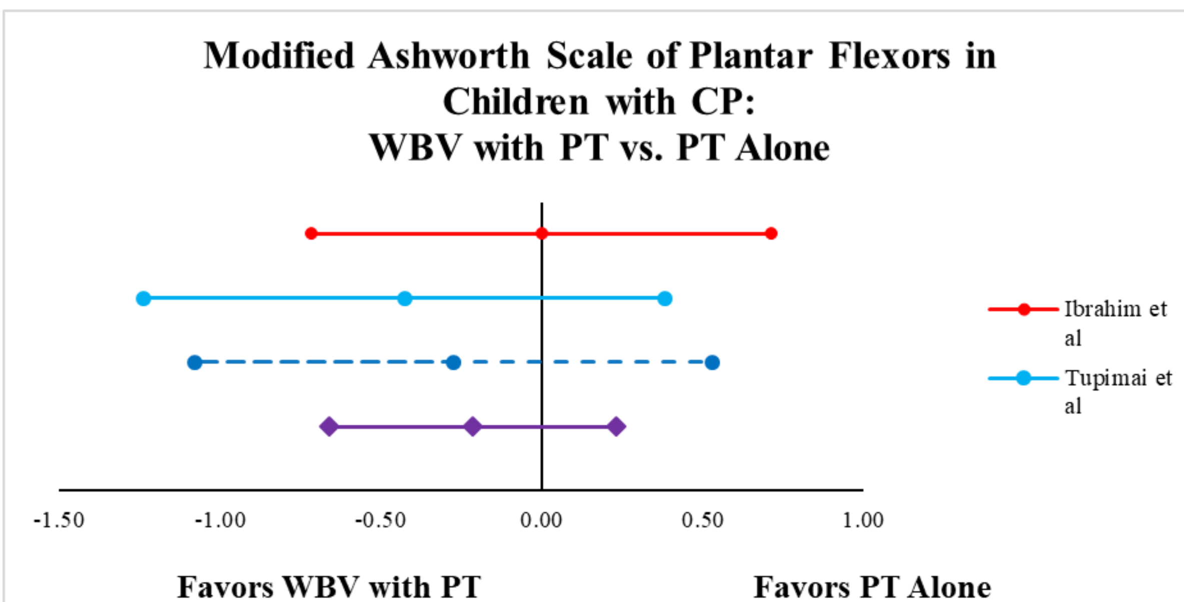

Figure 4. WBV with PT intervention versus PT intervention alone in reducing spasticity in the plantar flexors.

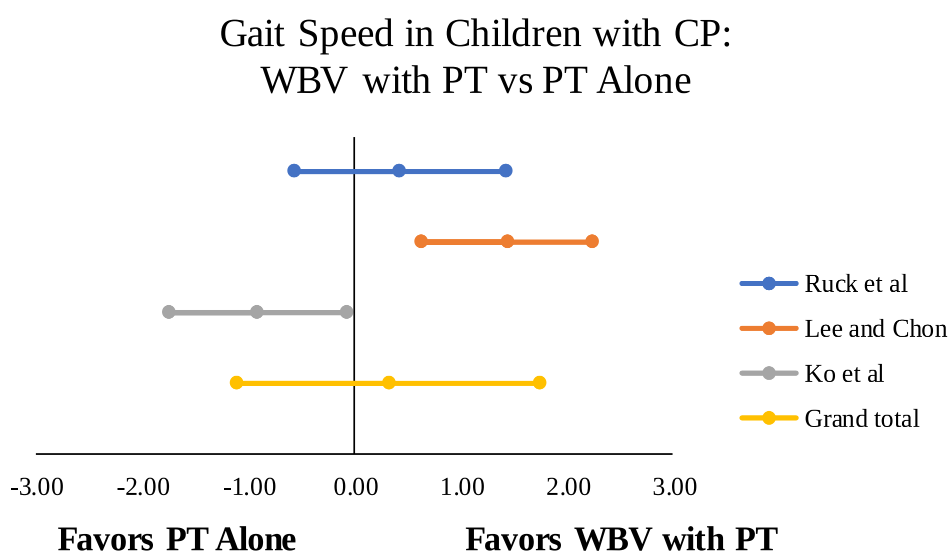

Figure 5. WBV with PT intervention versus PT intervention alone in improving gait speed.