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Acute Effect of Whole-Body Vibration on Motor and Cognitive Function in Children with Down Syndrome: A Series of Case Studies

Diego Ferreira

ACCEPTANCE

This dissertation, ACUTE EFFECT OF WHOLE-BODY VIBRATION ON MOTOR AND COGNITIVE FUNCTION IN CHILDREN WITH DOWN SYNDROME: A SERIES OF CASE STUDIES, by DIEGO FERREIRA, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree, Doctor of Philosophy, in the College of Education & Human Development, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chairperson, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty.

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2) **Ferreira D**, Liang H, Wu J (2020). Knee joint kinematics of the pendulum test in children with and without Down syndrome. Gait and Posture. 76, 311-317. https://doi.org/10.1016/j.gaitpost.2019.12.025

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1) Henderson G, **Ferreira D**, Wu J. The effects of direction and speed on treadmill walking in typically developing children. Gait and Posture. 1st Revision.

2) Beerse M, **Ferreira D**, Wu J. Muscle activation pattern during two-legged hopping in children with and without Down syndrome. Journal of Motor Behavior. In Review.

3) **Ferreira D**, Liang H, Wu J. Effect of body position and external load on knee joint kinematics during the pendulum test in adults. Gait and Posture. In Review.

B. Manuscripts in Progress

1) **Ferreira D**, Zeid R, Daniell J, Wu J. The Effect of Ankle Vibration on Vibration Perception Threshold and Peak Muscle Torque. Journal of Electromyography and Kinesiology. Anticipated submission in August 2020.

ACUTE EFFECT OF WHOLE-BODY VIBRATION ON MOTOR AND COGNITIVE FUNCTION IN CHILDREN WITH DOWN SYNDROME: A SERIES OF CASE STUDIES

by

DIEGO FERREIRA

Under the direction of Dr. Jerry Wu

ABSTRACT

Children with Down syndrome (DS) typically present delays in motor and cognitive development compared to typically developing (TD) children. This may be due to low muscle tone, greater joint laxity and lower joint moment and power generation at the ankle and knee. Currently, there are few effective interventions to improve joint biomechanics of motor tasks and cognitive function for children with DS. Recent studies have shown some evidence that whole-body vibration (WBV) may improve muscle strength, bone growth, and balance control in adolescents and adults with DS. There have also been some studies that show WBV can improve cognitive function in TD children, healthy adults, and even in adults with attention deficit hyperactivity disorder. However, little is not known on the effect of WBV on both motor and cognitive function in children with DS.

This study aims to investigate the acute effects of a single session of WBV on joint biomechanics and cognitive function in children with DS. Five subjects completed one cognitive task (the Flanker test), and two motor tasks (stair ascent, and timed up-and-go) at 3 time points (baseline, pre-WBV, and post-WBV). One session of 10 bouts of 30-second vibration (25 Hz, 2 mm) with 1 minute of rest was administered. Subjects demonstrated qualitative and quantitative improvements following the session of vibration in the motor and cognitive tasks. These preliminary results suggest that WBV could be used as a therapy modality to elicit acute benefits in the motor and cognitive domains in children with DS. Further investigation into the lasting of effects of WBV is warranted.

INDEX WORDS: whole-body vibration, children, attention, inhibition, motor performance, Down syndrome

ACUTE EFFECT OF WHOLE-BODY VIBRATION ON MOTOR AND COGNITIVE FUNCTION IN CHILDREN WITH DOWN SYNDROME: A SERIES OF CASE STUDIES

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Diego Ferreira

A Dissertation

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DEDICATION

To my parents, Raul and Mariela, who left their friends, family and life behind to give my brothers and I a better life. Who made sacrifices to ensure that I could pursue my dreams.

To my brothers, Rodrigo and Matias, who inspired me to always give my best.

To the rest of my friends and family who encouraged me and supported me throughout my life.

Thank you.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBRIVIATIONS

ADHD	Attention deficit hyperactivity disorder
AP	Anterior-posterior
ASIS	Anterior superior iliac spine
BF	Biceps femoris
BMI	Body mass index
CA	Chronological age
CMJ	Counter-movement jump
DS	Down syndrome
EMG	Electromyography
FPA	Foot progression angle
FRA	Foot rotation angle
GRF	Ground reaction forces
Hz	Hertz
ID	Intellectual disability
kg	Kilogram
LG	Lateral gastrocnemius
m	Meters
MA	Mental age
ML	Medial-lateral
mm	Millimeters
NIH	National Institute of Health
OG	Over ground

PA	Physical activity
PSIS	Posterior superior iliac spine
RI	Relaxation Index
ROM	Range of motion
SA	Stair ascent
StS	Sit-to-stand
TA	Tibialis anterior
TUG	Timed up-and-go
TD	Typically developing
VL	Vastus lateralis
WO	Walk-out
WBV	Whole-body vibration

1. LITERATURE REIVEW OF ACUTE EFFECT OF WHOLE-BODY VIBRATION ON MOTOR AND COGNITIVE FUNCTION IN CHILDREN WITH DOWN SYNDROME: CASE STUDIES

Guiding questions

1. What is the degree of motor and cognitive impairments that children with Down syndrome (DS) have?
2. Does whole-body vibration (WBV) provide enhancements to motor and cognitive function in populations other than DS?
3. What have previous studies using WBV on individuals with DS found?
4. What are the underlying mechanisms of WBV in individuals with DS?
    - A. What are the mechanisms that underpin motor function improvement?
    - B. What are the mechanisms that underpin cognitive function improvement?

Literature review

Overview and clinical presentation of Down syndrome

Due to improvements in healthcare and treatment of congenital heart problems, the life expectancy of those with DS has grown significantly from 5 years in 1970s to over 60 years nowadays (Carfi et al., 2014). Despite this, there are still several cognitive, motor, and health issues that individuals with DS experience throughout their life. Several of the health issues that individuals with DS develop are due to hypothyroidism, decreased basal metabolic rate and increased leptin levels (Murray & Ryan-Krause, 2010) as well as sedentary behavior (Pitetti, Rimmer, & Fernhal, 1993). Children and adolescents with DS demonstrate lower levels of physical activity (PA) compared to TD groups, and decreases as they age (Ketcheson, Pitchford, Kwon, & Ulrich, 2017; Pitetti, Baynard, & Agiovlasitis, 2013). Children with DS are also more likely to be overweight or obese compared to TD children (Bertapelli, Pitetti, Agiovlasitis, & Guerra-Junior, 2016; Foerste, Sabin, Reid, & Reddihough, 2016). A study found that children with DS were less likely to participate in PA due to characteristics that are typically associated with DS, competing family responsibilities, reduced physical or behavioral skill and a lack of accessible programs for those with DS (Barr & Shields, 2011). Those characteristics that are typically associated with DS included: hypotonia, weak muscle strength, risk for obesity, congenital heart defects, and cognitive and communication impairments.

This reduced PA pattern in DS is concerning due to the health status in this population. Individuals with DS typically show a higher rate of obesity, a lower level of lean mass, reduced bone mass, reduced strength, and lower levels of cardiovascular capacity (Gonzalez-Aguero et al., 2010). Regular PA has been shown to have psychological and physical benefits, which could be beneficial to individuals with DS (Pitetti et al., 2013). However, there are other factors that limit their ability to engage in PA. Individuals with DS typically demonstrate increased levels of joint laxity (Livingstone & Hirst, 1986) and decreased muscle strength (Cioni et al., 1994; Croce, Pitetti, Horvat, & Miller, 1996) along with the hypotonia (Dey et al., 2013; Morris, Vaughan, & Vaccaro, 1982) which contribute to the reduced ability to engage in PA.

Motor development in children with DS is delayed in the acquisition and shows poorer quality of activities such as standing, walking, ascending stairs, and jumping compared to TD children (Malak, Kostiukow, Krawczyk-Wasielewska, Mojs, & Samborski, 2015; Palisano et al., 2001). These delays occur early in infancy (about 3 months of age) and continue throughout childhood. Compared to TD infants, infants with DS learn to sit independently at an average age of 14 months compared to 6 months, crawl between 12-18 months compared to 8 months, and walk between 24-74 months compared 10-15 months (Fox, Farrell, & Davis, 2004; Malak, Kotwicka, Krawczyk-Wasielewska, Mojs, & Samborski, 2013; Palisano et al., 2001). Along with these delays, there are alterations in motor skills due hypotonia, increased joint laxity, and alterations in reflexes (Ferreira-Vasques & Lamonica, 2015).

Children with DS also demonstrate reduced performance compared to TD children in simple tasks such as standing from a seated position. Beerse, Lelko, and Wu (2019) performed a study evaluating the difference in performance in the timed up-and-go (TUG) test between children and children with DS. The TUG test is composed of different motor tasks including standing from a seated position, walking to a target, turning around, walking back, and finally sitting back down. The results of this study showed that children with DS took a significantly longer time to complete each of the phases, resulting in a longer time to complete the test. During the sit-to-stand portion of the TUG test, children with DS demonstrated slower peak knee and hip extension velocities, which suggest that power generation in children with DS is reduced compared to TD children (Beerse, Lelko, et al., 2019).

During walking, children with DS demonstrate compensatory strategies in order to increase stability at the expense of energy cost (Rigoldi, Galli, & Albertini, 2011). Compared to TD children, children with DS demonstrate lower levels of joint power generation (Cionim, Cocilovo, Rossi, Paci, & Valle, 2001; Galli, Rigoldi, Brunner, Virji-Babul, & Giorgio, 2008; Rigoldi et al., 2011) as well as shorter and wider steps (Rigoldi et al., 2011; B. A. Smith, Stergiou, & Ulrich, 2011; Ulrich, Haehl, Buzzi, Kubo, & Holt, 2004). Children with DS also walk with increased hip flexion throughout gait, as well as increased plantarflexion at initial contact (Beerse, Henderson, Liang, Ajisafe, & Wu, 2019; Galli et al., 2008; Wu & Ajisafe, 2014; Wu, Beerse, Ajisafe, & Liang, 2014).

Children with DS make compensatory strategies when performing tasks such as ascending stairs. Liang et al. (2018a and 2018b) conducted a study investigating the transition between a level surface and stairs with different riser heights in DS and TD children. They found that children with DS used a more conservative approach to ascend the stairs than TD children. The DS children would change from a walking strategy to a crawling strategy as the riser height of the stair increased, while the TD maintained the walking strategy. These strategies could likely be due to the diminished ability to generate joint power in those with DS. Also, the children with DS demonstrated a higher toe clearance and a slower horizontal toe velocity than the TD children, as well as taking shorter and slower steps as they approached the staircase.

Along with the delays in motor development, children with DS demonstrate delays in cognitive development compared to TD children (Campbell et al., 2013; Edgin, 2013) and typically expend additional cognitive effort to achieve similar performances to those of TD children (Angulo-Chavira, Garcia, & Arias-Trejo, 2017). These cognitive delays lead to deficiencies in several areas including attention (Atkinson & Braddick, 2012; Brown et al., 2003; Cornish, Munir, & Cross, 2001; Edgin, 2013; Trezise, Gray, & Sheppard, 2008). Lanfranchi, Jerman, Dal Pont, Alberti, and Vianello (2010) found that adolescents with DS had reduced levels of working memory, inhibition, and attention shifting than their TD counterparts. Working memory is a set of processes that allow for mental representations to be temporarily accessible when conducting motor and cognitive activities (Baddeley, 2010; Cowan, 2017; Diamond, 2013; Miyake & Shah, 1999; Oberauer et al., 2018). Inhibitory control is the suppression of distractors and remain focused (Chen, Ringenbach, Crews, Kulinna, & Amazeen, 2015; Diamond, 2013).

Sustained attention is the period when an individual is engaged with processing a stimulus (Brown et al., 2003). Selective attention requires focus on a given stimulus or task and ignoring surrounding stimuli (Diamond, 2013).

One of the areas of concerns that are related to learning and education are those that require attention (Trezise et al., 2008). A study by Brown et al. (2003) found that children with DS aged between 24 and 37 months of age had fewer periods of sustained attention and shorter durations of sustained attention compared to CA matched and mental age (MA) matched children. In this study, infants with DS were recorded while they sat in a fixed position as stimuli, in this case toys, were introduced for 45 seconds (Brown et al., 2003). The amount of time they spent focused on the toy and the number of times they were focused on toy for longer than two seconds was recorded. Munir, Cornish, and Wilding (2000) also found that children with DS aged between 7 and 15 years old had significantly more errors during their attention task than the CA and MA matched groups. In this study, selective attention, divided attention and sustained attention were measured using the Visearch task from the Wilding Attention Test for Children (WATT). In the selective attention task, subjects were presented with a picture of a forest with trees and other shapes on a computer screen. Each subject was required to search for a particular shape or object in the image. In the divided attention task, subjects had to search for two different types of shapes alternatively while other shapes served as a distraction. In the sustained attention task, subjects were required to watch the screen until a stimulus appeared, in this case a monster, and click on the monster before it disappeared until the protocol was finished.

Kittler, Krinsky-McHale, and Devenny (2006) found that adults with DS produced intrusion errors during the Word List recall than other adults with unspecified ID. During this task, two-word sequences are introduced and progressively increase by one word every three trials. These results indicate a compromised control of inhibition in the DS group. Palomino, Lopez-Frutos, and Sotillo (2019) found that adults with DS performed worse on cognitive inhibition over memory during a working memory task than a neurotypical developing group. During this task, they needed to solve an interference problem during the maintenance phase. These results indicate that the DS population may have issues with maintaining the information to be remembered.

Benefits of WBV on motor and cognitive performance

WBV has become a common tool for therapy purposes. WBV has been used to elicit improvements in muscle strength, balance, and body composition. WBV has been used across multiple populations including healthy young adults, athletes, elderly population, and other clinical populations such as cerebral palsy. Schlee, Reckmann, and Milani (2012) found that a single four-minute session of WBV improved balance control in healthy young adults compared to a group that did not receive WBV. Wallmann et al. (2019) found significant acute benefits in vertical jump height, agility, balance, and power in a group of healthy adults after receiving sixty seconds of WBV. Dallas, Mavvidis, Kirialanis, and Papouliakos (2017) also found that an eight-week WBV intervention improved balance and lower limb strength in young physical education students. Bruyere et al. (2005) also found that a six-week WBV therapy intervention significantly improved balance in nursing home residents compared to a group that did not receive WBV. B. Lee and Chon (2013) found that an eight-week WBV training intervention significantly improved gait speed, stride length, and increase in peak ankle angle in children with cerebral palsy.

WBV has been used to elicit improvements in cognitive function in healthy children, healthy adults, and adults with attention deficit hyperactivity disorder. Regterschot et al. (2014) found that two minutes of WBV had a significant acute improvement in attention and inhibition in a group of healthy young adults compared to a group of healthy young adults that did not receive WBV. Using the Color-Word Interference Test, the group that received WBV had significantly reduced times to complete the Color-Word Test compared to the group that did not receive WBV. This result is significant due to the fact this population already demonstrates high levels of cognitive function compared to those with ID. den Heijer et al. (2015) also found significant acute improvements in inhibition in a group of healthy children aged 8-13 that received WBV compared to the group that did not receive WBV. Using the Stroop Color-Word Interference Test, the group that received vibration demonstrated a significant reduction in the completion time (seconds) of the Color-Word Test compared to the group that did not receive vibration. Fuermaier, Tucha, Koerts, van Heuvelen, et al. (2014) found that two minutes of WBV had significant acute benefits on attention and inhibition for a healthy adult group, as well as a group of adults with ADHD. This study used a series of tests to measure cognitive function, including the Stroop Color-Word Interference Test. The ADHD group that received WBV saw improvements in the time to complete the Color-Word Test compared to the ADHD group that did not receive WBV. These results are also significant because it suggests that individuals with deficiencies in attention and inhibition, such as those with DS, may receive cognitive benefits from a single session of WBV as well. Edvardson et al. (2014) surveyed adults and children with DS previously undiagnosed ADHD and found that there is a relatively high prevalence of ADHD symptomatology in those surveyed. Ekstein, Glick, Weill, Kay, and Berger (2011) found that

44% of the children in their study, aged 5 to 16, met the criteria for ADHD according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR).

WBV in individuals with Down syndrome

The use of WBV has become a popular therapy intervention in those with disabilities. However, the literature on WBV studies in children, adolescents, and even adults with DS is very limited. There have been some studies that have used WBV interventions as a means to improve body composition. Gonzalez-Aguero, Matute-Llorente, Gomez-Cabello, Casajus, and Vicente-Rodriguez (2013) used a 20-week WBV intervention to determine if WBV training could be used to decrease fat mass and increase lean mass in adolescents with DS aged 12-18 years old. This group did not find significant differences in fat mass and lean mass after the 20-week WBV intervention compared to before the intervention. They did find a tendency of improvement in these areas after the intervention compared to the control group who did not receive WBV. Emara (2016) used a 6-month WBV training intervention similar to Gonzalez-Aguero et al., however found that WBV was not sufficient to elicit changes in body composition except for fat mass compared to the control group. Matute-Llorente et al. (2015&16) on two occasions used a 20-week WBV training intervention to determine if WBV could be used to increase bone mass, density and improve quality of the bone in adolescents with DS aged 12-18 years old. Both studies found significantly greater improvements in bone mineral content and bone mineral density in the WBV training group in several areas of the body compared to the control group who did not receive WBV. Mohamed, Sherief, and Aboelazm (2015) used a 3-month WBV intervention to evaluate bone mineral density and found that bone mineral density increased following the intervention in children with DS aged 6-8 years old. Ibrahim and Abdullah (2015) also used a 3-month WBV intervention to evaluate bone mineral density and also found significant increases in bone mineral density following the intervention in children with DS aged 8-11 years old.

Muscle strength and balance following WBV training has also been researched in children with DS. Eid (2015) used a 24-week WBV training intervention in children aged 8-10 years old and found that WBV combined with physical therapy had greater improvements in muscle strength and balance compared to the group that only received physical therapy. Villarroya, Gonzalez-Aguero, Moros, Gomez-Trullen, and Casajus (2013) used a 20-week WBV training intervention in adolescents and young adults aged 11-20 years old and also found significant improvements in balance compared to the group that only received physical therapy. Mohamed et al. (2015) also measured functional performance of a 6-minute walk test following their WBV intervention and found statistically significant improvements in the distance (meters) in the DS group following the intervention.

Most of these studies followed similar protocols for their interventions with the exception of Mohamed et al. All the studies required 3 sessions of WBV training per week. With the exception of Ibrahim and Abdullah (2015) and (Mohamed et al., 2015), the other studies began with 25 Hz as the frequency and gradually increased to 30 Hz as the intervention length increased. All the studies began with 2 mm as the amplitude of the vibration and increased amplitude as the intervention progressed. There were some notable differences between these studies as well. For example, Eid (2015), Emara (2016), Ibrahim and Abdullah (2015), and (Mohamed et al., 2015) used side-alternating platforms, with their subjects in a standing posture as the therapist blocked the knees of the subjects. Gonzalez-Aguero et al. (2013), Matute-Llorente et al. (2015), and Villarroya et al. (2013) used synchronous platforms, with their subjects in a squatted position so that the knees were flexed about 30-degrees as the therapist supervised the session. The interventions also differed in length (weeks), lasting between 12 and 24 weeks. These studies varied in duration of vibration, ranging from 30 seconds to 3 minutes per repetition, as well as the number of repetitions, ranging from 5 to 10 repetitions, resulting in differences between total vibration time. This was also true within studies, as Eid (2015), Emara (2016), Gonzalez-Aguero et al. (2013), Matute-Llorente et al. (2015), Villarroya et al. (2013) progressed from shorter intervals of vibration to longer intervals of vibration in as the vibration interventions progressed in duration.

Neuroanatomy of executive functions

Executive functions are a group of top-down mental processes that are used when there is a need to concentrate and pay attention (Diamond, 2013). Using executive functions require effort and are essential skills for mental and physical health, school and life success and cognitive, social, and psychological development (Diamond, 2013). It is suggested that executive functions incorporate high-level brain processes that include working memory, attention and inhibition that support goal-directed behavior (Jurado & Rosselli, 2007). Working memory is a set of processes that allow for mental representations to be temporarily accessible when conducting motor and cognitive activities (Baddeley, 2010; Cowan, 2017; Miyake & Shah, 1999; Oberauer et al., 2018). Inhibitory control is the suppression of distractors and remain focused (Chen et al., 2015; Diamond, 2013). Attention, or interference control at the level of perception, allows focus on what we choose to selectively attend to and suppress focus to other stimuli (Diamond, 2013). Children and adolescents depend on working memory, attention, and inhibitory control to develop behavioral and emotional control, as well as cognitive functions (Zelazo, Craik, & Booth, 2004).

Many of the neuroimaging studies used to identify the regions where executive functions are stored are based on Baddeley's model of working memory (described below) (E. E. Smith & Jonides, 1999). Most researchers agree that executive functions are mediated by the prefrontal cortex and help regulate the contents of working memory (Miller & Cohen, 2001; E. E. Smith & Jonides, 1999). By 6 months of age, infants with DS demonstrate differences in major structural indices such as brain size, shape, lobular proportions and neurotransmitter development (Edgin, Mason, Spano, Fernandez, & Nadel, 2012; Schmidt-Sidor, Wisniewski, Shepard, & Sersen, 1990; Wisniewski & Kida, 1994). There is evidence that there is foreshortening of the frontal lobes, narrowing of the superior temporal gyrus and the size of the cerebellum and brainstem is diminished in infants with DS (Crome, Cowie, & Slater, 1966; Greenfield, Blackwood, & Corsellis, 1976; Minckler, 1968). There is also evidence magnetic resonance imaging studies that there are structural differences in the medial temporal lobes, prefrontal cortex and cerebellum between individuals with DS and TD counterparts in the latter parts of development and adulthood (Edgin et al., 2012; Menghini, Costanzo, & Vicari, 2011; L. Nadel, 2003). Children and adults with DS also have been shown to have reduced grey matter density in the hippocampus (Menghini et al., 2011).

Research previously conducted in non-human primates found that when monkeys engaged in spatial-storage tasks, "spatial memory" cells in the dorsolateral prefrontal cortex, including Brodmann areas 46 and 9 were found. When the monkeys engaged in object-storage tasks, "object memory" cells were found in a more ventral region of the prefrontal cortex (E. E. Smith & Jonides, 1999). There is neuroimaging evidence that also supports a difference in spatial and object working memory in humans (Faillenot, Sakata, Costes, Decety, & Jeannerod, 1997; Owen, Evans, & Petrides, 1996). In humans, the object task activated regions in the right dorsolateral prefrontal cortex, while the spatial task activated a region in the premotor cortex (Faillenot et al., 1997; Owen et al., 1996; E. E. Smith & Jonides, 1999). A recently published study by Xu et al. (2020) investigated the brain activity difference in the motor and prefrontal cortex in children with DS and TD children using functional near-infared spectroscopy (fNIRS) during a fine motor task. The tasks was called “Catch the Hamster”, played on computer, where participants needed to press one of four keys on a keyboard using separate fingers on their right hand as fast as possible to indicate the correct hole where the hamster appeared. The children with DS demonstrated significantly lower accuracy and significantly higher response times than the TD children. The children with DS also demonstrated significantly lower brain activation in the dorsolateral prefrontal cortex and primary motor cortex compared to the TD children. The authors suggest that the impaired ability to activate this region was partially responsible for the lower performance in the children with DS. The authors also determined that the altered brain functional connectivity resulted in deficits in the motor and executive functions.

WBV Mechanisms

While the exact mechanisms of whole-body vibration (WBV) is not well understood (Cochrane et al., 2008), WBV has become a common tool for therapy purposes. One theory for the improvements is due to the activation of the alpha-motor neurons through muscle spindle activation (Cardinale & Bosco, 2003; Pollock, Provan, Martin, & Newham, 2011). There is also typically an increased muscle activity while the vibration is being administered to the muscle, compared to the muscle activity during voluntary muscular activation (Cardinale & Bosco, 2003). Vibration induces effects similar to hypergravity due to the high accelerations administered to the muscles, causing fast, short changes in the length of the muscle-tendon complex. The vibrations are detected by the sensory receptors that are responsible for modulating muscle stiffness, through reflex muscular activity, which attempt to dampen the vibration waves (Cardinale & Bosco, 2003). Additionally, these cutaneous receptors transmit the afferent signal to the primary somatic sensory cortex (Martin, 2012), which has a direct and indirect connection to the prefrontal cortex (Braak, Braak, Yilmazer, & Bohl, 1996), a region strongly involved in cognitive processing (Kolb & Whishaw, 1990; E. E. Smith & Jonides, 1999). Therefore, the vibration stimulus could influence neurotransmission in different regions of the brain, including the prefrontal cortex, hippocampus, amygdala, sensory regions, and other areas of the brain, which may help enhance certain cognitive functions (Regterschot et al., 2014).

Model of working memory

The theoretical model defined by Baddeley, is defined in cognitive psychology as the system or mechanism underlying the maintenance of task-relevant information while an individual is performing any cognitive task (Baddeley & Hitch, 1974). The system is separated into subcomponents (Baddeley & Hitch, 1994). The components include the phonological loop, the visuospatial sketchpad, the central executive, (Baddeley, 2000; Baddeley & Hitch, 1994) and the episodic buffer (Baddeley, 2000) as show below (Figure 1).

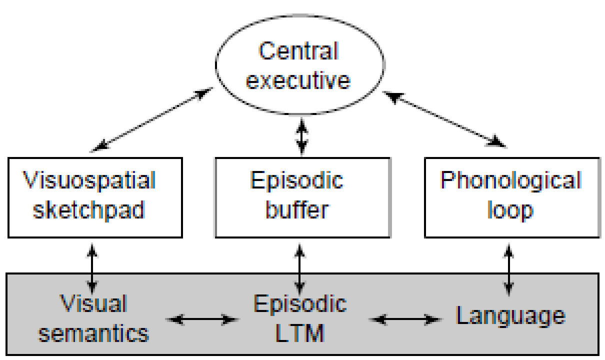

Figure.1 Working memory model by Baddeley (2000)

This updated model builds on a previous model by Baddeley and Hitch that did not include the episodic buffer. The central executive is less understood, but is strongly associated with the frontal lobes of the brain (Baddeley, 1996, 2000; Baddeley & Hitch, 1994). The central executive can also influence the stored content by attending to a given source of information, whether it is perceptual from other components of working memory or long-term memory (Baddeley, 2000). The phonological loop is the most studied aspect of working memory. It involves a phonological or acoustic store where memory traces fade after about 2 seconds unless it is rehearsed (Baddeley, 2000; Baddeley & Hitch, 1994). The visuospatial sketchpad is where visuospatial information, separated into spatial, visual, and maybe kinaesthetic components (Baddeley, 2000; Baddeley & Hitch, 1994). The visuospatial sketchpad is thought to reside in the right hemisphere of the brain (Baddeley, 2000). Lastly, the episodic buffer is the potential storage system that is capable of integrating information from variety of sources (Baddeley, 2000). The episodic buffer provides a temporary interface between the phonolongical loop and visuospatial sketchpad, and long-term memory (LTM) (Baddeley, 2000). The episodic buffer can be accessed by the central executive through conscious awareness when the task is less complex and does not require manipulation.

The working memory theory may help explain the decreased attention and inhibitory control of individuals with DS. Individuals with DS are typically associated with deficits in the phonological loop process (Baddeley & Jarrold, 2007). To date, there has not been any published study which has investigated the episodic buffer in the DS population. The evidence primarily comes from the study of the phonological loop. Information in the phonological loop decays within a few seconds (< 2 seconds), unless it is “refreshed” by rehearsal (Baddeley & Hitch, 1994). It is likely that individuals with DS do not engage in spontaneous rehearsal at all

(Baddeley& Jarrold 2007). This could be due to the intellecutal level of the individual with DS that results from delayed cognitive development. Research suggest that TD children may not be begin rehearsing until the age of 7 years (Henry, 1991). Children with DS may not develop this ability until much later and have reduced rehearsal abitlity than TD children when they develop this ability. Children with DS also have difficulties with speech production (Vicari, 2006). Ferreira-Vasques and Lamonica (2015) found that children with DS produce words roughly 16 months later than TD children. Visual, auditory, proprioceptive, and tactile information are important when learning motor skills (Magill, 1993; Maxwell, Masters, & Eves, 2003).

There are also some studies that suggest that individuals with DS have limitations in the central executive (Baddeley & Jarrold, 2007). Vicari, Carlesimo, and Caltagirone (1995) found that backwards digit and Corsi spans were impaired in children with DS. Research suggests that backwards recall is associated with greater involvement of executive function (Baddeley & Jarrold, 2007). Lanfranchi, Cornoldi, and Vianello (2004) used verbal and visuospatial working memory tasks that put various demands on executive processing in children with DS aged 7 to 16 years and MA-matched TD children. They found that when the executive load increased, children with DS performed poorer than the TD children. These studies suggest that the central executive has limitations in children with DS. The deficiencies in the phonological loop and central executive in individuals with DS could help explain the reduced performance in cognitive and motor tasks.

Studies have also shown the relationship between motor development on cognitive development. When children explore their environments they receive sensory information that allows for the acquisition of new cognitive and linguistic skills (Gibson, 1988; Gogate & Hollich, 2010; Oudgenoeg-Paz, Leseman, & Volman, 2015; L. Smith & Gasser, 2005). There have also been some studies that found evidence for a relationship between executive function and motor performance in TD populations. Wassenberg et al. (2005) found that there was a small positive relationship between cognitive performance and motor performance in a large-scale cross-sectional study with sample of over 300 5-6 year old children. Piek et al. (2004) found that gross and fine motor skills were significantly associated with attention and working memory. Hartman, Houwen, Scherder, and Visscher (2010) found that children with intellectual disabilities demonstrate problems with qualitative motor performance. These problems were especially seen executive function and object control skills. They also determined that deficits in motor performance and excutive performance are intertwined. Poorer motor control and performance results in worse executive function and poorer executive function results in worse motor control and performance. Schott and Holfelder (2015) found that there was a positive correlation between motor performance and executive function with medium to high effect sizes in school-aged children with DS. These results reveal the importance the use of early intervention that address the improvement in cognitive abilities and motor skills, preferably in combination (Schott & Holfelder, 2015).

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2. ACUTE EFFECT OF WHOLE-BODY VIBRATION ON MOTOR AND COGNITIVE FUNCTION IN CHILDREN WITH DOWN SYNDROME: A SERIES OF CASE STUDIES

Down syndrome (DS) is a genetic condition that occurs from an abnormal number of the 21st chromosomal pair in the genetic matrix in the cells of the body. DS is the most common intellectual disability (ID), with nearly 1 in 800 newborns affected in the United States each year (Health, 2019). Motor development is significantly delayed in children with DS compared to chronological age (CA)-matched typically developing (TD) children (Gómez Álvarez et al., 2018; Malak et al., 2015; Malak et al., 2013). The delays in motor development can be seen at an early age, including in the infancy period (Ferreira-Vasques & Lamonica, 2015; Yamauchi, Aoki, Koike, Hanzawa, & Hashimoto, 2019). For example, TD children develop the ability to sit without support by the age of 7 months and walk independently around 1 year old while DS children sit independently around the age of 15 months and walk by 30 months old (Fox et al., 2004). Along with the motor development delays, DS children demonstrate altered mechanics and reduced performance during motor tasks compared to TD children. For example, during stair ascent, children with DS took a more conservative approach to climbing up the stairs compared to walking up the stairs by TD children (Liang, Ke, & Wu, 2018a, 2018b). In addition, children with DS took wider and shorter steps during walking (Beerse, Henderson, et al., 2019; Rigoldi et al., 2011; B. A. Smith et al., 2011), and demonstrated reduced balance control during two-legged hopping in-place (Beerse & Wu, 2018) compared to TD children.

Children with DS also demonstrate delays in cognitive development (Edgin, 2013; Yamauchi et al., 2019) compared to TD children with the same CA. These delays are attributed to underdeveloped neural systems of the frontal cortex, medial temporal lobe and cerebellum of individuals with DS (Edgin, 2013; L Nadel, 1986), resulting in lower IQs that indicate moderate to severe ID (Edgin, 2013; Määttä, Tervo-Määttä, Taanila, Kaski, & Iivanainen, 2006). Individuals with DS also have other cognitive issues including maintaining attention (Atkinson & Braddick, 2012; Brown et al., 2003; Cornish et al., 2001; Edgin, 2013; Trezise et al., 2008) and inhibition (Chen et al., 2015; Ringenbach et al., 2016), and with difficulty performing tasks (Breckenridge, Braddick, Anker, Woodhouse, & Atkinson, 2013; Cornish et al., 2001; Cowley et al., 2010; Rihtman et al., 2010) that are directly influenced by the intellectual problems (Ferreira-Vasques & Lamonica, 2015). Attention has an important role in the development of visual cognition and impacts the ability to process visual stimuli (Brown et al., 2003) and therefore also impacts performance to complete a task. Due to the cascading effects of motor intervention on both motor and cognitive function in TD children (Iverson, 2010; Malak et al., 2013), it is important to understand to what extent motor intervention improves both motor and cognitive development in children with DS.

Whole-body vibration (WBV) has shown its potential to become an intervention paradigm for individuals with disabilities. One of the appeals of WBV, is the ease of use for this treatment. To administer WBV, an individual simply stands on a platform that oscillates at a frequency and amplitude that is either standardized to the device or modified based on the desire of the individual(s) administering the intervention. WBV has been used to elicit health benefits in cognitive and motor function. WBV has been shown to improve cognitive function in healthy children (den Heijer et al., 2015), healthy young adults (Regterschot et al., 2014), and adults with attention deficit hyperactivity disorder (Fuermaier, Tucha, Koerts, van den Bos, et al., 2014; Fuermaier, Tucha, Koerts, van Heuvelen, et al., 2014). In healthy populations, WBV has been shown to improve performance on motor tasks such as increasing maximal jump height (Perez-

Turpin et al., 2014; Wallmann et al., 2019), sit-to-stand performance (Ming-Chen et al., 2017), and balance control (Dallas et al., 2017; Schlee et al., 2012).

WBV has also been used to improve muscle strength (Bruyere et al., 2005; K. Lee, Lee, & Song, 2013; Park, Son, & Kwon, 2015; Stania et al., 2017), balance (Dallas et al., 2017; Schlee et al., 2012), power (Osawa, Oguma, & Ishii, 2013; Wallmann et al., 2019), and performance of motor tasks (Ebrahimi, Eftekhari, & Etemadifar, 2015; B. Lee & Chon, 2013; Perez-Turpin et al., 2014) in various populations.

While there is evidence that WBV can provide beneficial effects to cognitive and motor function in healthy and some clinical populations, the use of WBV in the DS population has been very limited. WBV has been used to elicit improvements in bone composition (Emara, 2016; Gonzalez-Aguero et al., 2013; Ibrahim & Abdullah, 2015; Matute-Llorente et al., 2015; Matute-Llorente et al., 2016; Mohamed et al., 2015), muscle strength and balance (Eid, 2015; Villarroya et al., 2013), and walking performance (Mohamed et al., 2015) in children and adolescents with DS. While these studies provide critical information to benefit this population, it is not known to what extent WBV alters joint biomechanics during motor tasks and whether it can improve cognitive function (particularly selective attention and inhibition control) in children with DS. It is important to determine if WBV can improve attention and inhibition in this population since they are critical in task completion and are diminished in this population.

Therefore, this study aims to investigate the acute effects of a single session of WBV on motor and cognitive function in children with DS aged 6 to 17 years old. The central hypothesis of this study is that there would be improvements in motor performance resulting from increased spatial-temporal parameters, peak joint extensor moment and power, and joint kinematics.

Additionally, there would be improvements in cognitive performance resulting from improved attention and inhibitory control while completing the cognitive tasks.

Methodology

Participants

Five (3F/2M) children with DS participated in this study. Inclusion criteria included a medical diagnosis of DS and between the ages 6 -17 years at the time of the data collection. Subjects were excluded if they had additional cardiovascular and musculoskeletal diseases, had any lower body injuries and experienced any seizures in the past six months, had uncorrected visual or hearing problems, or had any other medical problems that may have prevented them from participating in this study. This study was approved by the Georgia State University Institutional Review Board. Parental permission was obtained from the parent/legal guardians and verbal assent was obtained from the children before any data collection took place.

Protocol

This study was conducted at the Center for Movement and Rehabilitation Research at Georgia State University in Atlanta, Georgia. Subjects were invited to participate in the study on a single day of their choosing to complete the study. A flowchart of the protocol is provided below (Figure 2).

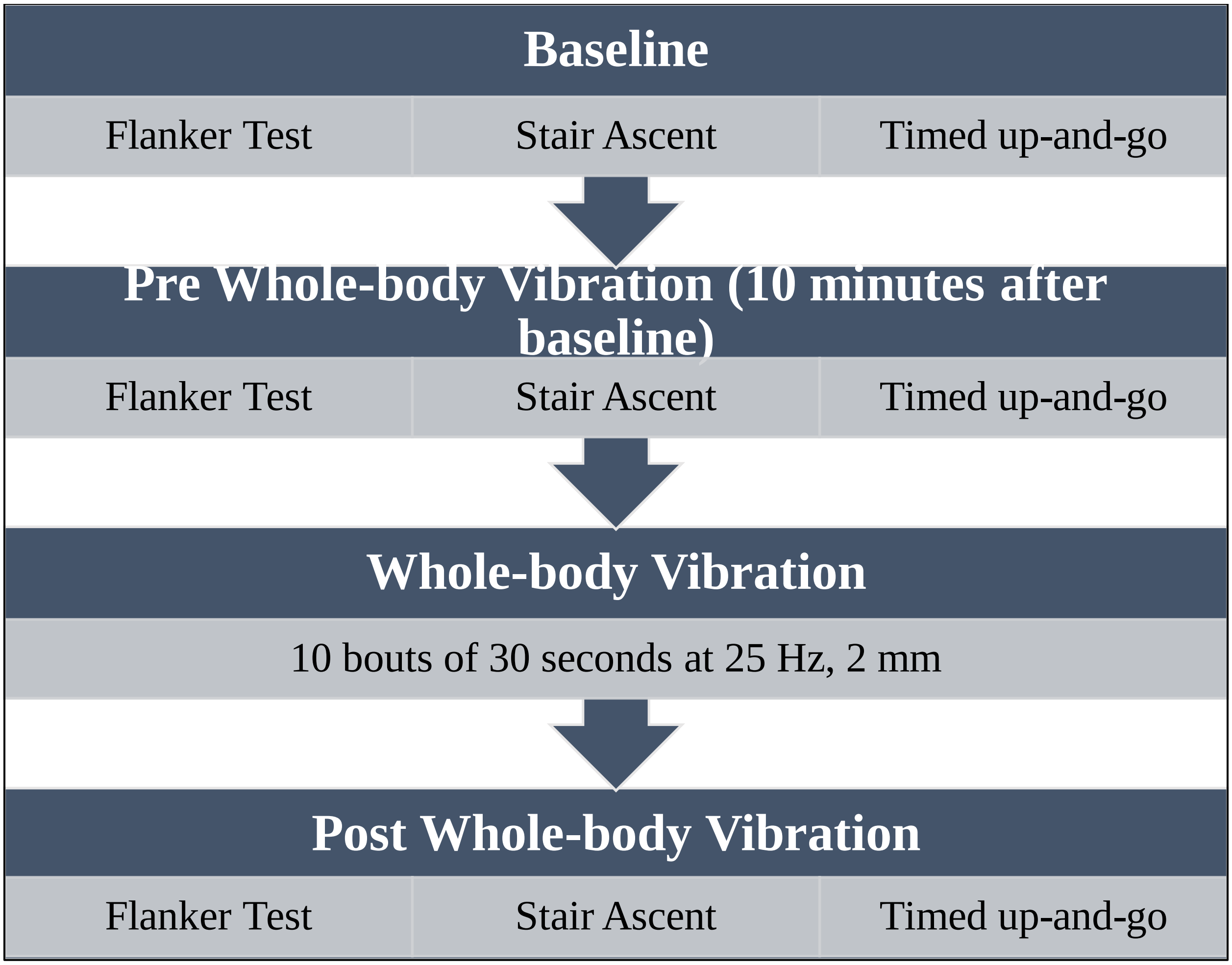


Figure 2: Flowchart of protocol

After parental permission and verbal assent was obtained, subjects were asked to complete the Flanker Inhibitory Control and Attention Test using the National Institutes of Health (NIH) Toolbox iPad App. This task measures inhibitory control and selective attention. For this study, subjects were asked to complete the Developmental Expansion version for ages 3 to 7. This version was chosen due to the unknown MA of the subjects. While MA was not measured for the subjects in this study, children with DS typically have a lower MA compared to TD children. In a study by Costanzo et al. (2013), when MA matched with TD children (CA 6.1-8.4 years of age), the CA of the DS group was between 8.6 and 21.2 years of age. Thus, this version was selected to ensure the subjects were able to complete this task (using fish). Additionally, this version allows for the subjects to complete the standard version of the Flanker Test (using arrows) if the subject obtains an accuracy score of 90% or greater from the Flanker test using fish. For the Flanker Test, the subject must focus on a particular stimulus while they inhibit attention to the other stimuli surrounding it. The subject must identify the direction of the arrow (or image of a fish) in the middle of an array that may show images in the same or opposite direction to the middle image (as shown below, Figure 3). The protocol includes 5 practice trials to ensure that subjects are able to complete the task after they receive a demonstration of how to complete the task. Subjects were required obtain at least 80% correct on the practice trials to proceed to protocol (Zelazo et al., 2013). These practice trials were not included in the analysis. Each subject was presented with 20 trials (12 congruent, 8 incongruent). Congruent trials were those where the flanking stimuli were in the same direction as the middle stimuli. Incongruent trials were those where the flanking stimuli were in the opposite direction of the middle stimuli. Every subject began with the developmental extension, where the stimuli were presented as fish. If the subject answered 90% correctly, they progressed to the test where the stimuli were arrows.

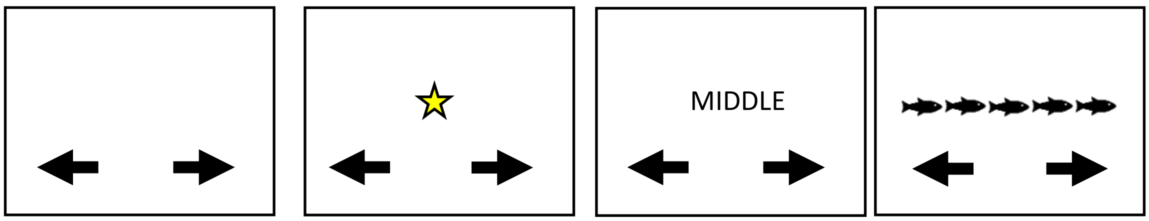


Figure 3: Visual illustration of Flanker Test with fish stimuli

Following the completion of the Flanker Test, the parent/legal guardian of the child with DS completed the Behavior Rating of Executive Function®, Second Edition (BRIEF® 2) (PAR, Lutz, FL, USA) (Appendix A) while the child had their height, body mass, and other anthropometric measurements taken. For the BRIEF-2, lower parent reported scores indicate higher performance in that construct. For example, a lower parent reported working memory score on the BRIEF-2 indicates better working memory. After the anthropometric measurements were taken, the subject then completed the Flanker Test following the same procedures as previously described. This second measurement occurred 10 minutes after the initial Flanker Test measurement. If there was time between the Flanker Test measurements, subjects had their skin marked to place the reflective markers as described below. If there was not sufficient time, subjects waited by sitting in a chair.

The subject then had their skin marked with an eyebrow pencil to identify the location for the placement of reflective markers using Vicon's lower body plug-in gait model. This model required placing 16 reflective markers at anatomical landmarks to recreate the model. Those placements included placing the markers bilaterally at: anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral aspect of the thigh in line with the hip and knee joint centers, lateral aspect of the knee on the flexion-extension axis of the knee, lateral aspect of the lower leg, the lateral malleolus, the calcaneus at the same height as the toe marker, and the second metatarsal head (Figure 4). The reflective markers were attached to the skin using double-sided tape. The markers on the foot were additionally secured using medical tape.

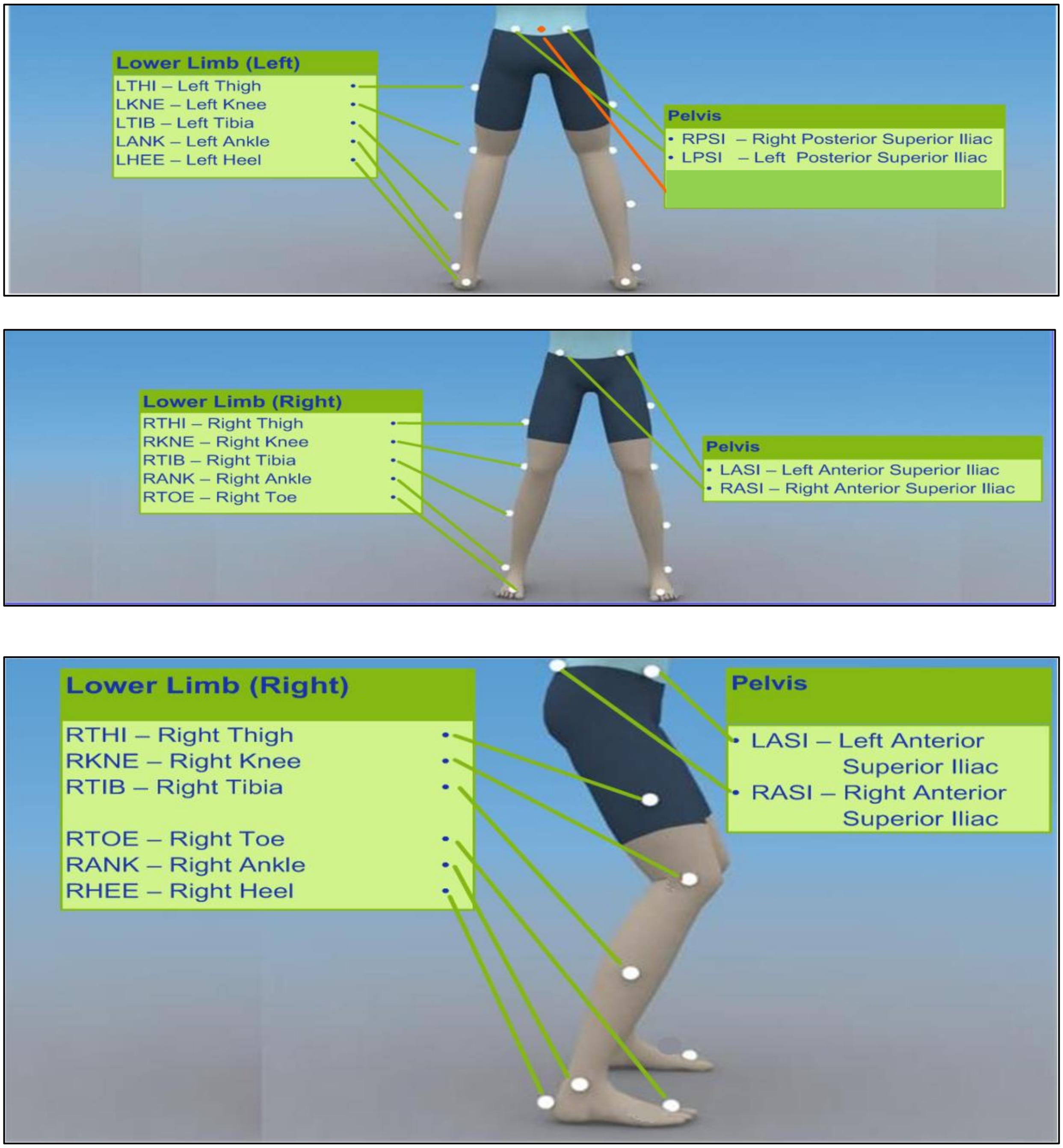


Figure 4: Visual illustration of reflective marker placement

Subjects then completed two motor tasks in a randomized order with 2 minutes of rest between motor tasks. Additional rest time was given to subjects who needed it. One of the motor tasks was a stair ascent (SA) task. For the SA task, subject walked along a walkway, then ascended a 3-step staircase, with a riser height of 24 cm, with the staircase positioned so that the subjects had to step on the force plates before ascending the staircase. This height was chosen due to proximity of the typical residential riser height of stairs (Liang et al., 2018a, 2018b; Oh-Park, Wang, & Verghese, 2011). Subjects completed five trials of this task, with 20 seconds of rest between trials. The other motor task was the timed up-and-go test (TUG). For the TUG test, subjects started in a seated position so that their knees were at a 90-degree angle. Subjects then quickly stood, walked 3 meters to a target, turned around, walked 3 meters back and quickly sat down. Subjects were instructed to complete the task as quickly as possible without running. Subjects completed five trials of this task, with 20 seconds of rest between trials. Practice trials were given for both motor tasks to ensure the subjects understood the instructions.

After a 10-minute break, the subjects completed the motor tasks in a randomized order again. After another 2-minute break, subjects stood on a Galileo Med-L WBC side-alternating vibration platform (StimDesigns LLC, Carmel, CA, USA). Each subject was asked to complete 10 bouts of 30 seconds on the platform, with 1 minute of rest between each bout. During each bout of vibration, each subject held onto a handrail with both hands without leaning on the handrail. Subjects were instructed to stand with their knees in a slightly flexed position and keep their heels on the platform. Reminders were given to subjects who did not maintain this position throughout the entirety of the bout. Manual assistance was given to any subject that had difficulty with either of those instructions. The settings of the vibration was set to a frequency of 25 Hz and amplitude of 2 mm (Eid, 2015; Gonzalez-Aguero et al., 2013; Matute-Llorente et al., 2015; Saquetto et al., 2018; Villarroya et al., 2013) for all bouts. Immediately following the vibration, the subjects completed the Flanker Test. Immediately following the Flanker Test, the subjects completed the motor tasks in a randomized order. This resulted in three time points of analysis: baseline, pre-WBV, and post-WBV. The baseline measurement was included as a controlled condition to ensure there was no learning effect for the motor and cognitive tasks.

Recording systems

An 8-camera Vicon motion capture system (Vicon, Denver, CO, USA) was used to collect all kinematic data at a frequency of 100 Hz. Two embedded AMTI force plates embedded in the floor (Advanced Mechanical Technology Inc., Watertown, MA, USA) were used to collect ground reaction forces (GRF) during the TUG test and the stair ascent task. Data were collected at a frequency of 1000 Hz. Vicon Nexus (Vicon, Denver, CO, USA) was used for the collection, processing, and labeling of the kinematic data. Custom written MATLAB (Mathworks, Natick, MA, USA) programs were used for the calculation of all the outcome variables.

Data analysis and outcome measures

The outcome measures for the cognitive task included response time and accuracy of performance. The response time was calculated automatically by the NIH Toolbox app. Accuracy was calculated in Excel (Microsoft Corporation, Redmon, Washington, USA) using the response scores from the NIH Toolbox app. The analysis was organized by the direction of the stimulus (congruent and incongruent). The time spent completing the task was additionally organized by average response time for each stimulus, average response time for correct responses, and average response time for incorrect responses. The Flanker Test using fish was analyzed separately from the Flanker Test using arrows due to the different stimuli presented during the tasks.

The outcome measures for the motor tasks include spatial-temporal parameters, kinematics of the hip, knee and ankle, and kinetic parameters. The spatial-temporal variables were calculated using the kinematic data collected through Vicon. The spatial variables include step length, step width, and distance from the staircase for the SA task. Step length was normalized by leg length and was calculated as the anterior-posterior (AP) difference in position between the ipsilateral heel marker and contralateral heel marker when the ipsilateral side was at initial contact. Step width was also normalized by leg length and calculated as the medial-lateral (ML) difference between ipsilateral heel marker and the corresponding contralateral foot segment (line formed by the heel and toe markers) for each corresponding step. Step time was calculated as the time between contralateral initial contact and next ipsilateral initial contact. Step velocity was calculated by dividing step length by step time. Step time and step velocity was normalized according to Stansfield et al. (2003):

$$\textit{Normalized step time} = \textit{step time} / \sqrt{leg\ length/g}$$

$$\textit{Normalized step velocity} = \textit{step velocity}/\sqrt{leg\ length *\ g}$$

where g is gravitational acceleration (9.81 m/s^2). The kinematic variables include the joint angles of the hip, knee and ankle in the sagittal and were obtained using the model output data from Vicon. Positive angles represent flexion for the hip and knee and dorsiflexion for the ankle. The sagittal plane kinetic variables include the peak joint power generation of the hip, knee and ankle, which were also obtained from the model output data from Vicon.

For the SA task, the approaching phase and ascent phase were analyzed separately. The steps approaching the staircase were coded using negative values. Step -2 was the second to last step before ascending the staircase. Step -1 was the last step of the approach phase before ascending the staircase. The steps ascending the staircase were coded using positive values where step 1 is the first step on the staircase and step 2 was the second step on the staircase. For step 2, the subject showed two strategies: either ascending to the second step of the staircase (i.e., step-over-step strategy) or bringing the foot to the first step of the staircase (both feet on the same step; i.e. step-on-step strategy) (Figure 5). The third step was not included in the analysis due to the possible altered mechanics that the drop-off of the third step created. The step coding corresponds to the swing leg (i.e. step 1 is the swing to the first step of the staircase). Thus, the stance phase corresponds to the contralateral leg from the previous swing step (i.e. step 1 stance phase corresponds to step -1). The staircase was placed directly next to the force plates embedded in the floor, so that subjects stepped on the force plates before ascending the staircase.

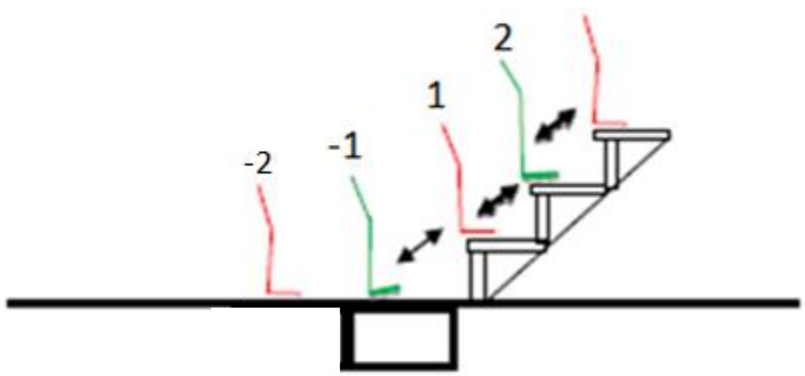


Figure 5: Visual illustration of the SA coding

The TUG test was broken into different phases for analysis. The first phase was the sit-to-stand (StS) phase. The initiation of the StS was determined as the point where the PSIS markers moved upward and forward for at least 10 consecutive frames. The end of the StS was determined as the frame before vertical movement of the heel markers. These points were determined by visual inspection of the reconstructed and labeled Vicon data. The second phase was walk-out (WO) phase. This was measured as the time immediately following the end of the

StS phase to the turn phase. The initiation step and adjustment steps (i.e. bringing the feet together or shuffling feet before the turn phase of the TUG test) were not included in the analysis of the WO phase since they do not represent the typical walking steps of the subject. The turn phase was not analyzed due to the poor quality of the data due to the dimensions of the lab space.

Statistical Analysis

Statistical analyses were conducted on the available data to determine if the results indicate a trend in the data. Due to the limited number of subjects, results were primarily analyzed using the descriptive statistics and in the form of a series of case studies by measuring the percentage change between the time periods. Paired T-tests were conducted between the baseline and pre-WBV conditions for the motor and cognitive variables to control for any learning effects and serve as a control due to a lack of control group. For the cognitive task, paired T-tests were conducted by direction of stimulus for each stimulus (fish and arrow) separately. For the comparison between the pre-WBV and post-WBV of the cognitive task, a series of two-way (2 direction x 2 time) mixed ANOVAs with repeated measures on direction and time were performed on accuracy, total time to complete task, time for correct responses, and time for incorrect responses. Additionally, correlation analyses were conducted between the dependent variables and scales from the BRIEF-2 including inhibit and working memory.

For the SA task, paired T-tests were conducted by step for the approach and ascent phase. For the SA task, a series of two-way (2 step x 2 time) mixed ANOVAs with repeated measures on step and time were performed on the spatial-temporal, kinematic and kinetic variables to compare the pre-WBV and post-WBV conditions. For the TUG task, paired t-tests were performed on the spatial-temporal, kinematic and kinetic variables to compare the pre-WBV and post-WBV conditions. Normality was checked for each variable. When appropriate, log transformations were conducted for the variables that were not normally distributed. Statistical analyses were performed using SAS, version 9.4 (SAS Institute Inc., Cary, NC). A significance level was set at $\alpha = 0.05$ for all tests. Effect sizes (Cohen's d) were calculated for the variables of the motor tasks. An effect size of 0.2 or less was considered small, between 0.2 and 0.5 was considered moderate, between 0.5 and 0.8 was considered large, and greater than 0.8 was considered very large (Cohen, 1988; Thomas & Nelson, 2001).

Results

The subject characteristics and BRIEF-2 scores are presented in Table 1. For the cognitive task, one subject did not complete the task (Subject # 3). Of the remaining four subjects, one subject only completed the fish flanker task (Subject # 1). The remaining three completed both the fish and arrow flanker tasks. All subjects completed both of the motor tasks at all three time points. Individual and mean results for the Flanker Tests are presented in Table 2 and Table 3. Two of the subjects (Subject # 1 and # 5) did not complete all 10 bouts of WBV. Both of these subjects complete 5 bouts due to skin hypersensitivity in their lower legs. The remaining three subjects completed all 10 bouts of vibration.

Table 1: Subject characteristics

Subject	Gender	Age (years)	Height (cm)	Mass (kg)	BMI	Leg length (cm)	BRIEF-2 Inhibit	Shift	Emotional Control	Working Memory	Plan/ Organize	Task Monitor
1	M	8.52	125.5	27.5	17.46	64.5	14	20	8	17	17	14
2	F	10.63	131.5	35.3	20.41	67.5	16	19	14	17	19	14
3	F	10.03	127	26.8	16.62	67	19	17	9	18	18	15
4	M	14.48	149	58.2	26.22	81.5	19	16	23	18	16	10
5	F	12.83	128	33	20.14	71	8	8	8	13	15	7
Mean (SD)		11.3 (2.36)	132.2 (9.65)	36.13 (12.84)	20.17 (3.76)	70.3 (6.68)	15.2 (4.55)	16 (4.74)	12.4 (6.43)	16.6 (2.07)	17 (1.58)	12 (3.39)

Group trend in the cognitive task

For the fish flanker test (Table 2), the subjects performed more accurately for the congruent trials than the incongruent trials. There was a main effect of direction ($F(2,18) = 7.32$, $p = 0.015$) on average total response time. Subjects responded more quickly for the congruent trials than the incongruent trials. There was also a main effect of direction ($F(2,18) = 6.27$, $p = 0.022$) on average response time during correct responses. There were no significant differences between the baseline and pre-WBV conditions. There were also no significant differences between the pre-WBV and post-WBV conditions for any of the variables for the fish stimuli. However, there was a trend for time ($p = 0.067$) for total response time. Subjects tended to take longer to respond following vibration. There were no significant correlations between the dependent variables and the BRIEF-2 constructs. There was a trend between the congruent response total time and inhibit construct ($p = 0.070$).

Table 2: Flanker Test with fish stimuli

Subject	Variable	Congruent					Incongruent				
		Baseline	Pre-WBV	Post-WBV	% Δ (B-Pre)	% Δ (Pre-Post)	Baseline	Pre-WBV	Post-WBV	% Δ (B-Pre)	% Δ (Pre-Post)
1	Accuracy (%)	75	100	91.67	33.33	-8.33	37.5	37.5	50	0	33.33
	Time total (s)	1.35	1.61	1.25	19.72	-2.47	1.34	1.99	1.73	48.36	-12.98
	Time (correct)	1.59	1.61	1.07	1.32	33.37	1.69	1.25	2.09	-25.63	66.48
	Time (incorrect)	1.06		3.18			1.14	2.44	1.38	114.12	-43.3
2	Accuracy (%)	100	100	100	0	0	100	100	100	0	0
	Time total (s)	1.49	1.11	1.39	-25.69	25.18	1.83	1.78	2.04	-2.42	14.54
	Time (correct)	1.49	1.11	1.39			1.83	1.78	2.04		
	Time (incorrect)										
4	Accuracy (%)	100	100	100	0	0	100	87.5	87.5	-12.5	0
	Time total (s)	0.75	1.58	1.72	111.53	9.17	0.97	2.56	3.71	163.3	45.27
	Time (correct)	0.75	1.58	1.72			0.97	2.38	3.94		65.39
	Time (incorrect)							3.79	2.15		-43.29
5	Accuracy (%)	100	100	100	0	0	100	100	100	0	0
	Time total (s)	0.95	1.05	1.09	9.83	4.1	0.98	1.36	1.8	38.87	32.23
	Time (correct)	0.95	1.05	1.09			0.98	1.36	1.8		
	Time (incorrect)										
Mean (SD)	Accuracy (%)	93.75 (12.5)	100	91.92 (4.17)			84.38 (31.25)	81.25 (29.76)	84.38 (23.66)		
	Time total (s)	1.13 (0.34)	1.34 (0.3)	1.36 (0.27)			1.28 (0.4)	1.92 (0.5)	2.32 (0.94)		
	Time (correct)	1.2 (0.41)	1.34 (0.3)	1.32 (0.31)			1.37 (0.45)	1.69 (0.51)	2.47 (0.99)		
	Time (incorrect)	1.06		3.18			1.14	3.11 (0.95)	1.76 (0.54)		

For the arrow flanker responses (Table 3), there was a main effect of direction (F(1,12) = 9.25, $p = 0.010$) on accuracy. Subjects answered the congruent trials more accurately than the incongruent trials. There was also a main effect of direction (F(1,12) = 6.08, $p = 0.030$) on average response time. Subjects took longer to respond to the incongruent trials than the congruent trials. There was also a trend for direction for response time during correct responses (F = 4.63, $p = 0.057$). There was a strong significant negative correlation between the incongruent accuracy and the working memory scale (r = -0.998, $p = 0.037$). Subjects that received lower parent-reported working memory scores tended to have higher accuracy scores. There was also a trend between the congruent correct response time and the working memory scale (r = -0.996, $p = 0.054$). There were no significant differences between the baseline and pre-WBV conditions for any of the variables. There were also no significant differences between the pre-WBV and post-WBV conditions for any of the variables.

Table 3: Flanker Test with arrow stimuli

Subject	Variable	Congruent					Incongruent				
		Baseline	Pre-WBV	Post-WBV	% Δ (B-Pre)	% Δ (Pre-Post)	Baseline	Pre-WBV	Post-WBV	% Δ (B-Pre)	% Δ (Pre-Post)
2	Accuracy (%)	91.67	100	100	9.09	0	25	0	0	-100	0
	Time total (s)	1.05	1.27	1.38	21.18	8.27	3.25	2.9	2.15	-10.69	-25.71
	Time (correct)	1.09	1.27	1.38	16.77		4.23				
	Time (incorrect)	0.61					2.92	2.9	2.15	-0.07	
4	Accuracy (%)	91.67	100	75	9.09	-25	12.5	12.5	37.5	0	200
	Time total (s)	2.66	1.41	1.19	-47.07	-15.22	2.22	1.67	3.2	-25.08	92.21
	Time (correct)	1.99	1.41	1.34	-29.29	-4.71	7.81	3.74	2.5	-52.17	-33.1
	Time (incorrect)	10		0.75			1.43	1.37	3.63	-3.86	164.47
5	Accuracy (%)	100	100	100	0	0	100	100	100	0	0
	Time total (s)	1.08	1.44	1.68	33.05	15.55	1.33	1.34	2.27	0.63	69.87
	Time (correct)	1.08	1.44	1.68			1.33	1.34	2.27		
	Time (incorrect)										
Mean (SD)	Accuracy (%)	94.44 (4.81)	100	91.67 (14.43)			45.83 (47.32)	37.5 (54.49)	45.83 (50.52)		
	Time total (s)	1.6 (0.92)	1.37 (0.09)	1.41 (0.24)			2.27 (0.96)	1.97 (0.82)	2.54 (0.57)		
	Time (correct)	1.39 (0.52)	1.37 (0.09)	1.46 (0.18)			4.46 (3.25)	2.54 (1.7)	2.39 (0.16)		
	Time (incorrect)	5.31 (6.64)		0.75			2.17 (1.06)	2.14 (1.08)	2.89 (1.04)		

<u>Group trend in the stair ascent task</u>

There was no significant difference between the baseline and pre-WBV conditions for the approach phase (Table 4.1). Between Pre- and Post-WBV conditions, there was a main effect of step on step length (F (1,16) = 6.97, p = 0.018) and step velocity (F(1,16) = 8.16, p = 0.011). Step -2 had a longer step length and a faster step velocity than step -1. There were no significant differences between the Pre and Post-WBV conditions for the approach phase. Effect sizes for the approach phase variables are presented in Table 4.2.

Table 4.1: Mean (SD) of SA normalized spatial-temporal variables – approach phase

Variable	Step	Baseline	Pre-WBV	Post-WBV
Step length	-2	0.52 (0.11)	0.58 (0.07)	0.63 (0.14)
	-1	0.41 (0.14)	0.39 (0.17)	0.43 (0.23)
Step width	-2	0.15 (0.08)	0.18 (0.04)	0.21 (0.06)
	-1	0.21 (0.07)	0.2 (0.09)	0.24 (0.12)
Step velocity	-2	0.11 (0.03)	0.13 (0.03)	0.15 (0.03)
	-1	0.09 (0.04)	0.08 (0.04)	0.1 (0.05)

Table 4.2: Effect sizes for the normalized spatial-temporal variables – approach phase

Variable	Step	Pre-WBV/Post-WBV
Step length	-2	0.45
	-1	0.20
Step width	-2	0.59
	-1	0.38
Step velocity	-2	0.67
	-1	0.44

For the ascent phase, there were no significant difference between the baseline and pre-WBV conditions for the spatial-temporal variables (Table 5.1), joint kinematics (Table 6.1) nor joint power (Table 7.1). Between the pre-WBV and post-WBV there was a main effect of step for step length (F(1,16) = 88.15, $p < 0.001$) and step velocity (F(1,16) = 21.54), $p = 0.003$). Step 1 was longer and faster than step 2. There was also a main effect of step for the ankle ROM (F(1,16) = 43.08, $p < 0.001$), knee ROM (F(1,16) = 47.99, $p < 0.001$), and hip ROM (F(1,16) = 22.03, $p = 0.002$). Step 1 had a larger ankle ROM, smaller knee ROM and smaller hip ROM compared to step 2. There were no significant difference between the pre and post-WBV conditions for the spatial-temporal variables, joint kinematics nor joint power. Effect sizes for the spatial-temporal variables are presented in Table 5.2, for the joint kinematics in Table 6.2, and for the joint power in Table 7.2.

Table 5.1: Mean (SD) of SA normalized spatial-temporal variables – ascent phase

Variable	Step	Baseline	Pre-WBV	Post-WBV
Step length	1	0.7 (0.09)	0.67 (0.09)	0.68 (0.1)
	2	0.37 (0.05)	0.35 (0.04)	0.36 (0.05)
Step width	1	0.22 (0.09)	0.27 (0.06)	0.24 (0.05)
	2	0.35 (0.07)	0.3 (0.04)	0.31 (0.03)
Step velocity	1	0.1 (0.02)	0.09 (0.04)	0.1 (0.03)
	2	0.03 (0.01)	0.03 (0.01)	0.04 (0.001)

Table 5.2: Effect sizes for the SA normalized spatial-temporal variables – ascent phase

Variable	Step	Pre-WBV/Post-WBV
Step length	1	0.11
	2	0.22
Step width	1	0.54
	2	0.28
Step velocity	1	0.28
	2	1

Table 6.1: Mean (SD) of SA joint kinematics – ascent phase

Variable	Step	Baseline	Pre-WBV	Post-WBV
Ankle ROM (degrees)	1	41.06 (4.52)	39.96 (3.71)	41.81 (4.74)
	2	28.88 (6.89)	29.69 (4.06)	24.63 (5.9)
Knee ROM (degrees)	1	17.25 (5.19)	21 (10.08)	22.79 (9.49)
	2	51.53 (15.58)	53.91 (12.82)	56.49 (5.9)
Hip ROM (degrees)	1	21.13 (7.25)	29.75 (8.33)	33.54 (10.57)
	2	48.89 (11.09)	45.77 (4.89)	49.22 (4.78)

Table 6.2: Effect sizes of SA joint kinematics – ascent phase

Variable	Step	Pre-WBV/Post-WBV
Ankle ROM (degrees)	1	0.43
	2	1
Knee ROM (degrees)	1	0.18
	2	0.22
Hip ROM (degrees)	1	0.40
	2	0.71

Table 7.1: Mean (SD) of SA joint power – ascent phase

Variable	Baseline	Pre-WBV	Post-WBV
Ankle power (W/kg)	2.7 (1.87)	3.53 (1.68)	3.22 (0.78)
Knee power (W/kg)	0.98 (0.37)	0.93 (0.64)	1.66 (1.52)
Hip power (W/kg)	1.85 (1.6)	3.31 (4.81)	2.56 (1.93)

Table 7.1: Effect sizes of SA joint power – ascent phase

Variable	Pre-WBV/Post-WBV
Ankle power (W/kg)	0.24
Knee power (W/kg)	0.63
Hip power (W/kg)	0.20

Group trend in the TUG test

For the TUG task (Table 8), there was no significant difference in the duration to complete the task between any of the time periods. The TUG task was further divided into StS and WO phase. For the StS phase, there was no significant differences in the joint kinematics of the hip, knee or ankle, nor the joint kinetics between any of the time periods. For the WO phase, there were also no significant differences in the normalized spatial-temporal parameters between any of the time periods. Effect sizes for the TUG variables are presented in Table 8.2.

Table 8.1: Mean (SD) of the TUG variables

Variable	Baseline	Pre-WBV	Post-WBV
TUG Duration (s)	10.87 (2.18)	9.16 (0.66)	9.04 (1.93)
StS phase			
Peak ankle angle (degrees)	-4.58 (8.95)	-2.17 (5.75)	1.14 (6.29)
Peak knee angle (degrees)	38.24 (22.23)	36.3 (17.9)	45.42 (19.91)
Peak hip angle (degrees)	47.31 (35.14)	54.94 (18.96)	58.09 (20.73)
Peak ankle power (W/kg)	0.28 (0.44)	0.15 (0.15)	0.23 (0.3)
Peak knee power (W/kg)	0.6 (0.4)	0.67 (0.47)	0.91 (0.55)
Peak hip power (W/kg)	1.49 (1.15)	1.83 (0.99)	1.32 (0.45)
WO phase			
Step length	0.67 (0.08)	0.71 (0.09)	0.73 (0.14)
Step width	0.28 (0.07)	0.3 (0.08)	0.29 (0.06)
Step velocity	0.16 (0.04)	0.16 (0.04)	0.16 (0.04)

Table 8.2: Effect sizes of the TUG variables

Variable	Pre-WBV/Post-WBV
TUG Duration (s)	0.08
StS Phase	
Peak ankle angle (degrees)	0.55
Peak knee angle (degrees)	0.48
Peak hip angle (degrees)	0.16
Peak ankle power (W/kg)	0.34
Peak knee power (W/kg)	0.47
Peak hip power (W/kg)	0.66
WO Phase	
Step length	0.17
Step width	0.14
Step velocity	0

Case # 1

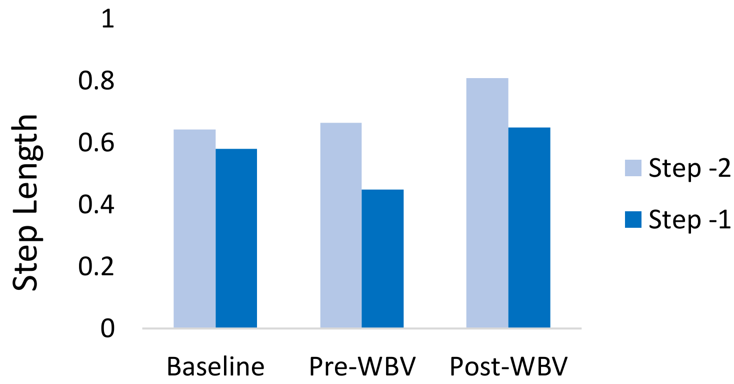
Subject 1 was an 8.5-year-old male. The parent's rating of the BRIEF-2 placed their inhibit score in the 71st percentile, shift in the 99th percentile, emotional control in the 40th percentile, working memory in the 84th percentile, plan/organize in the 86th percentile, and task monitor in the 97th percentile for their age group by gender (8-10 TD year olds) (Table 1).

Subject 1 only completed the Flanker Test with the fish stimuli. Between the baseline and pre-WBV conditions there was an increase in accuracy from 75% to 100% and increase in response time from 1.35 to 1.61 seconds for the congruent trials. For the incongruent trials, there was no change in accuracy, increase in total response time from 1.34 to 1.99 seconds, decrease in response time for correct responses from 1.69 to 1.25 seconds and increase in response time for incorrect responses from 1.14 to 2.44 seconds. Between the pre-WBV and post-WBV conditions there was a decrease in accuracy from 100% to 91.67%, decrease in total response time from 1.61 to 1.25 seconds and decrease in response time for correct responses from 1.61 to 1.07 seconds for the congruent trials. For the incongruent trials, there was an increase in accuracy from 37.5% to 50%, decrease in total response time from 1.99 to 1.73 seconds, increase in response time for correct responses from 1.25 to 2.09 seconds and decrease in response time for incorrect responses from 2.44 to 1.38 seconds (Table 2).

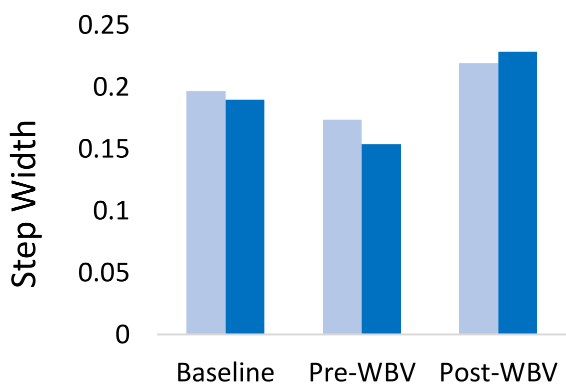
For the SA task, the subject relied on the use of his hands to assist himself to climb the staircase for the baseline and pre-WBV conditions. Following the session of WBV, the subject was able to complete 2 of the 5 trials without the use his hands. During the baseline and pre-WBV conditions the subject demonstrated two strategies to ascend the staircase. One of those strategies included placing both feet together at the bottom of the staircase (feet adjacent) before ascending the staircase. The other strategy was a step-over-step strategy, where the subject did not stop at the bottom of the staircase and continued to ascend the staircase one leg at a time. He chose the feet adjacent strategy 80% of the time before vibration. After WBV, the subject used the step-over-step strategy for all the trials.

During the approach phase of the SA task, following the session of vibration, the subject demonstrated an increase in the normalized step length from 0.45 to 0.65 (Figure 6.1a) and normalized step velocity from 0.11 to 0.15 (Figure 6.1c) for step -1 and for step -2 from 0.66 to 0.81 and 0.17 to 0.19 respectively. The subject also demonstrated shorter and slower steps at step -1 compared to those at step -2.

a.



b.



c.

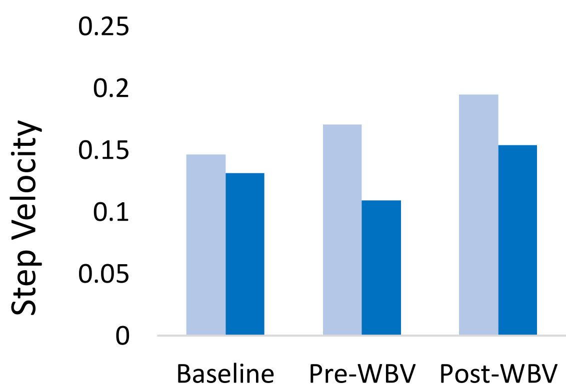
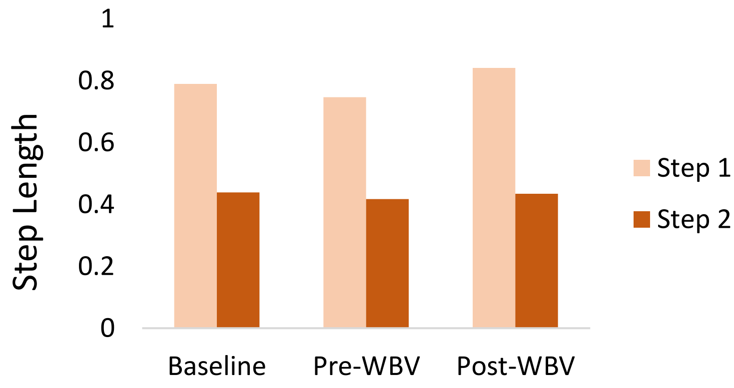


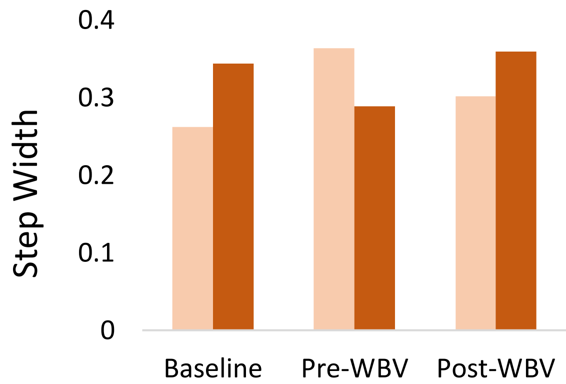
Figure 6.1: Spatial-temporal variables for the SA task – approach phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

During the ascent phase of the SA task, there were no apparent changes in the normalized spatial-temporal gait parameters after vibration. However, the subject demonstrated a difference in normalized step length (Figure 7.1a) and normalized step velocity (Figure 7.1c) between the first and second ascending step with the step 2 being shorter and slower respectively.

a.



b.



c.

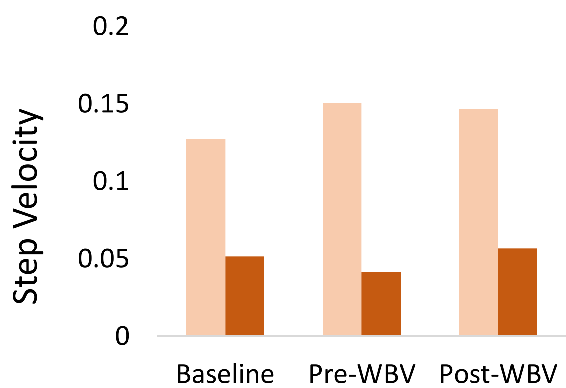
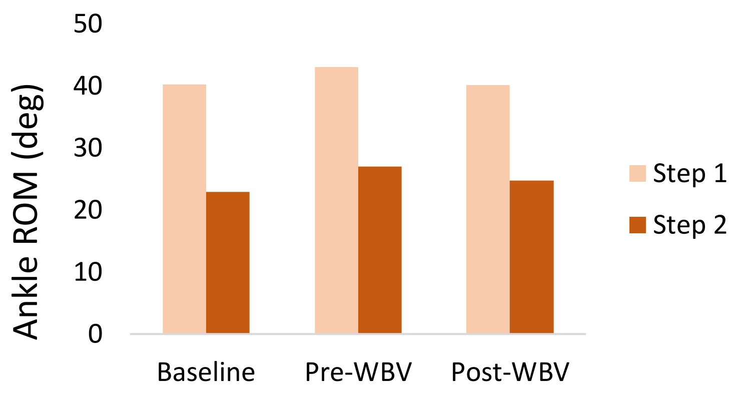


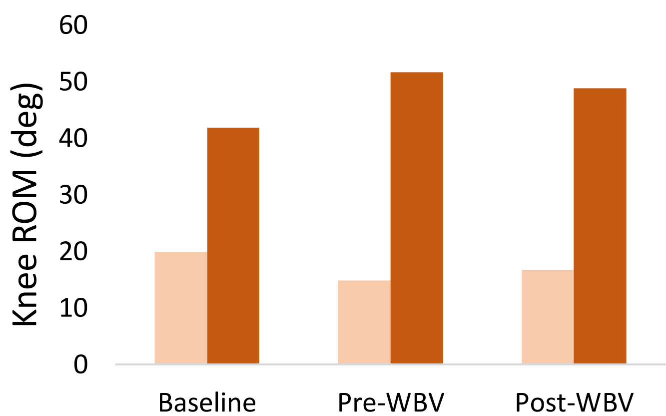
Figure 7.1: Spatial-temporal variables for the SA task – ascent phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

There were no apparent changes in the ankle, knee and hip ROM during stance phase before and after vibration. However, the subject demonstrated a difference in the ankle, knee and hip ROM stance phase between step 1 and step 2. The ankle ROM during step 2 was less compared to step 1 (Figure 8.1a). The knee (Figure 8.1b) and hip (Figure 8.1c) ROM during step 1 was less compared to step 2.

a.



b.



c.

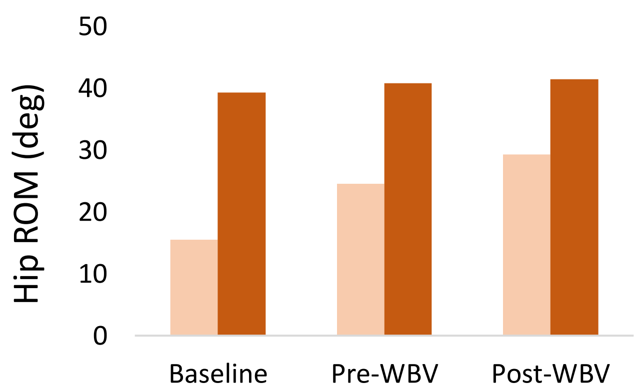
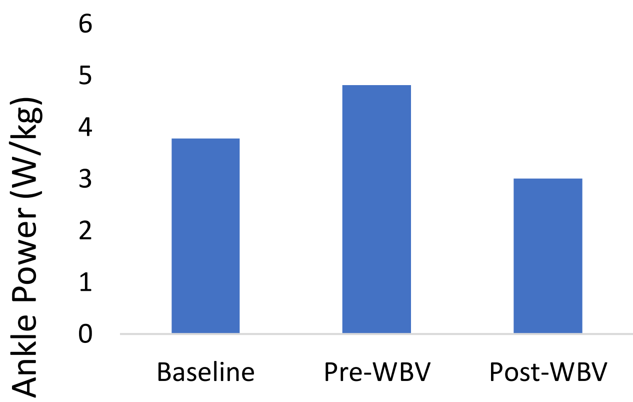


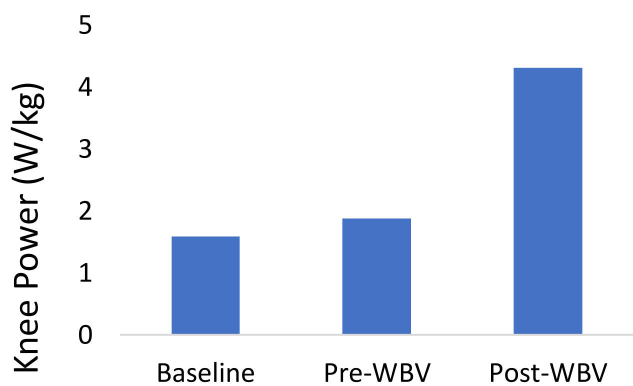
Figure 8.1: Joint range of motion (ROM) measured in degrees, (a) Ankle ROM, (b) Knee ROM, (c) Hip ROM.

The subject demonstrated decreased ankle (Figure 9.1a) and hip (Figure 9.1c) power generation, but increased knee power generation following vibration (Figure 9.1b) for the first step ascending the staircase. Ankle power decreased from 4.81 W/kg to 3 W/kg, hip power decreased from 11.87 W/kg to 5.81 W/kg, and knee power increased from 1.87 W/kg to 4.31 W/kg.

a.



b.



c.

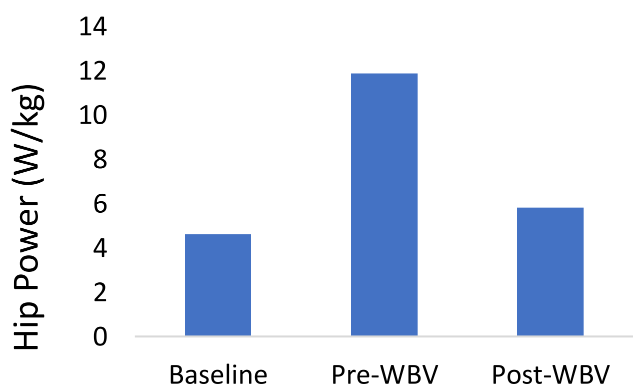


Figure 9.1: Peak joint power during ascent up first step of staircase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

The total duration of the TUG test was highest during the baseline condition and decreased during the pre-WBV and post-WBV conditions (Figure 10.1). The duration of the TUG decreased by one second after vibration.

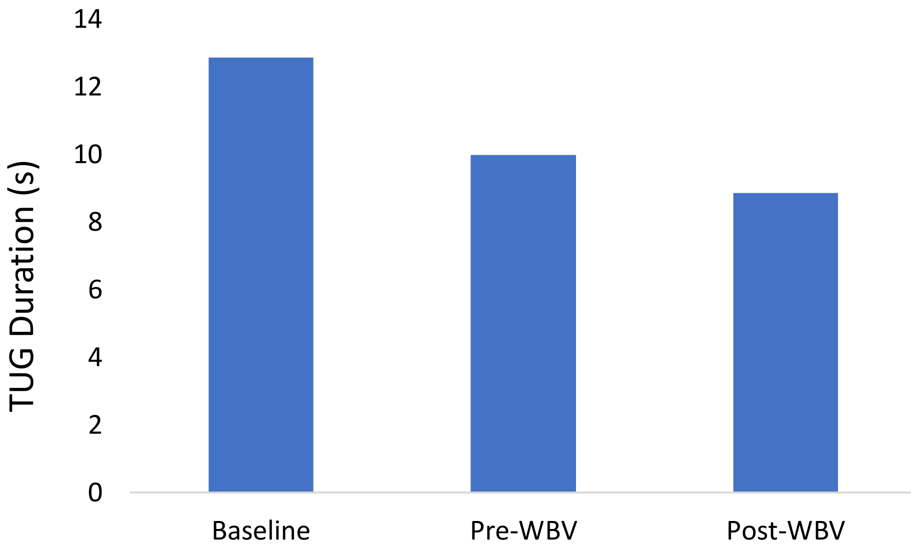
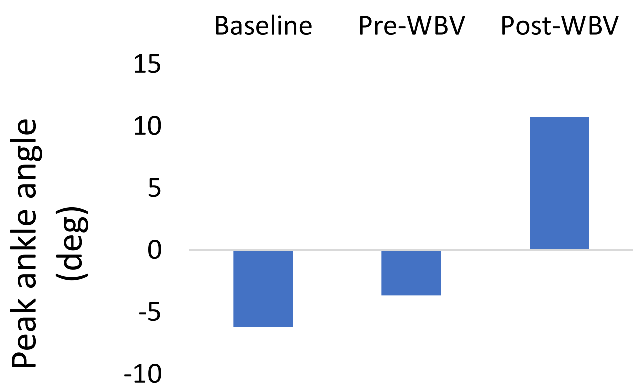


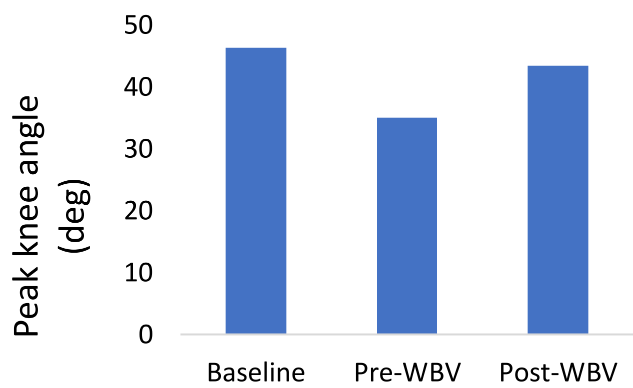
Figure 10.1: Duration of the timed up-and-go (TUG) test in seconds.

During the StS phase, the subject demonstrated a change in peak angle from a plantarflexed angle to a dorsiflexed angle (Figure 11.1a) after vibration. The subject also demonstrated a greater angle of knee flexion following vibration (Figure 11.1b).

a.


Baseline
Pre-WBV
Post-WBV
15
10
5
0
-5
-10
Peak ankle angle (deg)

b.


50
40
30
20
10
0
Peak knee angle (deg)
Baseline
Pre-WBV
Post-WBV

c.

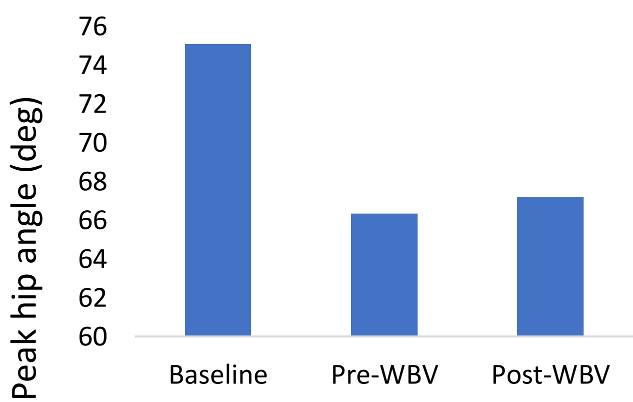
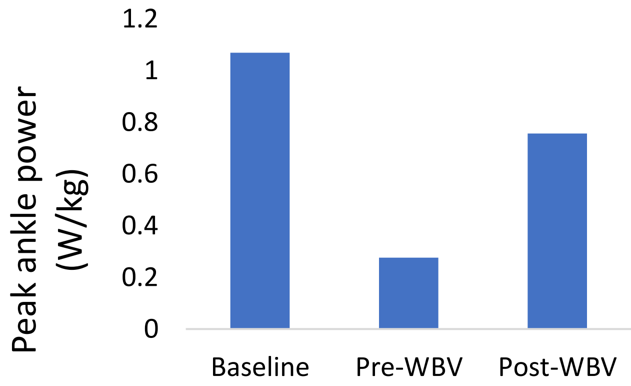

76
74
72
70
68
66
64
62
60
Peak hip angle (deg)
Baseline
Pre-WBV
Post-WBV

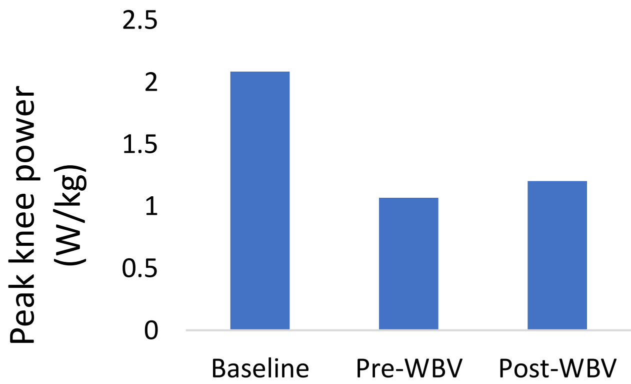
Figure 11.1: Peak joint angle during sit-to-stand (StS) phase, (a) Peak ankle angle, (b) Peak knee angle, (c) Peak hip angle. Positive angles represent joint in flexed position (dorsiflexed for ankle).

The subject demonstrated an increase in ankle power generation (Figure 12.1a) following vibration, but there were no apparent changes in knee or hip power after vibration. Ankle power increased from 0.28 W/kg to 0.77 W/kg.

a.



b.



c.

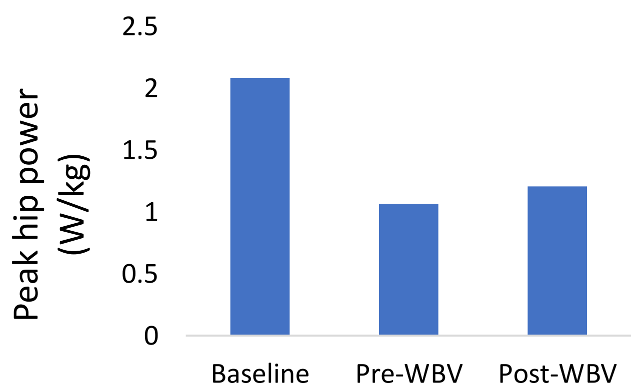
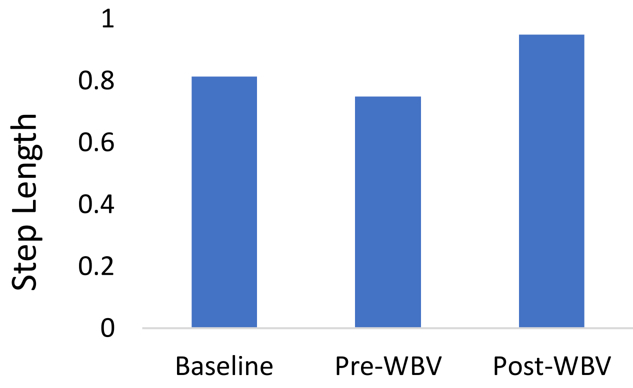


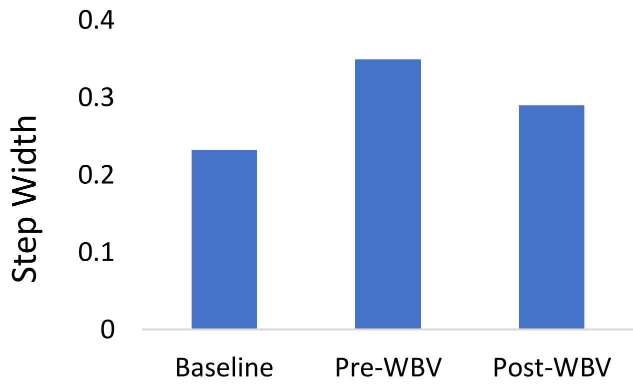
Figure 12.1: Peak joint power during the sit-to-stand (StS) phase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

During the WO phase, the subject demonstrated an increased step length from 0.75 to 0.95 (Figure 13.1a) after vibration. There were no apparent changes in the step width or step velocity after vibration.

a.



b.



c.

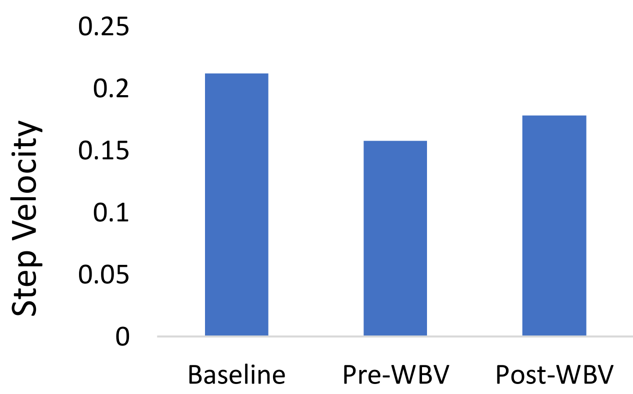


Figure 13.1: Spatial-temporal variables of the walk-out (WO) phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

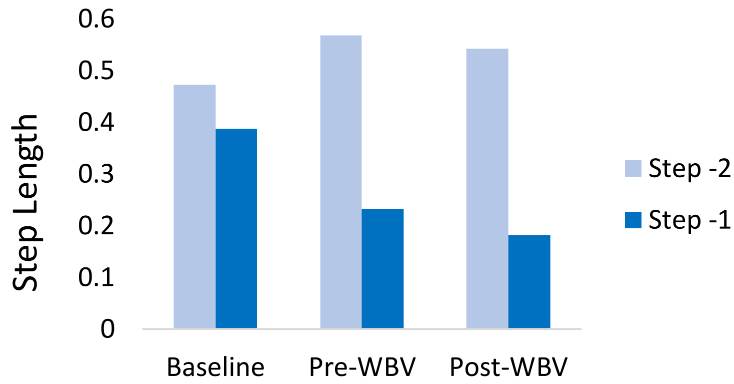
Case # 2

Subject 2 was a 10.6-year-old female. The parent's rating of the BRIEF-2 placed her inhibit score in the 93rd percentile, shift in the 97th percentile, emotional control in the 79th percentile, working memory in the 89th percentile, plan/organize in the 97th percentile, and task monitor in the 99th percentile for their age group by gender (8-10 TD year olds) (Table 1).

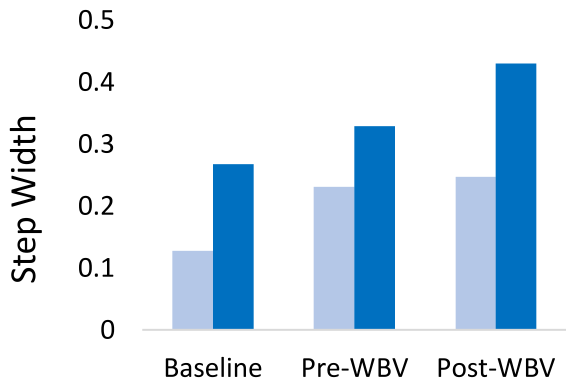
The second subject responded all the congruent and incongruent trials correctly for the Flanker Test with the fish stimuli. For the congruent and incongruent trials, there was a decrease in response time between the baseline and pre-WBV conditions from 1.49 to 1.11 seconds but increased between the pre-WBV and post-WBV from 1.11 to 1.39 seconds (Table 2). For the Flanker Test with the arrow stimuli, there was an increase in accuracy from 91.67% to 100% and response time for the congruent trials from 1.05 to 1.27 seconds between the baseline and pre-WBV conditions. There was no change in accuracy between the pre-WBV and post-WBV conditions. For the incongruent trials, there was a decrease in accuracy from 25% to 0% and response time from 3.25 to 2.9 seconds between the baseline and pre-WBV conditions. There was no change in accuracy and decrease in response time from 2.9 to 2.15 seconds between the pre-WBV and post-WBV conditions (Table 3).

For the SA task, the subject relied on her hands to assist herself ascend the staircase for each condition. The subject also demonstrated the feet adjacent strategy before ascending the staircase for each condition during all trials. During the approach phase, the subject demonstrated a shorter (Figure 6.2a) and slower (Figure 6.2c) step -1 than step -2. After vibration, the subject demonstrated a wider step for step -1 from 0.33 to 0.43 (Figure 6.2b). There were no apparent changes in the spatial-temporal variables after vibration.

a.



b.



c.

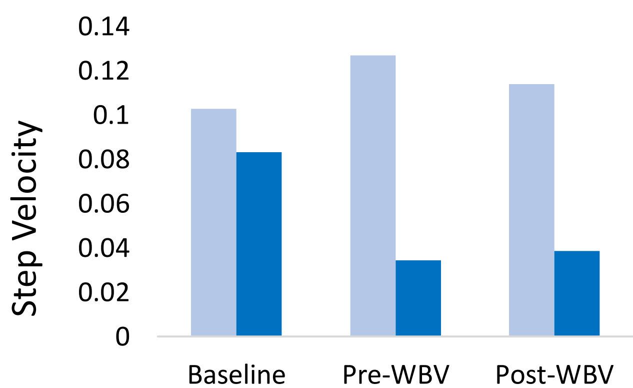
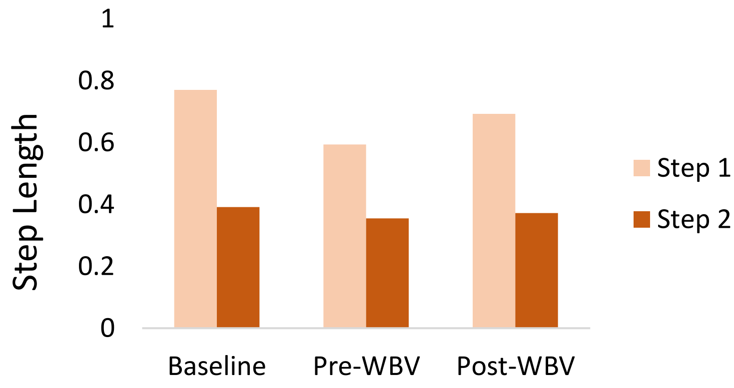


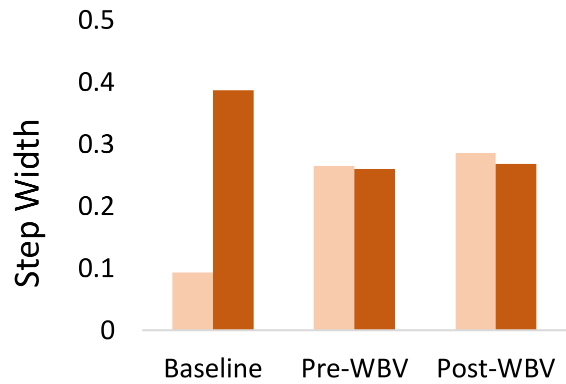
Figure 6.2: Spatial-temporal variables for the SA task – approach phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

During the ascent phase, the subject demonstrated a shorter (Figure 7.2a) and slower step (Figure 7.2c) for step 2 compared to step 1. There were no apparent change in the spatial-temporal parameters after vibration.

a.



b.



c.

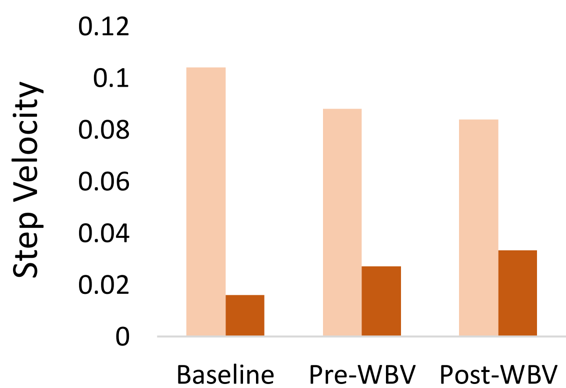
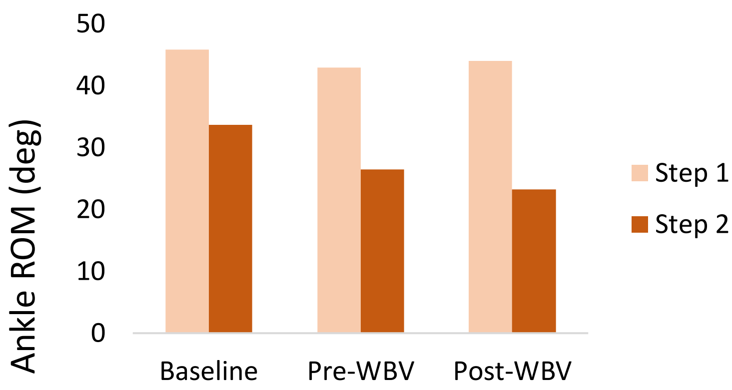


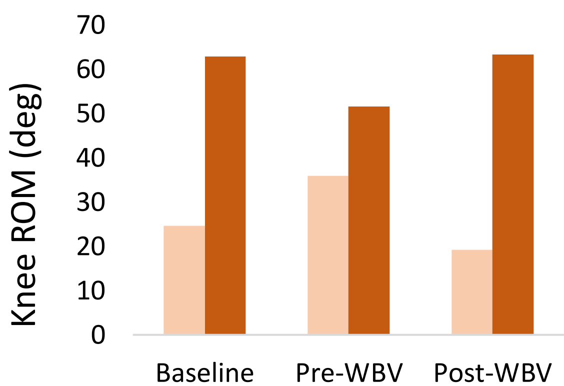
Figure 7.2: Spatial-temporal variables for SA task – ascent phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

The subject demonstrated a decreased ankle, knee and hip ROM for step 2 compared to step 1 during stance (Figure 8.2). Following vibration, the subject demonstrated a decrease in knee ROM during stance for step 1 from 35.98 to 19.15 degrees (Figure 8.2b) and increase in knee ROM during stance for step 2 from 51.55 to 63.28 degrees (Figure 8.2b).

a.



b.



c.

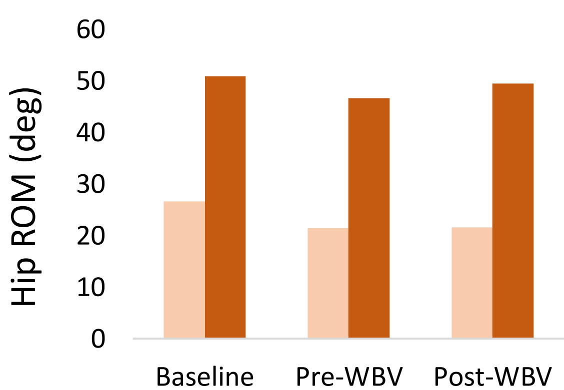
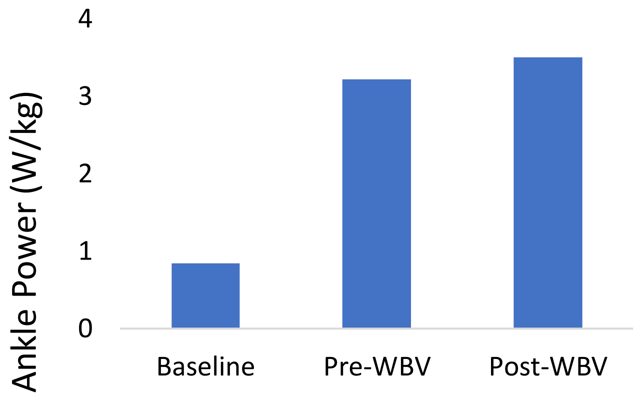


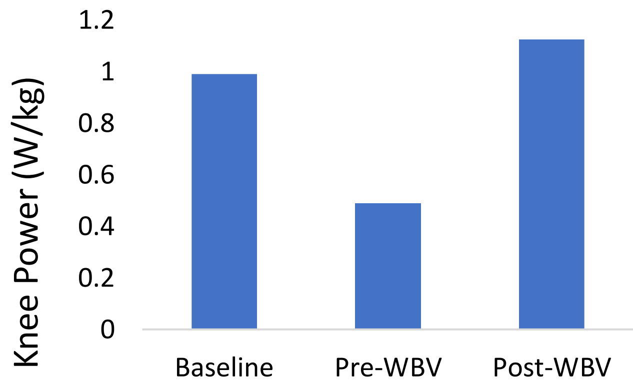
Figure 8.2: Joint range of motion (ROM) measured in degrees, (a) Ankle ROM, (b) Knee ROM, (c) Hip ROM.

The subject also demonstrated an increase in knee (Figure 9.2b) and hip (Figure 9.3c) power generation after vibration for the first step ascending the staircase. Knee power increased from 0.49 W/kg to 1.12 W/kg and hip power increased from 0.75 W/kg to 1.89 W/kg.

a.



b.



c.

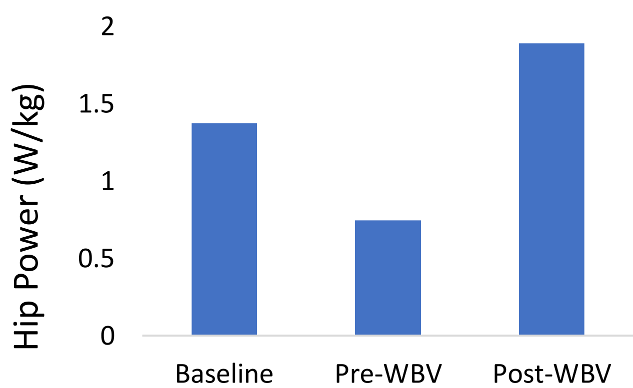


Figure 9.2: Peak joint power during ascent up first step of staircase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

There was no apparent change in the duration to complete the TUG test after vibration (Figure 10.2).

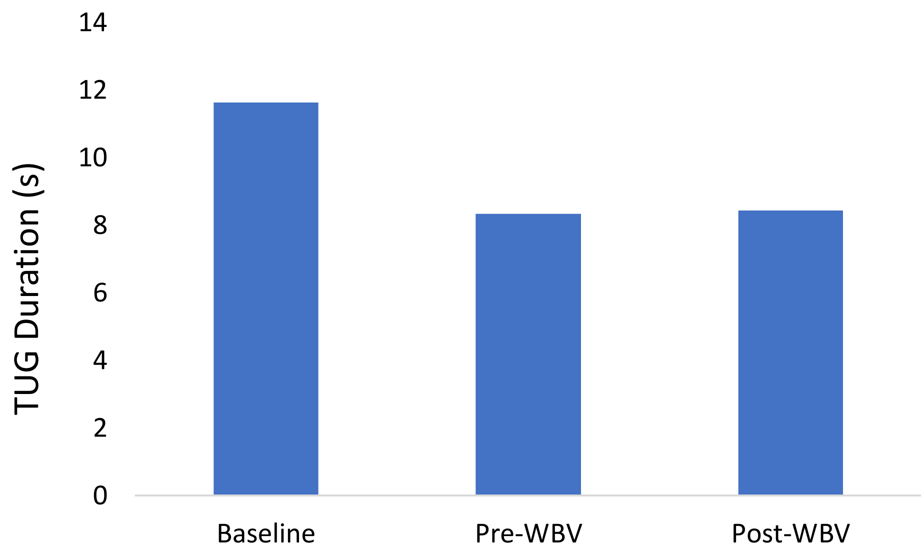
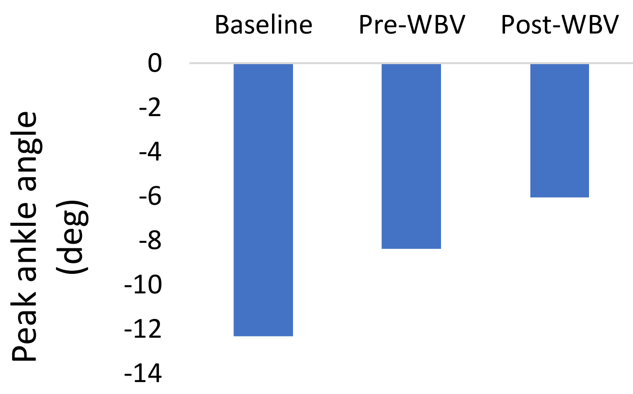


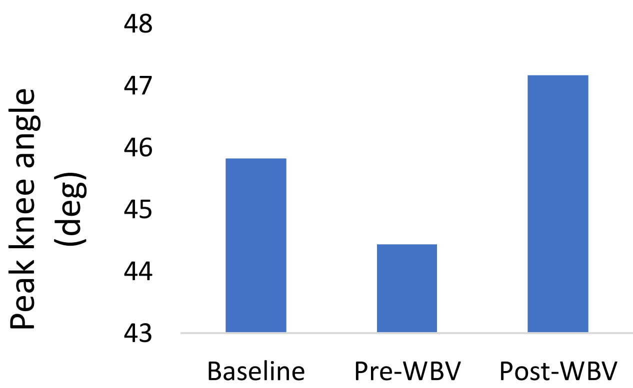
Figure 10.2: Duration of the timed up-and-go (TUG) test in seconds.

During the StS phase, the subject did not demonstrate any apparent changes in joint kinematics after vibration (Figure 11.2).

a.



b.



c.

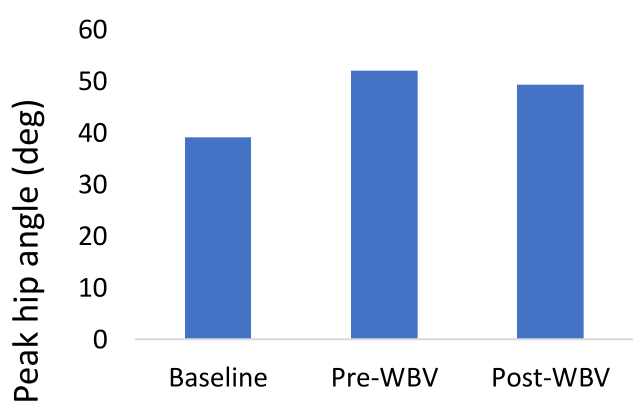
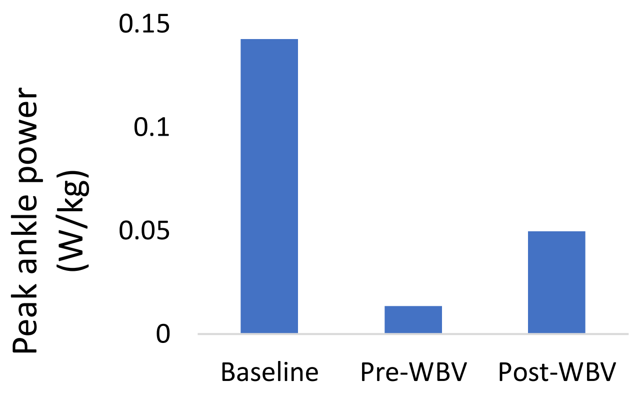


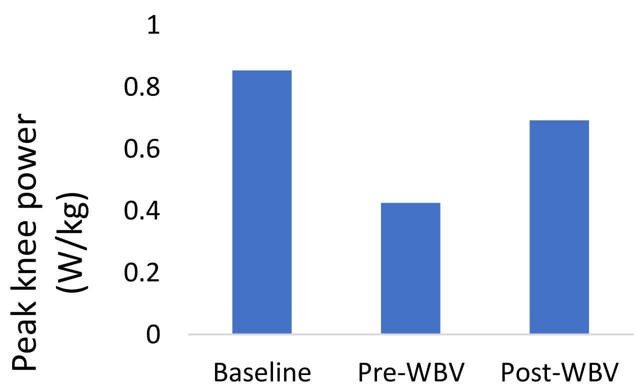
Figure 11.2: Peak joint angle during sit-to-stand (StS) phase, (a) Peak ankle angle, (b) Peak knee angle, (c) Peak hip angle. Positive angles represent joint in flexed position (dorsiflexed for ankle).

The subject demonstrated an increase in knee (Figure 12.2b) and hip (Figure 12.2c) power generation after vibration. Knee power increased from 0.42 W/kg to 0.69 W/kg and hip power decreased from 3.26 W/kg to 1.9

a.



b.



c.

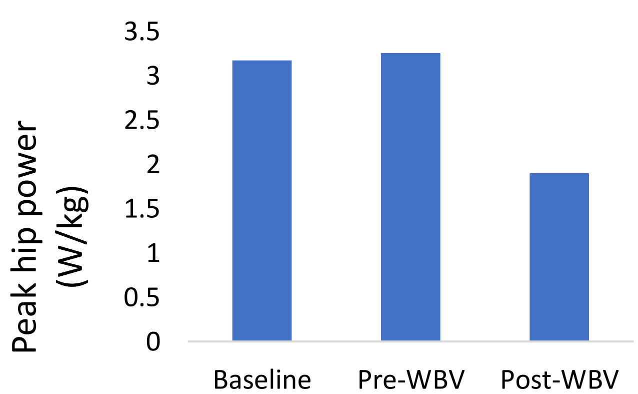
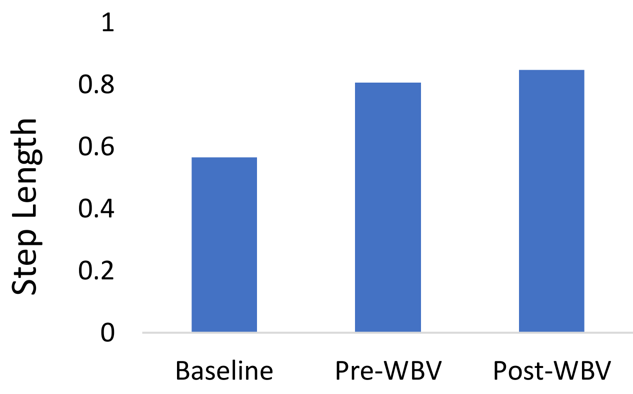


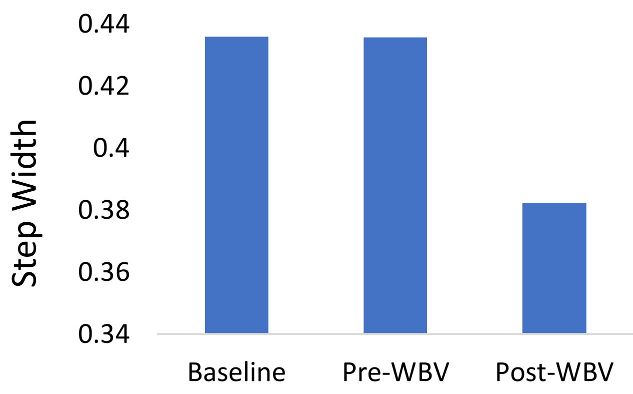
Figure 12.2: Peak joint power during sit-to-stand (StS) phase, (a) Peak ankle power, (b) Peak knee power, (c) peak hip power.

There were no apparent changes in the spatial-temporal variables during the WO phase after vibration (Figure 13.2).

a.



b.



c.

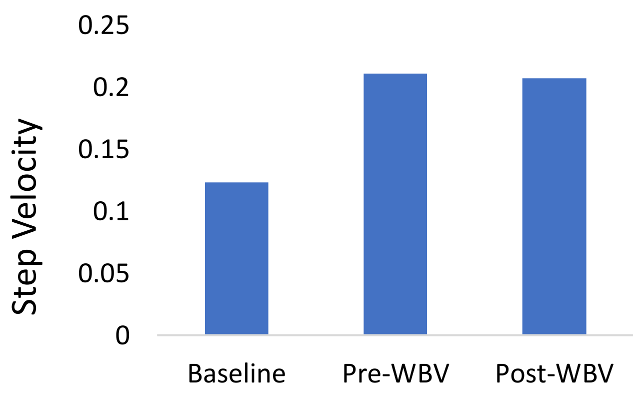


Figure 13.2: Spatial-temporal variables of the walk-out (WO) phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

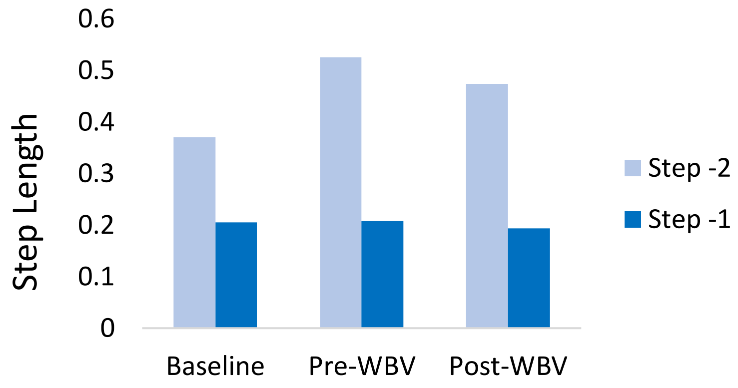
Case # 3

Subject 3 was a 10-year-old female. The parent's rating of the BRIEF-2 placed their inhibit score in the 97th percentile, shift in the 96th percentile, emotional control in the 39th percentile, working memory in the 91st percentile, plan/organize in the 95th percentile, and task monitor in the >99th percentile for their age group by gender (8-10 TD year olds) (Table 1).

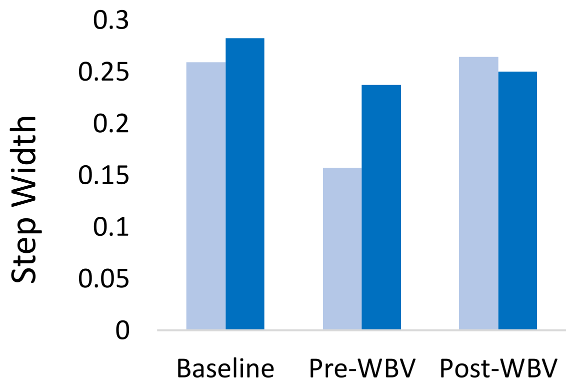
The third subject did not complete the Flanker Test. After multiple attempts to complete the task, the subject did not meet the requirements for threshold to proceed past the practice trials. The mother stated that the child struggled with directions and was the possible reason for the inability to complete the task.

For the SA task, the subject demonstrated the feet adjacent strategy and used her hands for assistance for all of the trails during each time condition. During the approach phase, the subject demonstrated a shorter (Figure 6.3a) and slower step (Figure 6.3c) for step -1 compared to step -2. They did not demonstrate any apparent changes in the spatial-temporal variables after vibration.

a.



b.



c.

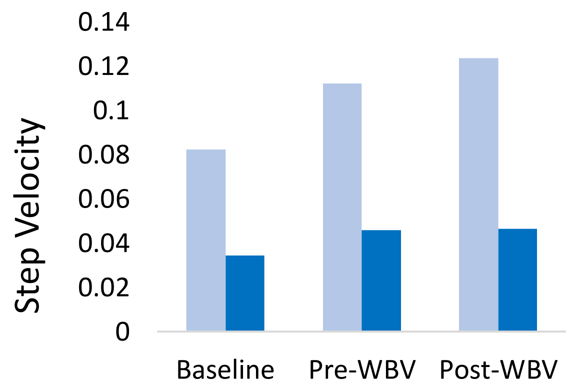
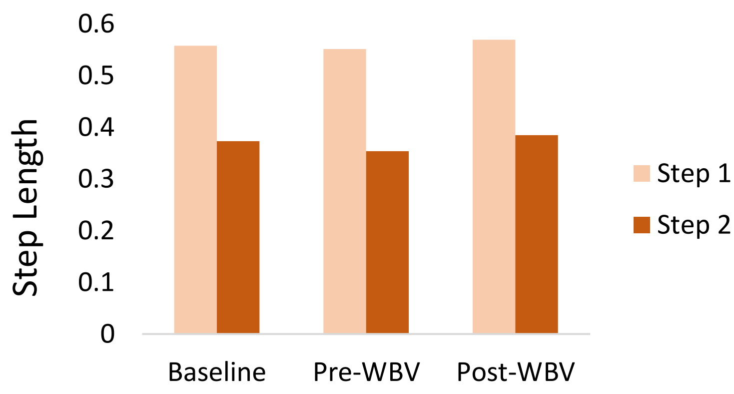


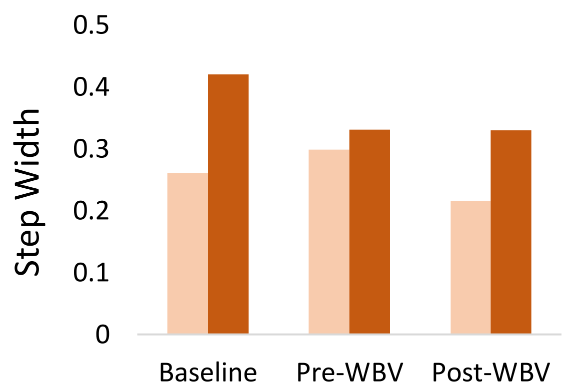
Figure 6.3: Spatial-temporal variables for the SA task – approach phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

During the ascent phase, the subject demonstrated a shorter step length (Figure 7.3a), larger step width (Figure 7.3b) and slower step velocity (Figure 7.3c) for step 2 compared to step 1. There were no apparent changes in the spatial-temporal variables after vibration.

a.



b.



c.

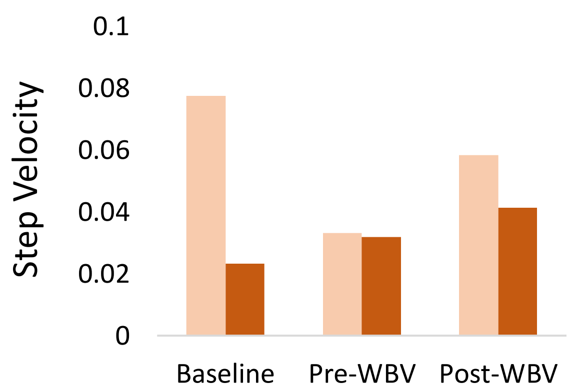
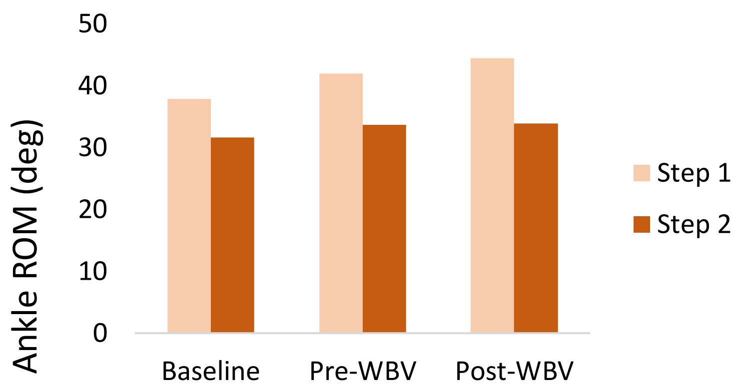


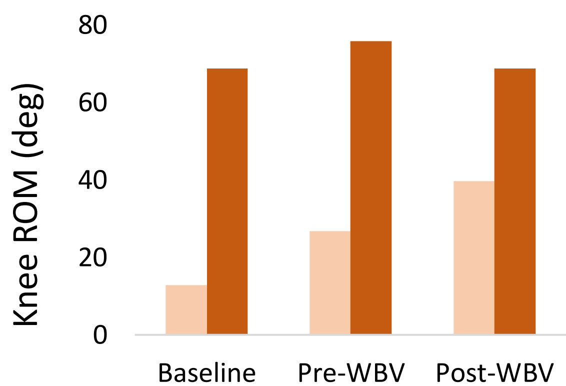
Figure 7.3: Spatial-temporal variables for the SA task – ascent phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

The subject demonstrated a larger ROM during stance at the knee for step 2 compared to step 1 (Figure 8.3b) and a smaller ROM at the ankle (Figure 8.3a) during stance for step 1 compared to step 2. Following vibration, the subject demonstrated an increased knee ROM from 26.85 to 39.66 degrees (Figure 8.3b) during stance for step 1. The subject also demonstrated an increase in hip ROM from 46.97 to 53.68 degrees during stance for step 2 and from 39.92 to 45.36 degrees during stance for step 1 (Figure 8.3c).

a.



b.



c.

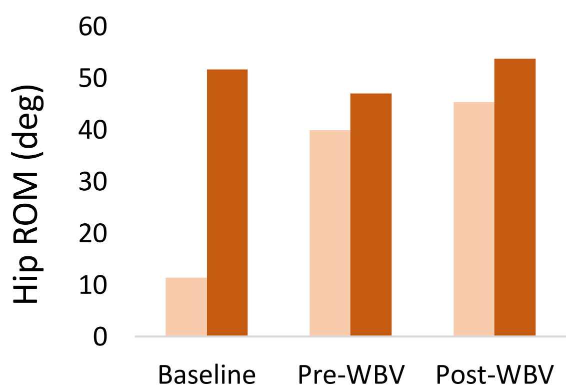
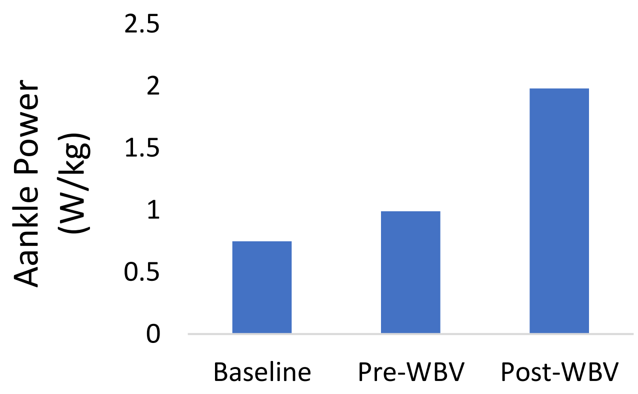


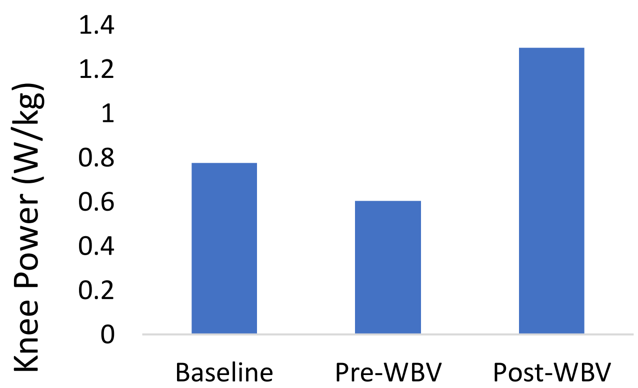
Figure 8.3: Joint range of motion (ROM) measured in degrees, (a) Ankle ROM, (b) Knee ROM, (c) Hip ROM.

The subject demonstrated an increase in ankle (Figure 9.3a), knee (Figure 9.3b) and hip (Figure 9.3c) power generation following vibration for the first step ascending the staircase. Ankle power increased from 0.99 W/kg to 1.98 W/kg, knee power increased from 0.60 W/kg to 1.30 W/kg, and hip power increased from 1.42 W/kg to 2.79 W/kg.

a.



b.



c.

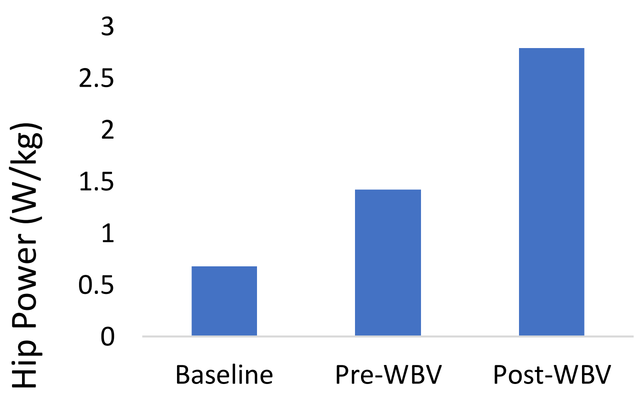


Figure 9.3: Peak joint power during ascent up first step of staircase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

For the TUG task, the subject did not show any changes in the duration to complete the task after vibration (Figure 10.3).

a.

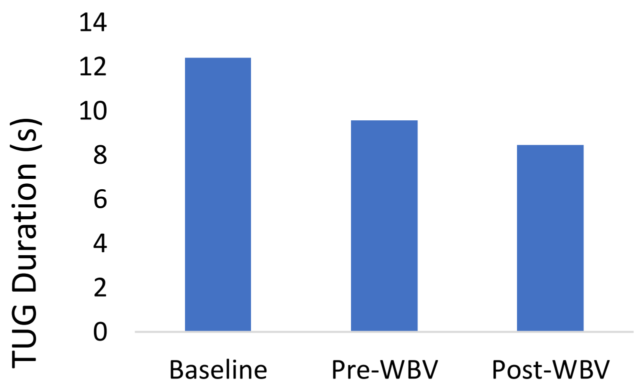
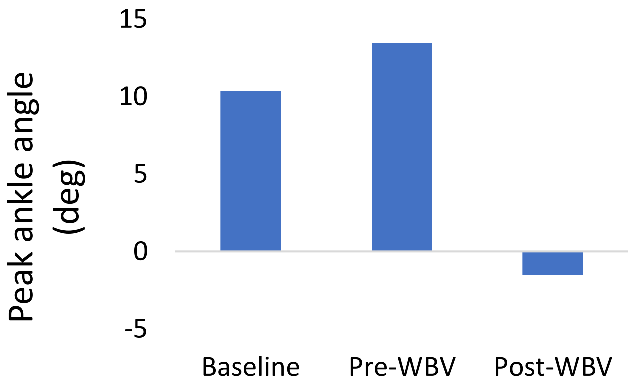


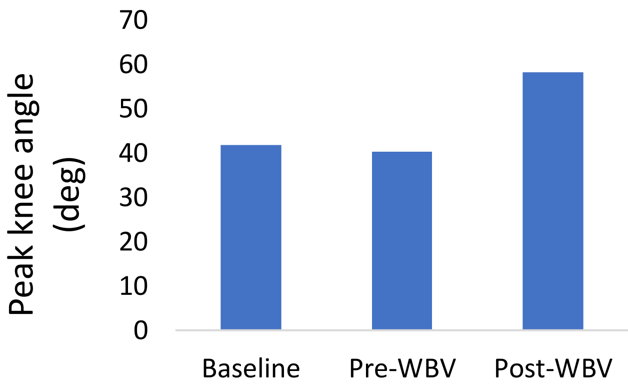
Figure 10.3: Duration of the timed up-and-go (TUG) test in seconds.

For the StS phase, the subject demonstrated a change in peak ankle angle from a dorsiflexed to plantarflexed position (Figure 13a) after vibration. The subject also demonstrated greater flexion at the knee following vibration (Figure 13b). The amount of flexion increased from 40.36 to 58.26 degrees of flexion after vibration.

a.


Peak ankle angle (deg)
15
10
5
0
-5
Baseline
Pre-WBV
Post-WBV

b.


Peak knee angle (deg)
70
60
50
40
30
20
10
0
Baseline
Pre-WBV
Post-WBV

c.

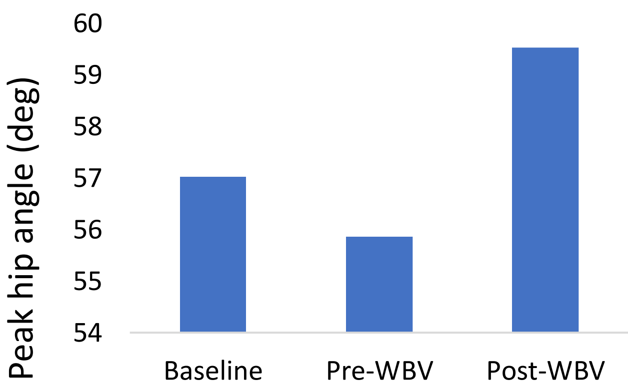
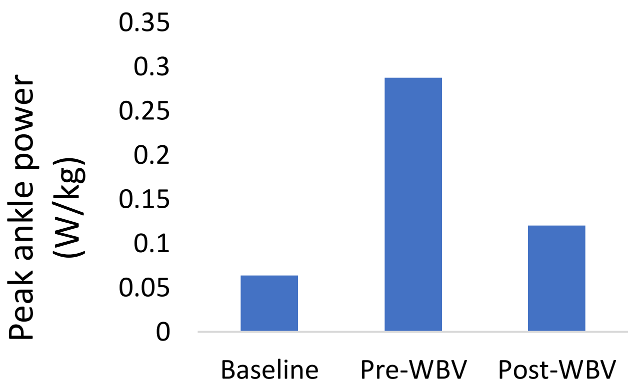

Peak hip angle (deg)
60
59
58
57
56
55
54
Baseline
Pre-WBV
Post-WBV

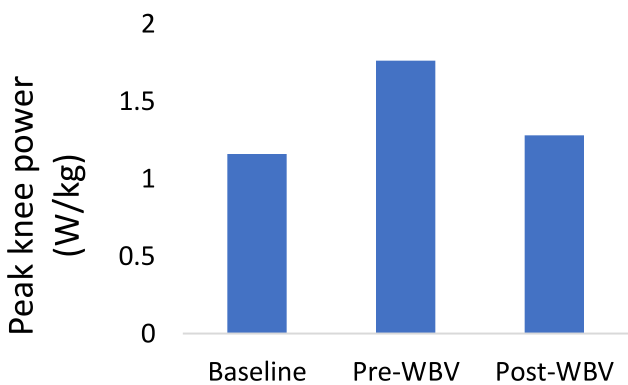
Figure 11.3: Peak joint angle during sit-to-stand (StS) phase, (a) Peak ankle angle, (b) Peak knee angle, (c) Peak hip angle. Positive angles represent joint in flexed position (dorsiflexed for ankle).

The subject demonstrated a trend of decreasing power generation at the ankle (Figure 12.3a), knee (Figure 12.3b) and hip (Figure 12.3c) after vibration.

a.



b.



c.

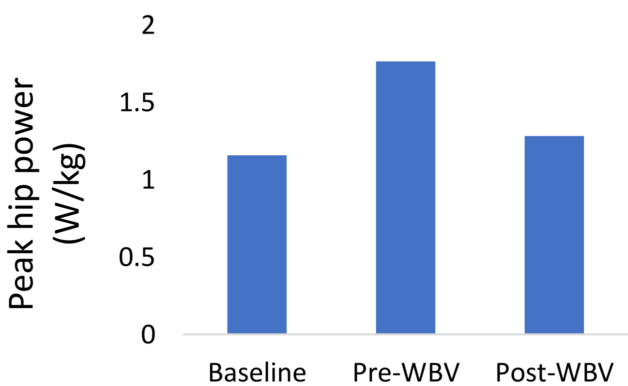
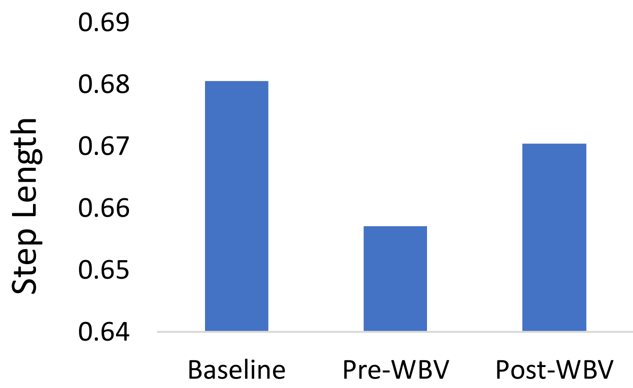


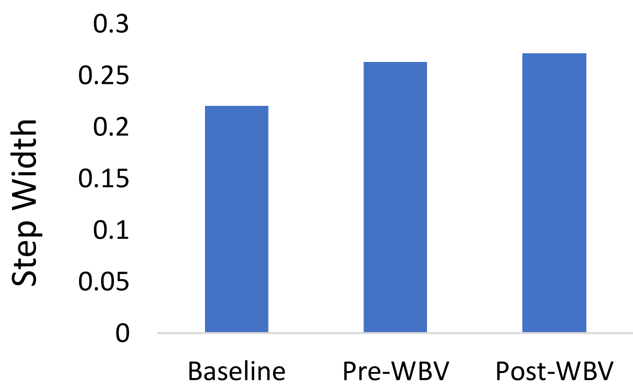
Figure 12.3: Peak joint power during sit-to-stand (StS) phase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

The subject did not demonstrate any apparent changes in the spatial-temporal variables for the WO phase after vibration.

a.



b.



c.

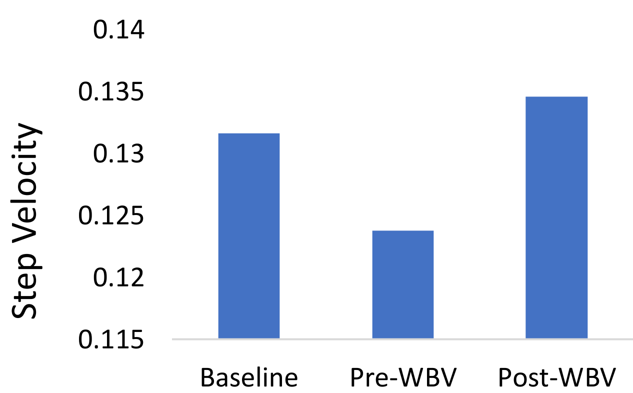


Figure 13.3: Spatial-temporal variables of the walk-out (WO) phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

Case # 4

Subject 4 was a 14.5-year-old male. The parent's rating of the BRIEF-2 placed their inhibit score in the 97th percentile, shift in the 94th percentile, emotional control in the >99th percentile, working memory in the 94th percentile, plan/organize in the 75th percentile, and task monitor in the 77th percentile for their age group by gender (14-18 TD year olds) (Table 1).

Subject 4 responded all the congruent trials correctly for the Flaker Test using the fish stimuli. The response time for the congruent trials increased from baseline to pre-WBV from 0.75 to 1.58 seconds and from pre-WBV to post-WBV condition from 1.58 to 1.72 seconds. For the incongruent trials, the accuracy decreased by one question and response time increased from the baseline to pre-WBV conditions from 0.97 to 2.56 seconds. There was no change in accuracy, but response time increased between the pre-WBV to post-WBV conditions from 2.56 to 3.71 seconds. The response time for correct responses increased from 2.38 to 3.94 seconds and decreased for incorrect responses from 3.79 to 2.15 seconds (Table 2).

For the Flanker Test using arrows, the subject had an increase in accuracy and decrease in response time between the baseline and pre-WBV conditions for the congruent trials. The accuracy increased from 91.67% to 100% and response time decreased from 2.66 to 1.41 seconds. There was a decrease in accuracy from 100% to 75% and response time from 1.41 to 1.19 seconds after vibration for the congruent trials.

For the incongruent trials, there was no change in accuracy but a decrease in response time between the baseline and pre-WBV conditions. The response time decreased from 2.22 to 1.67 seconds. There was an increase in accuracy and increase in response time after vibration. The accuracy increased 12.5% to 37.5% and response time increased from 1.67 to 3.2 seconds (Table 3).

For the SA task, the subject demonstrated the step-over-step strategy to ascend the staircase for all time conditions. For the approach phase, the subject did not demonstrate any apparent changes in the spatial-temporal variables after vibration.

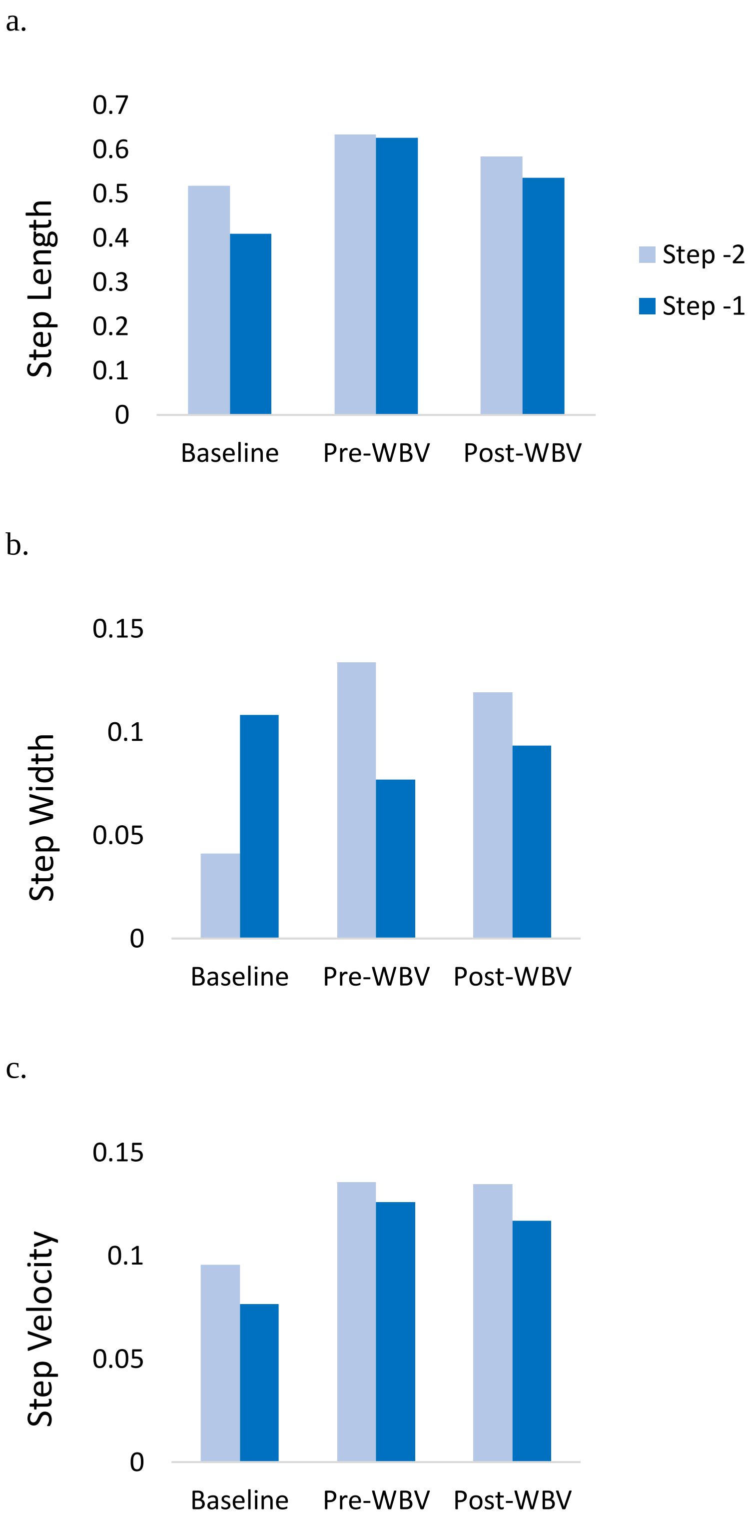
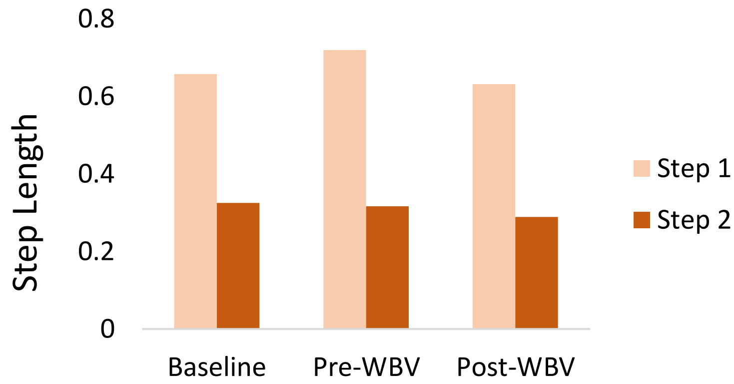


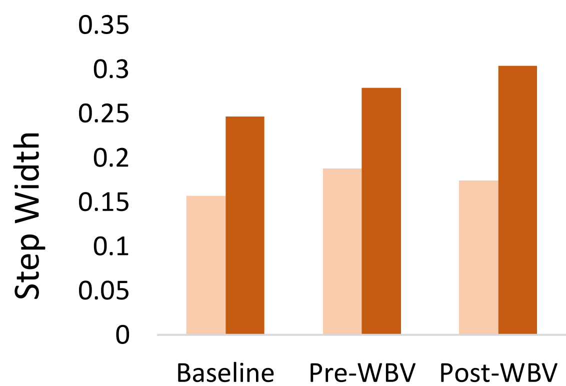
Figure 6.4: Spatial-temporal variables for the SA task – approach phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

For the ascent phase, the subject demonstrated a shorter (Figure 7a), slower (Figure 7e) and larger step width (Figure 7b) during step 2 compared to step 1. There were no apparent changes in the spatial-temporal variables after vibration during the ascent phase.

a.



b.



c.

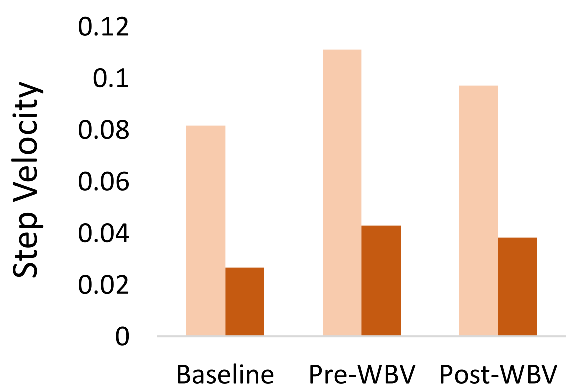
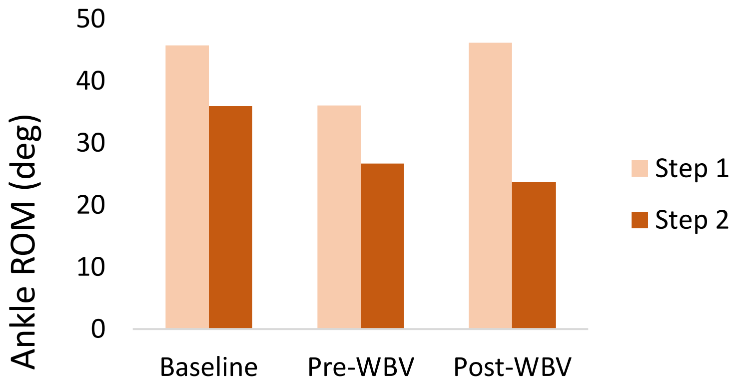


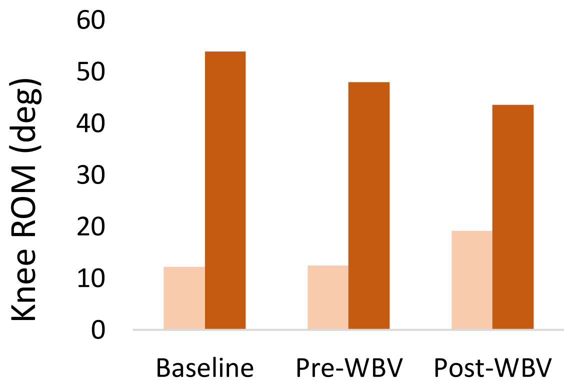
Figure 7.4: Spatial-temporal variables for the SA task – ascent phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

The subject demonstrated an increased ankle ROM (Figure 8.4a) and knee ROM during stance (Figure 8.4b) for step 2 compared to step 1. Following vibration, the subject demonstrated an increased ankle ROM during stance (Figure 8.4a) for step 1. He increased his ankle ROM from 36.01 to 46.2 degrees.

a.



b.



c.

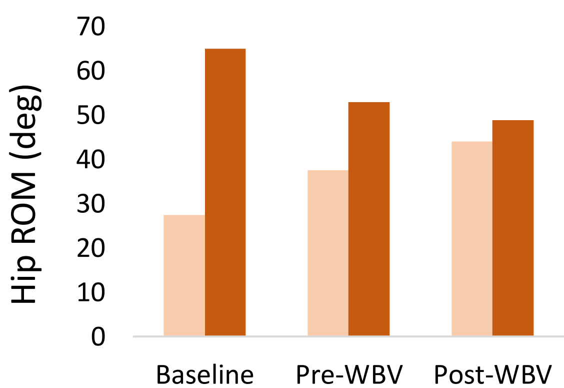
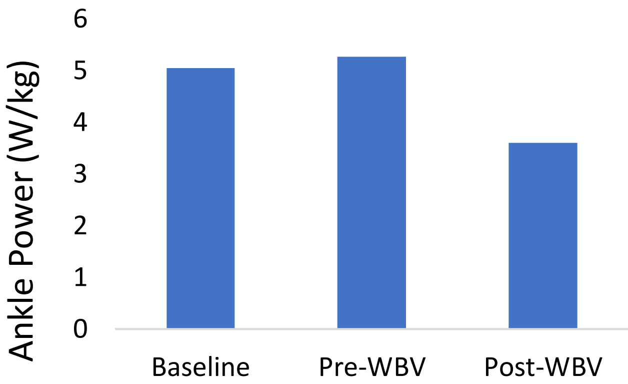


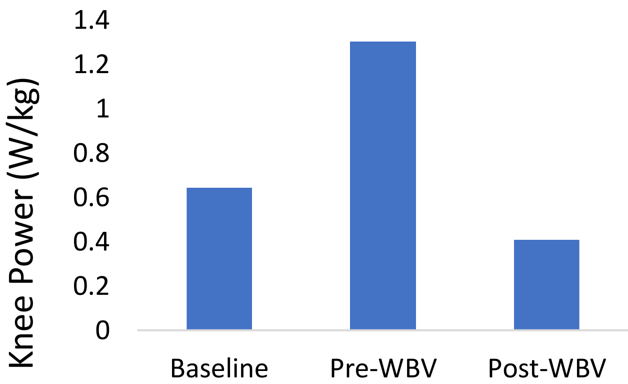
Figure 8.4: Joint range of motion (ROM) measured in degrees, (a) Ankle ROM, (b) Knee ROM, (c) Hip ROM.

The subject demonstrated a decrease in peak ankle (Figure 9.4a), knee (Figure 9.4b) and hip (Figure 9.4c) power generation following vibration during the first step ascending the staircase. He decreased his ankle power from 5.57 W/kg to 3.60 W/kg, knee power from 1.30 W/kg to 0.41 W/kg and hip power from 1.87 W/kg to 1.03 W/kg (Figure 9.4).

a.



b.



c.

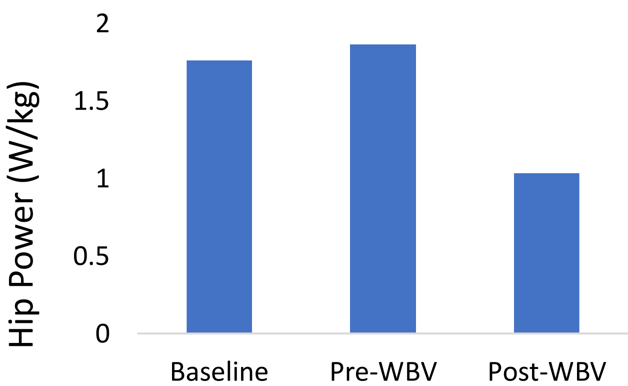


Figure 9.4: Peak joint power during ascent up first step of staircase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

This subject had missing data for the TUG test during the pre-WBV condition due to the subject being overweight and blocking the anterior pelvic makers not allowing the Vicon model to be run the pipeline for calculating the variables. This made it difficult to compare the pre-WBV and post-WBV conditions. He did not demonstrate any apparent changes in the spatial-temporal variables for the WO phase (Figure 13.4).

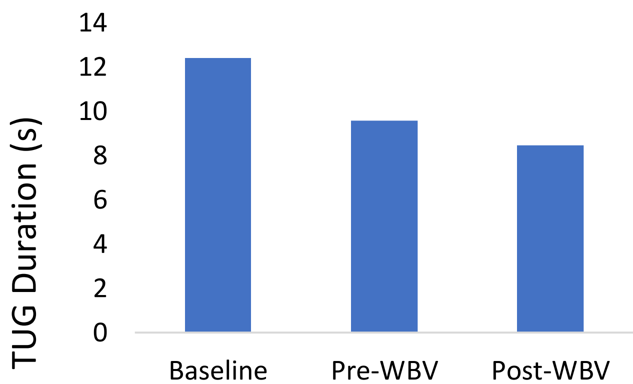
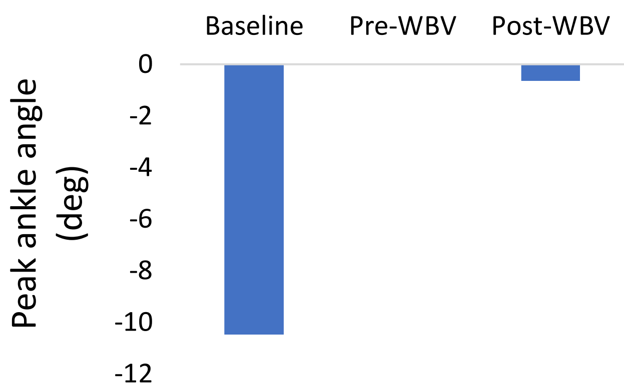
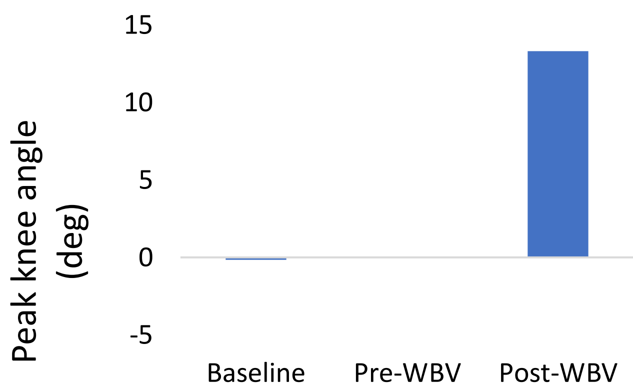


Figure 10.4: Duration of the timed up-and-go (TUG) test in seconds.

a.


Baseline
Pre-WBV
Post-WBV
0
-2
-4
-6
-8
-10
-12
Peak ankle angle (deg)

b.


15
10
5
0
-5
Baseline
Pre-WBV
Post-WBV
Peak knee angle (deg)

c.

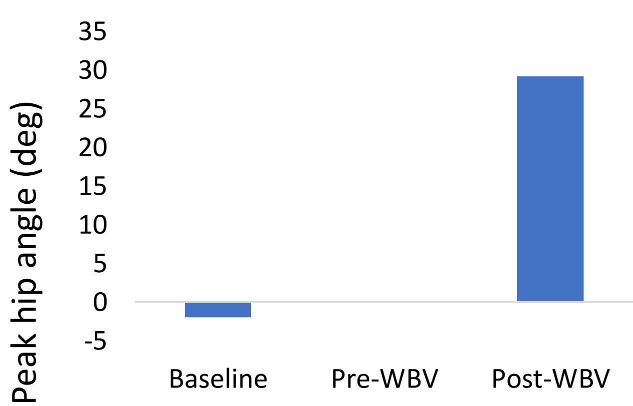
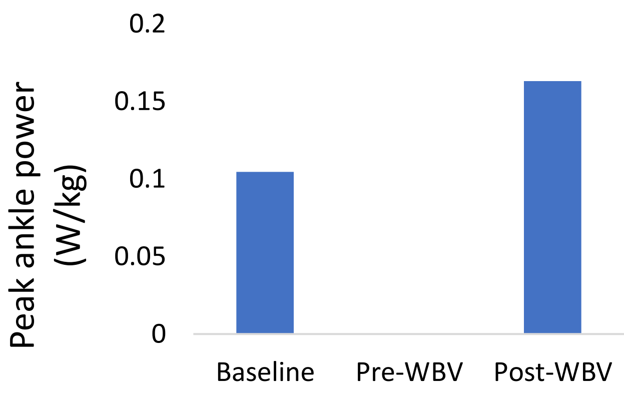
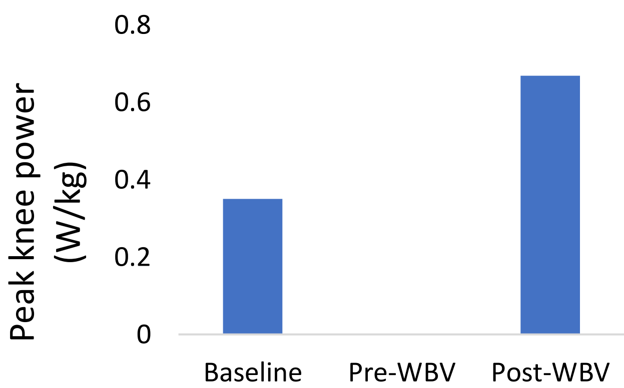

35
30
25
20
15
10
5
0
-5
Baseline
Pre-WBV
Post-WBV
Peak hip angle (deg)

Figure 11.4: Peak joint angle during sit-to-stand (StS) phase, (a) Peak ankle angle, (b) Peak knee angle, (c) Peak hip angle. Positive angles represents joint in flexed position (dorsiflexed for ankle).

a.



b.



c.

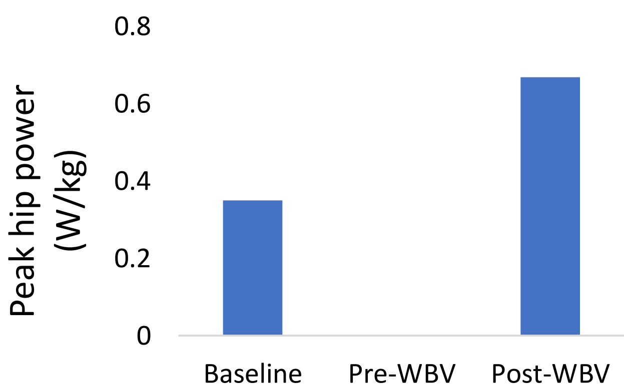
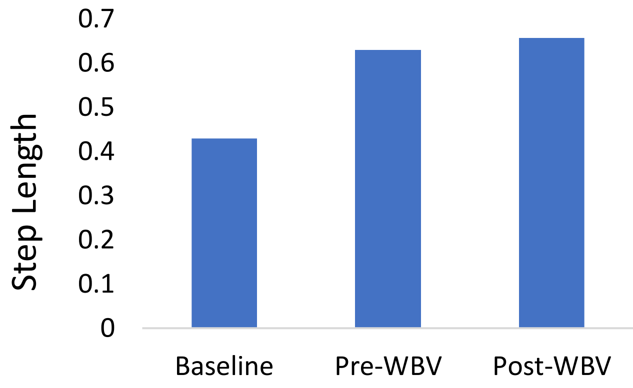
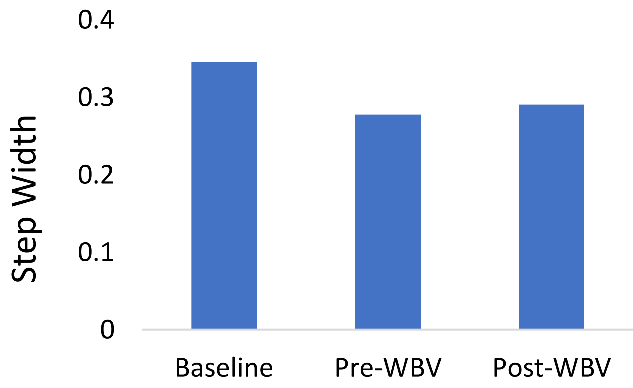


Figure 12.4: Peak joint power during sit-to-stand (StS) phase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

a.



b.



c.

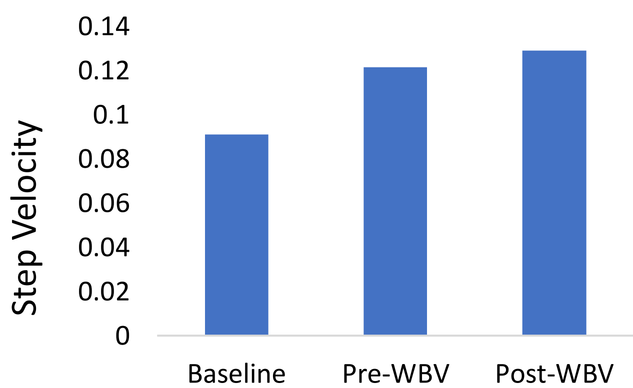


Figure 13.4: Spatial-temporal variables of the walk-out (WO) phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

Case # 5

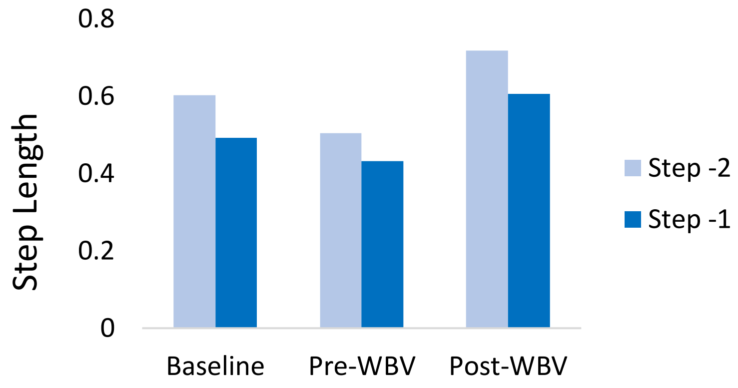
Subject 5 was a 12.8-year-old female. The parent's rating of the BRIEF-2 placed their inhibit score in the 15th percentile, shift in the 26th percentile, emotional control in the 26th percentile, working memory in the 69th percentile, plan/organize in the 80h percentile, and task monitor in the 52nd percentile for their age group by gender (11-13 TD year olds) (Table 1).

The fifth subject responded all the trials, congruent and incongruent, correctly for the Flanker Test using fish and arrows (Table 2&3). There was an increase in response time between the baseline and pre-WBV conditions as well as between the pre-WBV and post-WBV conditions. The response time was higher for the Flanker Test using the arrow stimuli compared to the fish stimuli. The response time for the incongruent trials was also higher compared to the congruent trials for both Flanker Test stimuli (Table 2&3).

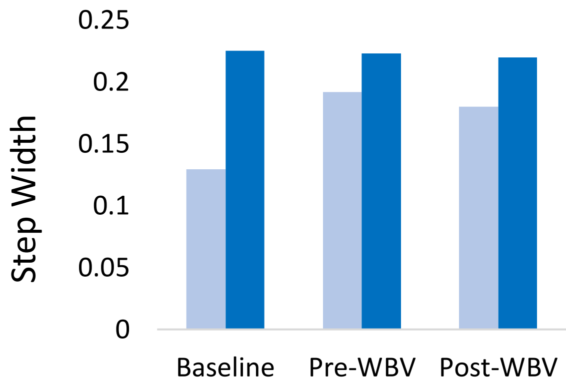
For the SA task, the subject demonstrated the feet adjacent and step-over-step strategy for the baseline and pre-WBV conditions equally. After the session of vibration, the subject only demonstrated the step-over-step strategy.

During the approach phase, the subject demonstrated an increased step length for step -2 and step -1 (Figure 6.5a), and increased step velocity for step -2 and step -1 (Figure 6.5c) following vibration. She increased her step length from 0.5 to 0.72 for step -2 and from 0.43 to 0.61 for step -1. She increased her step velocity from 0.09 to 0.17 for step -2 and from 0.07 to 0.13 for step -1.

a.



b.



c.

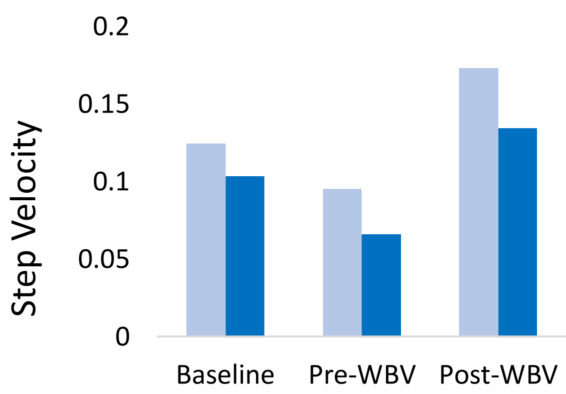
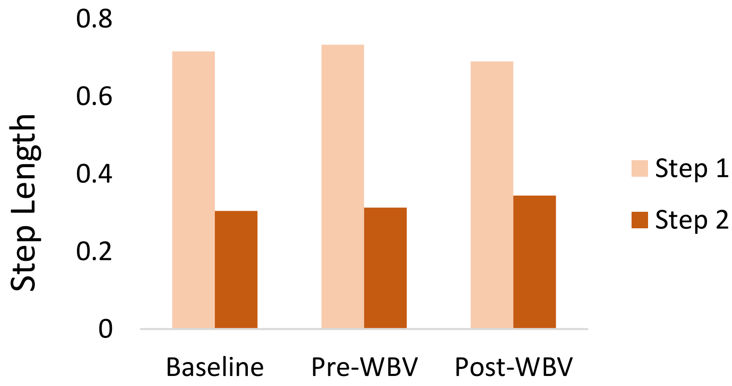


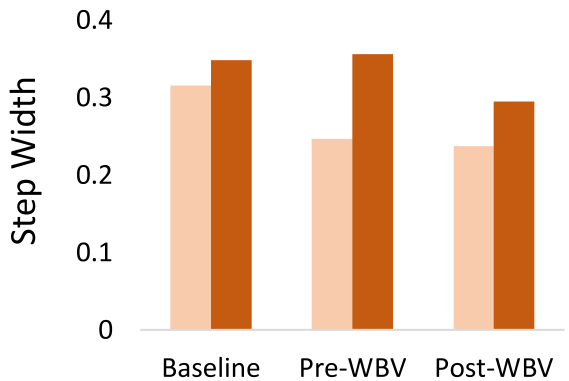
Figure 6.5: Spatial-temporal variables for the SA task – approach phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

During the ascent phase, the subject demonstrated a shorter (Figure 7.5a) and slower step (Figure 7.5c) for step 2 compared to step 1. There were no apparent changes in the spatial-temporal variables after vibration.

a.



b.



c.

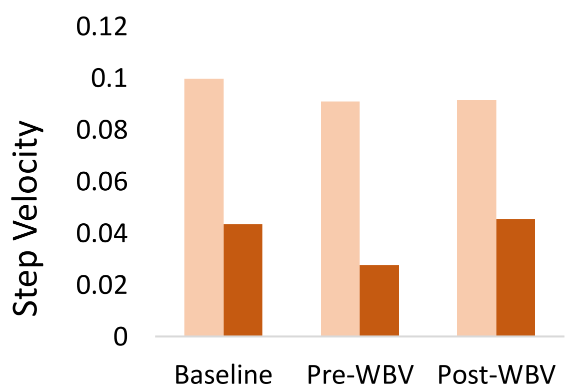
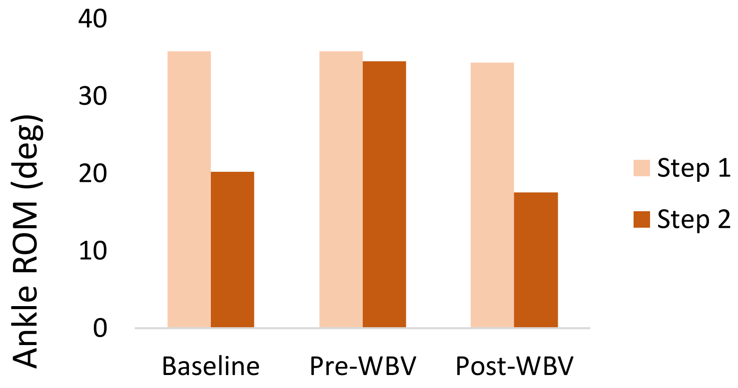


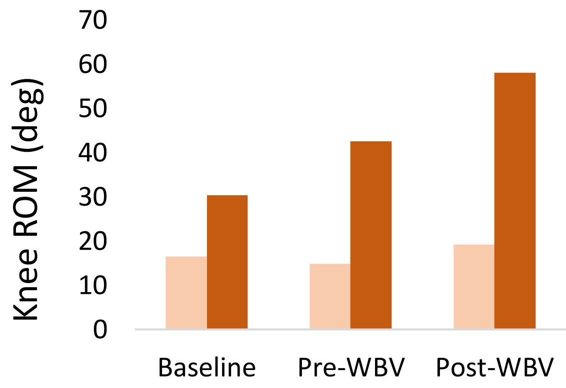
Figure 7.5: Spatial-temporal variables for the SA task – ascent phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

During stance phase, the subject demonstrated a decreased ROM at the knee (Figure 8.5b) and hip (Figure 8.5c) for step 1 compared to step 2. After vibration, she demonstrated a decrease in ankle ROM for step 2 from 34.64 to 17.53 degrees (Figure 8.5a). She also demonstrated an increase in ROM at the knee and hip for step 2. She increased her knee ROM from 42.52 to 58.02 degrees (Figure 8.5b) and hip ROM from 41.46 to 52.62 degrees (Figure 8.5c).

a.



b.



c.

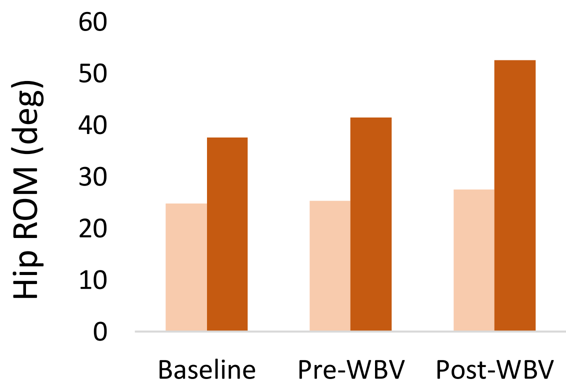
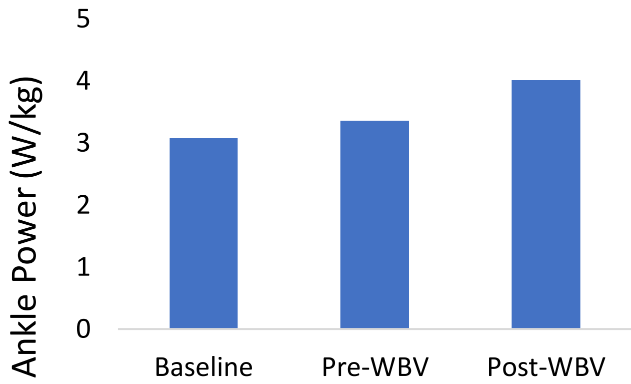


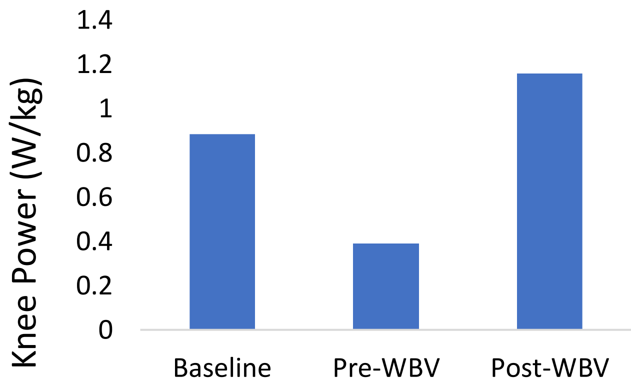
Figure 8.5: Joint range of motion (ROM) measured in degrees, (a) Ankle ROM, (b) Knee ROM, (c) Hip ROM.

The subject demonstrated an increase in ankle (Figure 9.5a), knee (Figure 9.5b) and hip (9.5c) power generation following vibration for the first step ascending the staircase. Ankle power increased 3.36 W/kg to 4.02 W/kg, knee power from 0.39 W/kg to 1.16 W/kg, and hip power from 0.65 W/kg to 1.30 W/kg.

a.



b.



c.

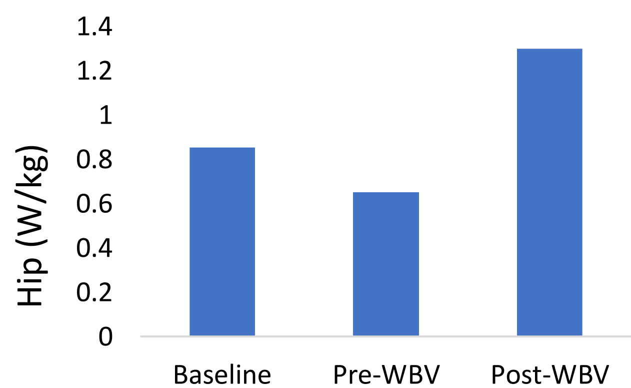
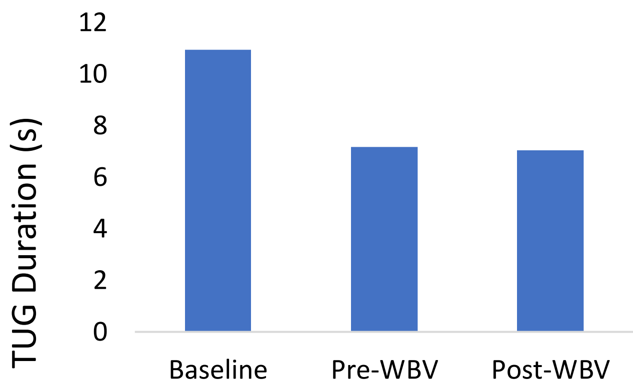


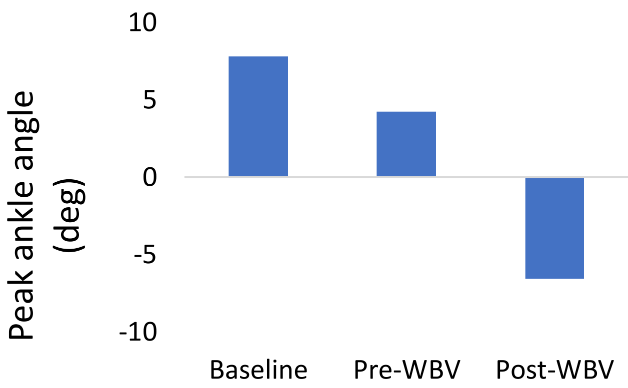
Figure 9.5: Peak joint power during ascent up first step of staircase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

For the TUG task, the subject did not demonstrate a change in the duration to complete the task after vibration (Figure 10.5).

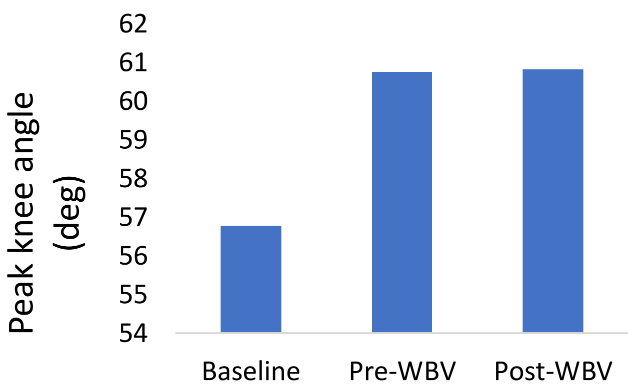


During the StS phase, the subject demonstrated a change in the peak angle from a dorsiflexor angle to a plantarflexor angle following vibration (Figure 11.5a).

a.



b.



c.

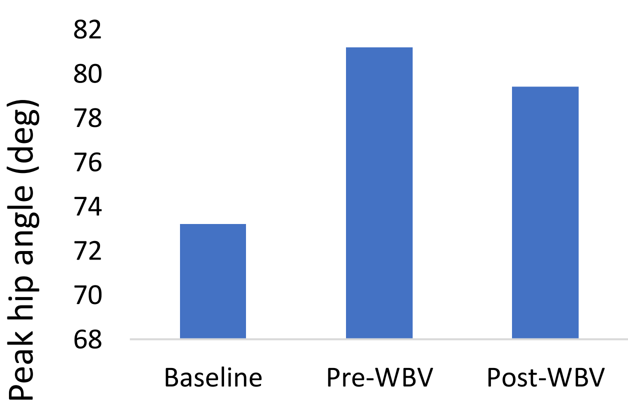
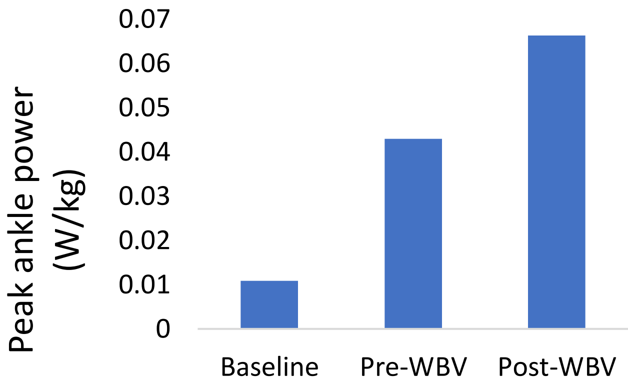


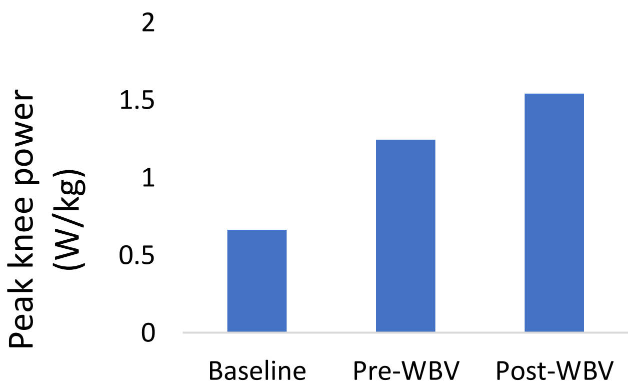
Figure 11.5: Peak joint angle during sit-to-stand (StS) phase, (a) Peak ankle angle, (b) Peak knee angle, (c) Peak hip angle. Positive angles represent joint in flexed position (dorsiflexed for ankle).

The subject demonstrated a trend of increase in joint power generation at the ankle (Figure 12.5a), knee (12.5b), and hip (Figure 12.c).

a.



b.



c.

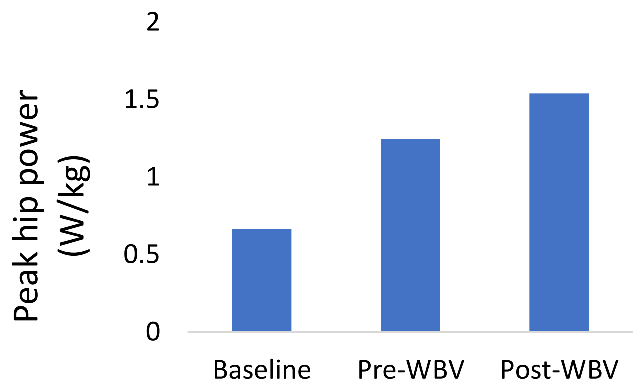
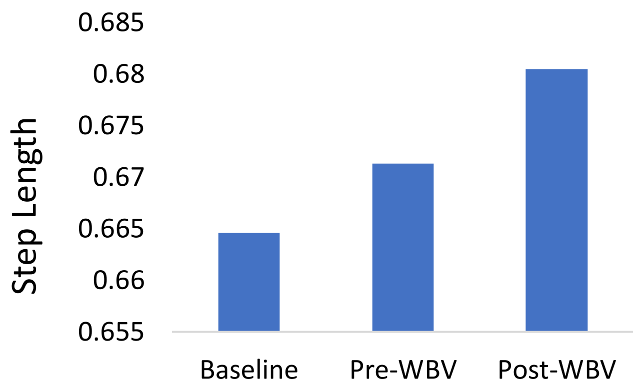


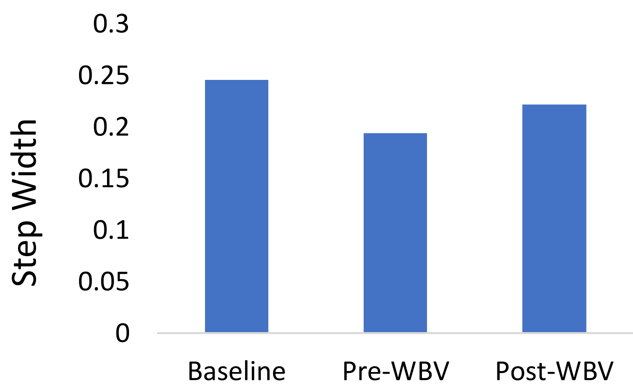
Figure 12.5: Peak joint power during sit-to-stand (StS) phase, (a) Peak ankle power, (b) Peak knee power, (c) Peak hip power.

The subject did not demonstrate any apparent changes for the spatial-temporal variables of the WO phase after vibration (Figure 13.5).

a.



b.



c.

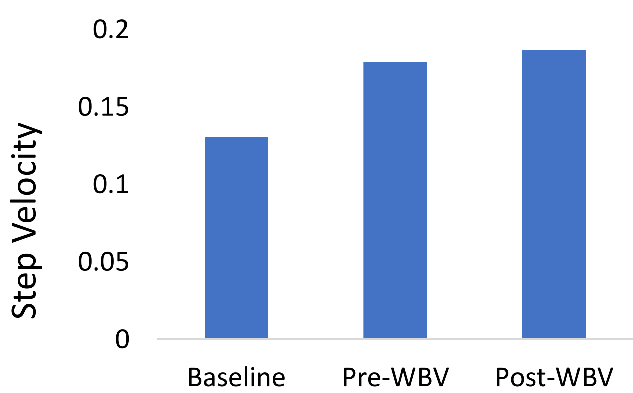


Figure 13.5: Spatial-temporal variables of the walk-out (WO) phase, (a) Normalized step length, (b) Normalized step width, (c) Normalized step velocity.

Discussion

This study investigated the acute effects of WBV on motor and cognitive function in children with DS. The preliminary results of this study indicate that WBV may be a beneficial modality in this population to elicit acute benefits. Several subjects in this study demonstrated positive trends for the cognitive and motor tasks after the session of WBV. This is consistent with previous studies that used WBV in healthy and some clinical populations to elicit acute benefits. Additionally, this study sought to identify the mechanisms that WBV provides to the cognitive and motor tasks.

Inhibitory control and selective attention

The subjects responded all the congruent trials correctly during the Flanker Test with fish stimuli for each time period, except for subject 1 under the post-WBV (answered 1 incorrectly). The Flanker Test with arrow stimuli showed similar patterns. Two of the subjects answered one incorrectly during the baseline condition. One of those subjects did demonstrate a reduction in performance following vibration (subject 4). This subject had the highest parent reported emotional control, which indicates a decreased ability to regulate emotions. It is possible that this subject was agitated or upset with having to complete this task for a third time. This could have negatively affected their performance and may have not been due to the vibration.

One of the subjects performed equally as well on the accuracy of the incongruent trials as the congruent trials for the Flanker Test with fish stimuli and arrow stimuli (Subject 5). This subject had the lowest parent reported inhibit score, which indicates that this subject had the best inhibitory control of the group. This could explain the subject’s higher performance compared to the other subjects. The other subjects performed more accurately with the fish stimuli than the arrow stimuli. This could be due to the presentation of the instructions and the stimuli. The instructions given during the fish stimuli is to “feed the fish” by tapping the arrow where the side of the mouth is to feed the fish in the middle of the array. The instructions for the arrow stimuli is to choose the matching arrow as the middle arrow in the array. Thus, it is possible that these children either understood the instructions for the fish stimuli better or they were able to inhibit the flanking fish better during the incongruent trials. It is possible that it may be a combination of the two. Because the instruction for the fish stimuli was to only feed the fish in the middle, it is likely the children only focused on the middle fish and ignored the flanking fish and thus performed more accurately.

The results of the preliminary data partially supports the hypothesis that WBV would improve attention and inhibitory control. One of the subjects did demonstrate an improvement in the accuracy of the Flanker Test with fish stimuli incongruent trials following vibration. Another subject demonstrated an improvement in accuracy of the Flanker test with arrow stimuli incongruent trials following vibration. The subjects however demonstrated an increase in their response time following vibration. These results are in contrast with den Heijer et al. (2015), Regterschot et al. (2014) and Fuermaier, Tucha, Koerts, van Heuvelen, et al. (2014). den Heijer et al. (2015) and Regterschot et al. (2014) found that the response time to complete the Stroop Color-Word Test was reduced after WBV in TD children and young adults, respectively. Fuermaier, Tucha, Koerts, van Heuvelen, et al. (2014) also found that the response to complete the Color-Word Test was reduced after WBV in healthy adults and adults with ADHD. This indicates that one session of WBV may be used to improve the inhibitory control but not response time in children with DS. Children with DS may need more than one session of WBV to see significant improvements in response time.

The subjects' response time was lower during the Flanker Test using the fish stimuli than the arrow stimuli. As previously mentioned, the subjects may have understood the instructions for the fish stimuli better or may have been more engaged by the fish stimuli than the arrow stimuli. The subjects also took longer to complete the incongruent trials than the congruent trials for both fish and arrow stimuli. Eriksen and Eriksen (1974) found that subjects took longer to respond during the incongruent trials due to the need to exercise top-down control (Diamond, 2013). There was also another pattern that emerged with respect to the time to complete the task. Subjects that took relatively longer to respond performed more accurately for both congruent and incongruent trials. These results support the hypothesis by Simpson and Riggs (2007). They hypothesized that more time helps the prepotent??? response to reach the response threshold and fade. This enables the correct response to be chosen more successfully (Diamond, 2013; Simpson & Riggs, 2007).

Executive functions are critical to aspects of learning during childhood and have strong influences on academic performance and achievement (Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; St Clair-Thompson & Gathercole, 2006; Swanson, 2006). There are several neurodevelopmental disorders including ADHD that are associated with problems in executive functions (Gioia, Isquith, Kenworthy, & Barton, 2002; Henry, 2010; Verte, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006). Rowe, Lavender, and Turk (2006) found that adults with DS had decreased executive function compared to healthy adults. They suggest that these impairments in executive function are likely due to the impaired development of the prefrontal cortex and that executive function deterioration may be an indicator dementia of the Alzheimer type (Rowe et al., 2006). Thus, addressing deficiencies in executive function, working memory, attention, and inhibition are critical in the DS population. Therapy modalities should be designed at a young age while the brain is still developing to help improve the development of the brain so that there less deterioration of the cognitive ability of individuals with DS as they age.

Motor performance

The results of this study also partially supported the hypothesis that WBV would improve motor performance. Some subjects demonstrated qualitative and quantitative improvements following WBV for both the SA and TUG tasks.

During the approach phase of the SA task, subjects demonstrated two strategies in the preparation for ascent. One strategy involved taking short steps with their feet together (shuffling of feet) in front of the staircase, while the other strategy did not involve either shuffling of steps or placing their feet together to prepare for ascent. These results are similar to results that Liang et al. (2018a) found, where children with DS demonstrated shorter toe-to-stair distance and shuffling steps in children with DS compared to TD children with DS while performing the same SA task. These results suggest that children with DS have underdeveloped locomotor ability (Liang et al., 2018a). Following vibration, many of the subjects demonstrated an improved preparatory strategy. They no longer shuffled their feet and took longer steps during the approach phase. This along with the increased ROM at the ankle, knee and hip demonstrated by some of the subjects indicates that WBV may provide benefits at the neuromuscular level improving performance during the task.

During the ascent phase of the SA task, subjects demonstrated two strategies to ascend the staircase. One involved the use hands to help ascend the staircase (crawling strategy), while the other strategy involved walking up the staircase without the use of hands. These strategies are similar to a study by Liang et al. (2018b), who previously found that children with DS nearly equally chose between walking (47%) and crawling (51%), where crawling involved using hands to assist their ascent on a staircase with the same riser height used in this study. These results indicate that children with DS may not have the muscular strength and/or coordination to perform this activity with the necessary stability to ascend the staircase with this riser height. Of the two subjects in this study that demonstrated this crawling technique, one was able to ascend the staircase without the assistance of their hands for two trials following vibration. While the subjects demonstrated a difference in the step length between the two ascending steps, this is likely due to the restriction of the staircase dimensions. Unless the subjects skipped a step on the staircase, they would be restricted to the length of the respective staircase step. Due to the variability within subjects and between subjects, it was difficult to determine if WBV had an overall positive effect on the joint kinematics and dynamics during ascent. Some subjects did demonstrate increases in joint ROM and extensor moment and power. However, some demonstrated a decrease in joint ROM and extensor moment and power during the first step ascending the staircase. These subjects may have altered their strategy to rely primarily on flexor moments and power to assist their ascent. They may have also altered their mechanics to ascend the staircase using increased motion in the frontal and transverse plane. Further analysis into the mechanics in all three planes is needed to determine if subjects altered their mechanics or if WBV caused decreases in sagittal plane kinematics and dynamics for those subjects.

The TUG test was chosen due to the functional activities of daily living that are incorporated in this test. Beerse, Lelko, et al. (2019) found that children with DS took longer to complete the test, produced smaller peak vertical center of mass velocity during standing and walked slower during the WO compared to TD children. These results indicate that children with DS were less able to anticipate/plan between transitions and initiate those tasks. Some of the subjects demonstrated decreases in the overall TUG duration, including during certain phases after vibration.

Interestingly, during the StS phase, two subjects demonstrated a change in peak ankle joint angle. Before WBV, their joints were in a dorsiflexed position. Following vibration, they demonstrated a plantarflexed position. One subject demonstrated a peak plantarflexed position before WBV but demonstrated a peak dorsiflexed position after vibration. Some subjects also demonstrated a more flexed knee angle following vibration. This means these subjects stood less vertically (less extension primarily at the knee) to begin the transition into the WO phase. This may indicate that subjects were more prepared to transition into the next phase instead of delaying the standing phase to a completely vertical posture before initiating the WO phase.

For the WO phase, most subjects demonstrated a slight increase in step length and velocity and decrease in step width after WBV. These trends indicate that these subjects were able to improve their spatial-temporal gait patterns after WBV. This indicates that WBV could be beneficial as a preparatory modality for treadmill training. If children with Down syndrome have improved gait patterns immediately after WBV, reinforcing those patterns with repetitive practice of those improved patterns should improve their overall gait pattern if continued as a therapy intervention.

Relationship between cognitive and motor function

While this study did not directly investigate the relationship between motor and cognitive performance, there are several studies that have demonstrated the strong relationship between motor and cognitive development in TD children. Yamauchi et al. (2019) found that motor development was significantly correlated with cognitive and language development between the ages of 1 and 3 years of age in children with DS. They also found that this positive relationship strengthened as the children aged. As previously mentioned, the first year of age is an important milestone in the motor development of a child. Around this time, children develop the ability to walk independently. This is an important milestone due to the ability to explore the surrounding environment more freely. This increases the amount and variety of stimuli that a child would be exposed to which would facilitate their cognitive development (Feldman & Acredolo, 1979; Karasik, Tamis-LeMonda, & Adolph, 2011; Needham, 2000; Yamauchi et al., 2019). As previously mentioned, children with DS may experience significant delays in developing the ability to walk independently. The longer the delay in development of this ability, the more detrimental it will be to the cognitive development of a child with DS. This produces a cascading effect that will result in significantly reduced motor and cognitive performance when skills are developed.

Motor skills are typically analyzed by observing the mechanical properties of the activity. However, motor skills require a certain level of cognitive ability in order to perform them properly. In a study with adults, Amboni, Barone, and Hausdorff (2013) determined that appropriate gait requires cognitive skills such as attention, executive function, judgment of the environment and internal physical cues. This is supported by neurological studies that illustrate the importance of the caudate nucleus and prefrontal cortex for the initiation and control of movement (Diamond, 2000). As previously mentioned, the prefrontal cortex also has strong involvement in cognitive processing (Kolb & Whishaw, 1990; E. E. Smith & Jonides, 1999). This relationship between the two domains highlights the need to develop interventions in children with DS at the earliest age possible to address motor and cognitive function. If WBV does affect the neurotransmission of the prefrontal cortex, it could serve as a therapy modality to address the motor and cognitive deficiencies in individuals with DS.

Vibration effects

As previously stated, the exact mechanisms for WBV are not well understood. This study did not investigate the mechanisms that elicit benefits to either cognitive or motor performance. The purpose of this study was to investigate if WBV can elicit acute benefits to cognitive and motor performance in children with DS. However, previous theories could explain the benefits provided to the subjects in this study. One of the prevailing theories for improvements in motor performance is that the vibration increases the sensitivity of the stretch reflex, inhibiting activation of the antagonistic muscles through Iα-inhibitory neurons (Cardinale & Bosco, 2003; Pollock et al., 2011). This could partially explain the motor improvements observed in this study. If children with DS have typically high levels of co-activation compared to TD children (Chang, Kubo, & Ulrich, 2009), WBV could reduce co-activation. This would bring the muscular activity of children with DS closer to the muscular activity patterns of TD children. This would allow children with DS to demonstrate mechanics closer to TD children on motor tasks. Further investigation into the muscular activity patterns of children with DS during SA and the TUG are warranted to determine if this corroborate this theory.

Another important theory proposed relates to cognitive performance. Martin (2012) proposed that benefits observed in the cognitive domain are due to the vibrations stimulating cutaneous receptors which transmit afferent signals to the primary sensory cortex. The primary sensory cortex has direct and indirect connections to the prefrontal cortex (Braak et al., 1996). As previously stated, research has shown that children with DS demonstrated significantly lower brain activation in the dorsolateral prefrontal cortex and primary motor cortex than TD children when completing tasks that require executive functioning (Xu et al., 2020). WBV may increase neurotransmission to these areas of the brain, increasing brain activity to levels closer to that of CA-matched TD children. This would theoretically improve executive function, including inhibitory control. This could explain the acute improvements observed in the Flanker Tests for some of the subjects in this study.

Limitations

The limited sample size only provides preliminary information about patterns or trends of the results. Additional subjects are needed to determine if WBV provides significant improvements in this population. This is also important due to the heterogeneity of the population. With a limited sample size, any potential benefits may not be seen due to the variability between and within subjects. While there was a control condition (baseline) included, there was no control group. While the control condition allows for the observation of learning effects, it does not eliminate the possibility that benefits following the WBV were not due to learning effects. Typically, there are improvements following rehearsal of an activity. Therefore, in the future a control group needs to be added, particularly if WBV will be used in a long-term intervention. Since this was only one session of WBV, it cannot be determined that WBV will provide lasting benefits. Any benefits elicited from one session would only be considered acute benefits. There is still a need to determine the lasting effects of WBV on cognitive and motor performance after a single session of WBV. Finally, while the BRIEF-2 provides some information about the subjects' behavior, there was no collection of other information such as MA. This information could potentially provide additional evidence for correlations between cognitive and motor performance before and after WBV. Inclusion of this information in future studies should be included to provide further information about possible correlations between motor and cognitive performance.

Conclusions

The results of the study indicate that WBV is a potential modality that can be used in the DS population to elicit motor and cognitive benefits. There is still a need to increase the sample size and investigate how long the acute benefits last. This can determine if WBV can be used as a preparatory tool for other therapy modalities, as a stand-alone therapy modality or in combination.

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APPENDICES

Appendix A. BRIEF-2 Parent Form

BRIEF®2

Behavior Rating Inventory of
Executive Function®, Second Edition

PARENT FORM

Gerard A. Gioia, PhD, Peter K. Isquith, PhD,
Steven C. Guy, PhD, and Lauren Kenworthy, PhD

Instructions

On the following pages is a list of statements that describe children. We would like to know if your child has had problems with these behaviors over the past 6 months. Please answer all the items the best that you can. Please DO NOT SKIP ANY ITEMS. Think about your child as you read each statement and circle:

N if the behavior is **Never** a problem

S if the behavior is **Sometimes** a problem

O if the behavior is **Often** a problem

For example, if your child **never** has trouble completing homework on time, you would circle **N** for this item:

Has trouble completing homework on time (N) S O

If you make a mistake or want to change your answer, DO NOT ERASE. Draw an "X" through the answer you want to change and then circle the correct answer:

Has trouble completing homework on time (X) (S) O

Before you begin answering the items, please fill in your child's name, gender, age, grade, your relationship to the child, today's date, and child's date of birth in the spaces provided at the top of the next page.

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BRIEF2 PARENT FORM

Date of birth ____________

Child's name ____________ Gender ____________ Age ________ Grade ________

Rater's name ____________ Relationship to child ____________ Today's date ____________

	N = Never S = Sometimes O = Often			
1.	Is fidgety	N	S	O
2.	Resists or has trouble accepting a different way to solve a problem with schoolwork, friends, tasks, etc.	N	S	O
3.	When given three things to do, remembers only the first or last	N	S	O
4.	Is unaware of how his/her behavior affects or bothers others	N	S	O
5.	Work is sloppy	N	S	O
6.	Has explosive, angry outbursts	N	S	O
7.	Does not plan ahead for school assignments	N	S	O
8.	Cannot find things in room or school desk	N	S	O
9.	Is not a self-starter	N	S	O
10.	Does not think before doing (is impulsive)	N	S	O
11.	Has trouble getting used to new situations (classes, groups, friends, etc.)	N	S	O
12.	Has a short attention span	N	S	O
13.	Has poor understanding of own strengths and weaknesses	N	S	O
14.	Has outbursts for little reason	N	S	O
15.	Gets caught up in details and misses the big picture	N	S	O
16.	Gets out of control more than friends	N	S	O
17.	Gets stuck on one topic or activity	N	S	O
18.	Forgets his/her name	N	S	O
19.	Has trouble with chores or tasks that have more than one step	N	S	O
20.	Does not realize that certain actions bother others	N	S	O
21.	Written work is poorly organized	N	S	O
22.	Small events trigger big reactions	N	S	O
23.	Has good ideas but does not get job done (lacks follow-through)	N	S	O
24.	Talks at the wrong time	N	S	O
25.	Has trouble finishing tasks (chores, homework, etc.)	N	S	O
26.	Does not notice when his/her behavior causes negative reactions	N	S	O
27.	Reacts more strongly to situations than other children	N	S	O
28.	Has trouble remembering things, even for a few minutes	N	S	O
29.	Makes careless errors	N	S	O
30.	Gets out of seat at the wrong times	N	S	O
31.	Becomes upset with new situations	N	S	O
32.	Has trouble concentrating on tasks, schoolwork, etc.	N	S	O

	N = Never S = Sometimes O = Often			
33.	Has poor handwriting	N	S	O
34.	Mood changes frequently	N	S	O
35.	Has good ideas but cannot get them on paper	N	S	O
36.	Has trouble counting to three	N	S	O
37.	Leaves messes that others have to clean up	N	S	O
38.	Needs to be told to begin a task even when willing	N	S	O
39.	Acts too wild or "out of control"	N	S	O
40.	Thinks too much about the same topic	N	S	O
41.	Forgets what he/she was doing	N	S	O
42.	Does not check work for mistakes	N	S	O
43.	Angry or tearful outbursts are intense but end suddenly	N	S	O
44.	Becomes overwhelmed by large assignments	N	S	O
45.	Loses lunch box, lunch money, permission slips, homework, etc.	N	S	O
46.	Needs help from an adult to stay on task	N	S	O
47.	Forgets to hand in homework, even when completed	N	S	O
48.	Has trouble putting the brakes on his/her actions	N	S	O
49.	Resists change of routine, foods, places, etc.	N	S	O
50.	Has trouble getting started on homework or tasks	N	S	O
51.	Mood is easily influenced by the situation	N	S	O
52.	Underestimates time needed to finish tasks	N	S	O
53.	Does not bring home homework, assignment sheets, materials, etc.	N	S	O
54.	Cannot find the front door of home	N	S	O
55.	Does not take initiative	N	S	O
56.	Becomes upset too easily	N	S	O
57.	Starts assignments or tasks at the last minute	N	S	O
58.	Has trouble moving from one activity to another	N	S	O
59.	Has trouble carrying out the actions needed to reach goals (saving money for special item, studying to get a good grade, etc.)	N	S	O
60.	Is disturbed by change of teacher or class	N	S	O
61.	Has trouble organizing activities with friends	N	S	O
62.	Becomes too silly	N	S	O
63.	Leaves a trail of belongings wherever he/she goes	N	S	O