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Hypothesis Study

Whole Body Vibration's Potential to Improve Balance and Function in Cerebral Palsy in Weight and Non-Weight Bearing Positions: A Hypothesis Study

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ABSTRACT

Cerebral palsy is one of the most prevalent neurological conditions in children. It has classical features of spasticity, poor balance and coordination, muscle weakness, proprioception, and inter-limb coordination. The primary cause is brain damage which affects certain circuits of the central nervous system. It has been reported that D1 inhibition is affected by cerebral palsy. The corticospinal and somatosensory pathways are also affected in the central nervous system along with abnormal activation of the motor neuron pool. There is abnormal presynaptic inhibition and post-activation depression of Ia afferents, while Group II facilitation is strongly enhanced. There are various therapies available to treat the symptoms of cerebral palsy, among which whole-body vibration therapy is considered to change the spinal transmission and somatosensory input. WBVT is typically administered in a weight bearing stance, targeting the lower extremities only. To the best of our knowledge, there is no research available exploring the cross-training effect of WBVT applied to upper and lower extremities, both weight and non-weight bearing positions, either alone on altogether. Hence, we propose that administering the WBVT across various configurations, incorporating weight and non-weight bearing positions for both upper and lower extremities could induce neural plasticity through cross training effect. We expect that by engaging all extremities in weight bearing positions may yield more significant outcomes compared to focusing solely on either upper or lower extremities.

Keywords: Balance, Cerebral Palsy, Inter-limb Coordination, Motor Function, Spasticity, Whole-Body Vibration Therapy.

INTRODUCTION

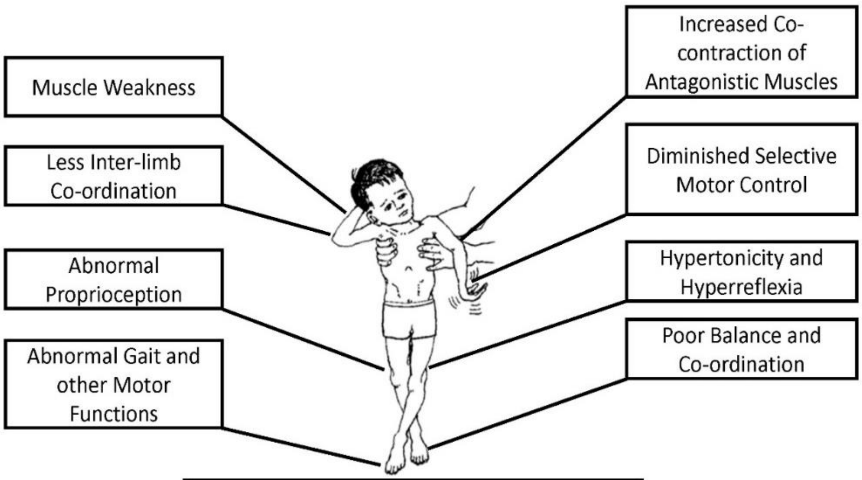
Various neurological conditions affect children, the most prevalent among them is cerebral palsy which is caused by the abnormal development of the fetal brain (1). Delayed spontaneous breathing at birth can cause brain hypoxia leading to brain damage that causes permanent neurological damage, leading to limitation in functional activities that is mostly attributed to the altered brain development, this also leads to abnormal afferent information like proprioception, altered perception, cognition behavior and communication (2). The children can be classified based on the involvement of extremities or sides of the body i.e., monoplegic, diplegic, and hemiplegic, and muscle tone i.e., spastic, flaccid, and athetoid. Spastic cerebral palsy is the commonest of all. This abnormal hypertonicity is usually seen in upper extremity flexor muscle and lower extremity extensor muscles (3). Children suffering from cerebral palsy live with lifelong disabilities, poor balance, and the functions of daily living are affected such that the quality of life is compromised if left untreated. In addition, the child with CP may also have limitations in vision, hearing, feeding, speech, swallowing, or breathing (4). There are various therapies available for the treatment and or management of cerebral palsy, among which physical therapy is considered safe and promising (5).

Using the evidence-based methods of physical therapy rehabilitation is a must for spasticity management, and improvement of flexibility, movement ability, and fine and gross motor skills (6). The muscular system of the CP child shows weakness and hypertonicity, these two along with poor growth cause functional limitations (7). That's why it is important to consider how to prevent these changes to make the patient independent. It is equally important to remember the fact that a fair amount of muscle strength is required to improve bone development and motor function. One of the most recent therapies that can improve muscle

Journal of Health and Rehabilitation Research 2791-156X JHRR

strength and bone mass is whole-body vibration therapy. WBVT proved to be effective in attenuating delayed onset muscle soreness, Pressure Pain Threshold, and plasma creatine kinase activity and controlling strength loss after a bout of eccentric exercise. (8, 9). This therapy has been advocated in the research literature to improve balance, motor function, and overall performance. It is a rather recent therapy but is being increasingly used nowadays. It is also used for various other neurological conditions (10, 11). Low-frequency WBVT (15 Hertz to 18 Hertz) has been used to minimize spasticity and improve function. It also improves flexibility by changing the hypertonicity of the muscles (12). The vibration stimulates muscle spindles of multiple muscles that can lead to muscle contraction, this is caused by a mechanism known as the tonic vibration reflex. This reflex is responsible for activating muscles that are usually not activated as much by the patient's voluntary efforts or passive movements by therapists. Hence, it can be considered to be more effective than simple passive range of motion exercises. This myotonic reflex is thought to be responsible for increased muscle strength of the spastic muscles of the limbs and torso. Therefore, it can be considered that this will not be achieved through conventional physical therapy alone (12). It is well known that with an increase in voluntary strength of the muscles, the walking ability and other mobility parameters including gait speed, step and stride length, gait cycle time, and limb joint ranges are also improved. Vibration represents a strong stimulus for musculoskeletal structures due to the need to quickly modulate muscle stiffness to accommodate the vibratory waves. This response is mediated by monosynaptic and polysynaptic afferent pathways, which are capable of triggering specific hormonal responses. It appears that a subsequent voluntary activation can be performed with central and peripheral structures in an elevated excitatory state. It proposes that vibration could represent an effective exercise intervention for enhancing neuromuscular performance (13). WBVT has positive effects on muscle strength, postural stability, and proprioceptive function, this might be due to improved synchronization of firing of the motor units and improved co-contraction of synergist muscles, which could bring about better balance control. Several types of receptors are sensitive to these mechanical stimuli. The most important effect of vibration is the stimulation of receptors on the sole of the foot including Merkel, Meissner, and Ruffini receptors. Furthermore, stimulation of proprioceptive receptors could initiate stretch and cutaneous reflexes and hence increase muscle strength (9). When a person is standing on a vibratory platform that has a frequency between 10 Hertz to 25 Hertz, the primary and secondary endings of the muscle spindle mainly trigger the motor neuron thus causing contraction of the muscle which is similar to the tonic vibration reflex.

Higher frequency vibrations (40 Hertz) cause hypertonicity while lower frequency vibrations (25 Hertz) cause reduced muscle tone (14). According to the latest systematic reviews and meta-analyses, the standing and walking function of cerebral palsy children can be improved with the application of whole-body vibration therapy, it can also induce reduction in spasticity, improved muscle strength, and enhanced coordination (10, 11, 15). Previous studies reported the immediate and long-lasting effects of WBV on gait, walking speed, standing function, spasticity, flexibility, strength, proprioception, and range of motion. There have only been measurements related to the lower extremity's function in a weight-bearing position. It is worth mentioning that there is strong evidence suggesting the effect of unilateral training on contralateral limb strength, it is called cross-education (16, 17). Hence, a standardized and quantitative measurement for the effect of whole-body vibration therapy applied to the lower extremity and its effect on upper extremities and vice-versa on balance and function remains unclear in patients with CP.



Clinical Features of Cerebral Palsy

HYPOTHESIS

1. The WBVT in Weight-Bearing and Non-weight-bearing positions for the Upper and Lower Extremities might improve balance and function in C.P. patients. There will be a pronounced effect of WBVT applied in weight-bearing positions as compared to non-weight-bearing positions.

Journal of Health and Rehabilitation Research 2791-156X JHRR

2. If WBVT is applied to both upper limbs it can affect or improve the function of lower limbs via interlimb coordination or propriospinal tracts.
3. If WBVT is applied to both upper and lower limbs simultaneously, it will have pronounced effects due to the summation of vibratory and proprioceptive inputs to the CNS as compared to either both upper or lower limbs alone.

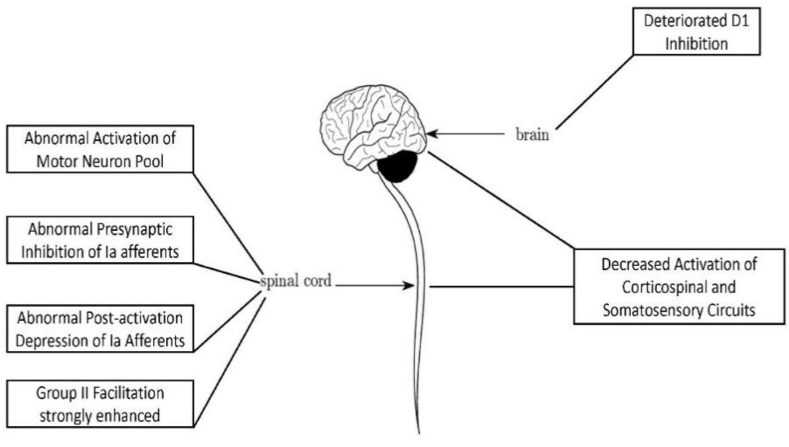
SPINAL CIRCUITRY CHANGES IN CEREBRAL PALSY CHILDREN

The sensory information from the skin receptors and musculoskeletal system is transmitted and processed by all the peripheral and central components of the somatosensory system (18).

Cerebral palsy children have problems in receiving and hence signaling to the somatosensory system and the most affected senses are likely proprioception (19) .

Facilitation or inhibition of proprioceptors, exteroceptors, vestibular and special sense organs can excite the anterior horn cell of the spinal cord, which will help normalize the muscular tone and motor recovery in Cerebral palsy children (20). These somatosensory modalities have at least two components movement sense known as Kinesthesia and joint position sense (21).

It is most likely that the pathological proprioception signaling is because of lesions in the brain and spinal cord circuitry, which in turn, can affect the afferent information coming from the skin, joint, Golgi tendon organs, and muscle spindle. Impairment in proprioceptive signaling of fascia tissue following tissue deformation due to injury and/or immobility can sensitize facial nociceptors and alter the function of related multimodal neurons in the spinal cord(22). Poor proprioception can aggravate disability as it can affect the motor control of the trunk and limbs which causes imbalance. Furthermore, the state of hypertonicity alters the muscle fibers which leads to abnormal signaling from joint receptors. Consequently, these changes affect the muscle spindle sensitivity and signaling (23). In cerebral palsy, the lesion to the immature brain can result in abnormal processing of the afferent information from the limbs to the spinal cord. Accordingly, these modifications can change the excitability (hyperexcitability) of the circuitry in the spinal cord, exaggerated stretch reflex, and increased antagonist co-contraction, concomitantly with poor voluntary control of movements (24). It is well documented that functional impairments lead to alteration in afferent discharge, autonomic response, and somatosensory pathways. It is hypothesized that by treating the periphery, the central circuitry (brain and spinal cord) can be altered (22). This poor motor control and hypertonicity are considered to be due to abnormal activation of the motoneuron in the spinal cord by the sensory pathways (25). It is suggested that D1 inhibition which seems to be associated with the excitability of those interneurons that mediate presynaptic inhibition of Ia afferents coming from the deteriorated muscle spindle in cerebral palsy (24). The somatosensory and corticospinal circuits are activated to a lesser extent and cortex excitability is also affected in children with cerebral palsy. These somatosensory changes may be the cause of poor kinesthetic and tactile senses (26). The corticospinal tract is essential for receiving and maintaining spinal reflex patterns and execution of motor tasks the spinal circuitry is altered in cerebral palsy. It is reported that Di synaptic reciprocal Ia inhibition is normal, but the presynaptic inhibition of Ia afferents and post-activation depression are altered and propriospinal mediated Group I facilitation is normal while Group II facilitation is strongly enhanced in cerebral palsy (27).



CNS changes in Cerebral Palsy

CHANGES IN GROSS MOTOR CONTROL IN CEREBRAL PALSY CHILDREN

The CP's children have disturbed motor + due to hypertonicity, myogenic and sometimes atherogenic contractures, muscular weakness, and diminished selective motor control, which may lead to poor gait and disturbance of the ADLs (28) (29).

Selective motor control (SMC) refers to the isolated activation of muscle in a particular pattern in response to the demanding posture or movement. This volitional isolated joint movement requires an intact corticospinal tract. The corticospinal tract descends from the motor cortex to the motor neuron pools in the spinal cord. In cerebral palsy, there is damage to the periventricular area that can be seen in MRI, as the most common finding associated with spastic diplegic in more than one-third of quadriplegic and hemiplegic cerebral palsy children (30). Due to poor SMC in cerebral palsy, it is not possible to measure the actual maximum voluntary

Journal of Health and Rehabilitation Research 2791-156X JHRR

contraction force that is developed during routine activities (31). The SMC is affected by the dominance of either flexor or extensor synergy that interferes with functional activities.

When the corticospinal tract is damaged the rubrospinal tract may compensate which results in near-normal selective motor control (32).

It has been reported that children with developmental coordination disorders such as cerebral palsy exhibit less interlimb coordination as compared to typically developing children. In other words, the coordination patterns of children with DCD reveal looser coupling between the left and right sides of the lower body joints (knees and ankles) in contrast to typically developing children, who show tighter coupling. Moreover, typically developing children display greater variability of inter-limb coordination at the shoulders and elbows, suggesting functional flexibility and adaptation in motor control (33). Children with cerebral palsy have altered central nervous system function as compared to their healthy counterparts; this causes abnormality in selective motor control and smooth execution of the movements. It is hypothesized that with the application of whole-body vibration therapy in different positions we can improve the afferent information coming to the CNS that can lead to improved motor control.

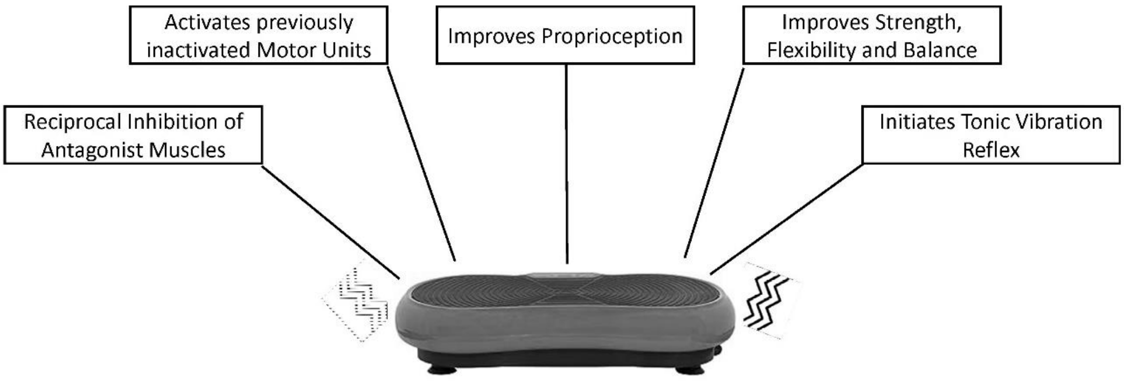
EFFECTS OF INTERVENTION

There are more than one hundred therapeutic interventions reported in the literature for the management of cerebral palsy and whole-body vibration therapy (WBVT) is one of these interventions.

The WBVT device has three parameters that could be varied alone or all together during interventions as follows; one is frequency which refers to the cycles per second and is represented in Hertz, the second is amplitude which refers to the total displacement measured in millimeters, the third one is direction which can be horizontal or vertical. The intensity is controlled by the frequency and amplitude of the platform (10).

The above-mentioned parameters in WBVT can be used for the activation of various receptors in weight-bearing and also in non-weight-bearing positions. As we know, WBVT produces vibration of the whole body (34) and therefore, causes adaptive responses to vibration throughout the body in different tissues (35). As mentioned earlier, it is reported that WBVT causes tonic vibration reflex mainly via muscle spindle signaling and results in alpha motor neuron excitation (13). It also causes reflex muscle contraction due to stretched muscles (36, 37).

The WBVT has been shown to reduce spasticity and improve range of motion and gross motor function in cerebral palsy children (38).



Therapeutic Effects of Whole-Body Vibration

EVALUATION OF HYPOTHESIS

There is non-progressive brain disturbance in cerebral palsy, the upper motor neuron lesion causes some changes in terms of hypertonicity and or hypotonicity, weak muscles, poor balance, and postural control. All of these lead to changes in the musculoskeletal system causing contractures, which further limit motor function (39). It has been reported that structural and functional changes in the brain can be brought about by the performance of physical exercises. In doing exercises, overall health benefits are not just limited to improvement in strength, flexibility, and balance. Studies done on mice have reported that WBVT

Journal of Health and Rehabilitation Research 2791-156X JHRR

causes neural plasticity, neurogenesis, and changes in the transmission across neurotransmitter systems (40). Vibration is a mechanical stimulus that has been used for neuromodulation in various neurological conditions. It can be applied to the muscle belly, tendon, or whole body by standing on the vibrating platform. Whole-body vibration therapy stimulates the loading response of the musculoskeletal system and sensory receptors (15). The WBVT activates the inputs from Ia fibers and reciprocally inhibits the antagonistic muscles at various rates based on the tasks. This tonic vibration reflex is mediated by monosynaptic and polysynaptic neuronal pathways. Normalized muscle tone achieved through this leads to an increase in muscle length and strength thus improving gait (41).

The WBVT also stimulates mechanoreceptors and induces neural plasticity through somatosensory and motor pathways. It also enhances the neural drive to the muscle and leads to the activation of previously inactive motor units which is responsible for increased muscle strength and mass (42). Some strong pieces of evidence have been reported in various scientific publications that WBVT stimulates proprioception, modulates muscle tonicity (reduces spasticity), and improves motor control during ambulation in stroke, spinal cord injury, and Parkinsonism patients (28, 43). It has been established that the neural control of rhythmic movements is different from non-rhythmic movements. According to a study leg cycling suppresses H-reflex and stretch reflexes, it also causes plasticity of inhibitory neuronal circuits in spastic diplegic cerebral palsy patients (24). Mechanical skin stimulation of the sole of the foot affects the excitability of the same and contralateral motoneurons (44) Our skins have mechanoreceptors that are very sensitive to vibratory stimuli. These receptors include Pacinian and Meissner corpuscle which are rapidly adapting, whereas the Ruffini and Merkel discs are slowly adapting and can contribute to the motoneurons modulation (45).

A study suggested that both slow and fast adapting fibers are stimulated by mechanical vibration, it is important to remember that the sense of pressure and touch are masked during WBVT therapy, and some cutaneous mechanoreceptor afferents seem to be aroused for many minutes even when the therapy has been stopped. Another study reported that WBVT is very effective to improve proprioceptive and tactile sense in spastic cerebral palsy children (46).

Based on the results of studies conducted on the muscle-tendon unit it has been shown that vibration is a strong proprioceptive stimulus that reaches both primary somatosensory and motor cortices directly, and different frequencies have a different effect on the firing rate of Ia afferents and also group II that can be observed in differential frequency-dependent effects in the excitability of the motor neurons in the corticospinal tract (47). Vibrotactile stimulus enhances physiological changes in the brain and its enhancement causes rapid activation of the contralateral sensorimotor areas of the brain and stronger cortical lateralization while leading to a richer causal brain network. It also causes the repair and development of cortical neural pathways (48). Neurophysiological observations suggest that balance and proprioception can be improved with training that incorporates tactile, vibratory, proprioceptive, and vestibular stimulation concurrently (49).

Consequently, we hypothesize that there may be changes or improvements in the gross motor function of the lower limb through inter-limb coordination or propriospinal tracts by applying WBVT to the upper limb or vice versa. Furthermore, it is also hypothesized, that by applying WBVT to both upper and lower limbs simultaneously, there will be pronounced effects due to the summation of vibratory and proprioceptive inputs to the brain.

DISCUSSION AND CONSEQUENCES OF THE HYPOTHESIS

We hypothesize that WBVT of both the upper limb and lower limb in weight-bearing and non-weight-bearing positions will have appropriate effects on balance and function in CP children. If the designated hypothesis is verified, perhaps it can be of significant importance for CP children. Previous studies have demonstrated that in routine clinical settings, WBVT intervention protocol is safe, feasible, and conventional for both children and adults CP (50). It is also reported that WBVT should be used as an alternate treatment protocol with conventional treatment methods in children with CP. WBVT improves standing and gait speed in children with CP (11). Another study reported that a 12-week intervention of WBVT can improve the strength of knee extensors and also decrease spasticity with positive effects on motor development as well as walking speed in Diplegic CP children (51). A systematic review on Whole body vibration suggested that it can be used as a low-cost, low risk and valuable treatment method that could be used in clinical settings or at homes (52). An RCT study reported that WBVT is a valuable tool for improving balance and strength in children with CP (53). Because WBVT has a constant connection in the entire human body and multi-sensorimotor training affects the wide series of sensory and mechanoreceptors that use vibration, tactile, proprioception, and vestibular senses which improves balance and proprioception.

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Journal of Health and Rehabilitation Research 2791-156X JHRR

CONCLUSION:

Previous studies and clinical applications of WBVT have reported the immediate and long-lasting effects on gait, walking speed, standing function, spasticity, flexibility, strength, proprioception, and range of motion. However, these effects only have been measured on the lower extremity's function in a weight-bearing position. Hence, a standardized and quantitative measurement for the effect of WBVT applied to the lower extremity and its effect on upper extremities and vice-versa on balance and function remains unclear in patients with CP. In the scientific literature, there is an effect of training of the lower extremity on the upper extremities as well, which is known as cross-training effects. To the best of our knowledge, there is no evidence available that examined these effects in the cerebral palsy population. Subsequently, these pieces of evidence encouraged us to propose a study that will shed light on the effectiveness of the application of WBVT in various configurations of weight and non-weight bearing positions of upper and lower extremities and the possible positive effects of summation of upper and lower extremities on the adverse effects on CP children.

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