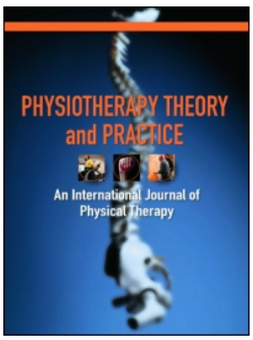

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RESEARCH REPORT

Whole body vibration on people with sequelae of polio

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ABSTRACT

Purpose: The purpose was to explore the feasibility of whole body vibration (WBV) on polio survivors with/without post-polio syndrome (PPS) by studying its effects on walking speed (10-m walk test), endurance (2-min walk test), pain severity/interference (Brief Pain Inventory [BPI]), sleep quality (Pittsburg Sleep Quality Index), fatigue (Fatigue Severity Scale), leg strength (manual muscle testing and hand-held dynamometry), and muscle cramping (written logs). ***Methods***: Fifteen individuals completed the study, participating in eight sessions in two 4-week blocks. Participants started with ten 1-min vibration bouts/session, increasing to 20 min. Low (amplitude 4.53 mm, *g* force 2.21) and higher (amplitude 8.82 mm, *g* force 2.76) intensity blocked intervention occurred in random order crossover design. Blinded testing ensued before/after intervention blocks and at follow-up. ***Results***: No study-related adverse events occurred. Participants starting first with higher intensity intervention improved in walking speed ($p = 0.017$). BPI pain severity significantly improved ($p = 0.049$) after higher intensity intervention. No significant changes were found after low intensity vibration or in other outcome measures. ***Conclusions***: WBV appears to be a safe exercise for this population. Long-term use in polio survivors needs to be researched, particularly in reducing barriers to participation to promote the physical aspects of health.

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Post-polio syndrome; weight-bearing exercise

Introduction

Survivors of polio with post-polio syndrome (PPS) present with increased muscle weakness and reduced functional capacity, and they frequently have pain, fatigue, and sleep disturbances (Bruno, 2002; Halstead, 2011; Quiben, 2013). They may have difficulty finding ways in which to exercise for wellness or to maintain bone mineral density due to their weakness or other PPS symptoms. Significant concern has been expressed that exercise can overly fatigue already overused muscles and exacerbate PPS symptoms of pain, fatigue, and increased weakness (Bruno, 2002; Quiben, 2013). People with PPS generally have fewer options for exercise than other people, due to weakness patterns. Little available literature exists about the use of exercise in symptomatic and asymptomatic people with PPS; however, a few small studies have found exercise to be safe and beneficial in this population (Agre, Rodriquez, and Franke, 1997; Chan et al., 2003; Ernstoff, Wetterqvist, Kvist, and Grimby, 1996; Klein et al., 2002; Koopman et al., 2011; Kriz et al., 1992).

A growing body of literature purports that whole body vibration (WBV) can provide benefits similar to traditional exercise in normal adults and people with various medical conditions. WBV provides a mechanical, oscillatory motion to the full body while standing on a vibrating platform. It has been shown to inhibit pain (del Pozo-Cruz et al., 2011; Rittweger et al., 2002), improve strength (Marin and Rhea, 2010; von Stengel, Kemmler, Engelke, and Kalender, 2011), improve functional balance (Bautmans, Hees, Lemper, and Mets, 2005; Bruyere et al., 2005; Gusi, Raimundo, and Leal, 2006), increase bone mineral density (Bruyere et al., 2005; Gómez-Cabello et al., 2012; Slatkovska, Alibhai, Beyene, and Cheung, 2010; von Stengel, Kemmler, Engelke, and Kalender, 2011), and increase flexibility (Bautmans, Hees, Lemper, and Mets, 2005).

WBV has been studied in neurologic populations with stroke, Parkinson's disease, cerebral palsy, incomplete spinal cord injury, and multiple sclerosis, with del Pozo-Cruz et al. (2012) conducting a systematic review presenting varying results pertaining to impairments, activity limitations, and health-related quality of life. In this review of 13 studies, vibration frequencies ranged from 2 to 50 Hz, amplitudes from 0 to 14 mm, 1-11 bouts with 60-180 s of rest between bouts, total vibration time per series of 30-900 s, and number of sessions from 1 to 240. WBV acute (immediately to 1-week post-intervention) significant effects were seen in the Sensory Organization Test, Timed Up and Go, and quadriceps isometric strength in people with multiple

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sclerosis, tandem standing postural control, and motor items on the Unified Parkinson Disease Rating Scale (UPDRS) in people with Parkinson's disease, and quadriceps isometric strength and eccentric strength in people with stroke. No significant acute changes were observed in proprioception, gait, and postural control in these populations, and the only long-term significant change that was observed in the UPDRS in people with Parkinson's disease. No significant changes have been observed in long-term effects in muscle tone, motor ability, gait, and balance in people with cerebral palsy. The authors expressed concern about the overall limited number of high methodological studies available for review and lack of homogeneity of the data (del Pozo-Cruz et al., 2012). In fact, Rauch et al. (2010) have published an article for the need for standardization of reporting WBV studies.

A pilot study with adults with chronic incomplete spinal cord injury showed significant acute improvement in gait speed and various gait characteristics (Ness and Field-Fote, 2009). However, another small study found that WBV failed to significantly improve strength or gait in people with PPS, and they discontinued the study after five participants (Brogårdh, Flansbjer, and Lexell, 2010). However, other common symptoms of PPS, such as pain, fatigue, sleep disturbances, and muscle cramping, were not measured.

The purpose of this study was to explore the feasibility of WBV as a means of weight-bearing exercise in survivors of polio with or without PPS by assessing its effects on walking speed and endurance, pain severity and interference, sleep quality, fatigue, lower extremity (LE) muscle strength, and muscle cramping. The null hypothesis was that there will be no significant improvements in walking speed, as measured by the 10-m walk test (10 mWT), walking endurance (2 min walk test [2 MWT]), pain (Brief Pain Inventory [BPI]: severity and interference subscales), sleep (Pittsburgh Sleep Quality Index [PSQI]), fatigue (Fatigue Severity Scale [FSS]), LE strength (manual muscle testing [MMT], hand-held dynamometry [HHD]), and muscle cramping (written logs throughout course of study) following WBV intervention in participants with or without PPS. Because the survivors of polio, especially those with PPS, have a chronic condition of greater than 20 years, walking speed and endurance and strength were not anticipated to improve. However, an intervention can cause symptom worsening of people with PPS, and an intervention causing no adverse events or worsening of the symptoms of pain, sleep, fatigue, muscle weakness, or muscle cramping may indicate potential safety of that intervention. Since only one published study has addressed the use of WBV in people with PPS, and this target population has unique needs related to exercise-related interventions, an exploratory limited-efficacy feasibility study was indicated (Bowen et al., 2009).

Methods

Participants

Twenty-one individuals were recruited from the outpatient post-polio clinic at TIRR-Memorial Hermann Rehabilitation and Research, Texas Polio Survivors' Association, and Post-polio Health International between January 2013 and September 2014, with all interventions and follow-up testing ending December 2014. Each of them participated in the informed consent process as approved by the human subjects Internal Review Boards of Texas Woman's University and Baylor College of Medicine. Inclusion criteria were the history of polio with or without the diagnosis of PPS, ages 40–85, body weight less than 227 kg, ability to bear weight through LEs for 20 min, fluency in English, and medical approval from personal physician. Exclusion criteria included acute medical conditions (i.e., cancer, infection, wound, fracture, and thrombosis/embolism), epilepsy, severe migraine headaches, severe vestibular conditions, implanted devices (i.e., metal fixators or joints), LE amputation, discopathy, or spondylolysis.

Unfortunately, the principal investigator did not record the number of people invited during clinic visits or number of people who inquired about the study from recruitment messages sent by the support groups. The most frequent reasons for not participating when asked were the exclusion criterion of metal implants, and the time, effort, and cost involved with commuting to the university research lab within the Texas Medical Center twice a week for the testing and intervention sessions. Fifteen participants completed the study, with withdrawals occurring because of non-study-related reasons. Two individuals withdrew due to medical reasons. One developed chest pain 3 days after a WBV session, and the second person withdrew due to a new medication being started during the 2-week scheduled washout period causing excessive fatigue. See Table 1 for demographic information of the participants. All except one participant met the diagnostic criteria for PPS (National Institutes of Health, 2015). See Figure 1 for participant study flow and attrition.

Table 1. Participant demographic information.

	Total sample (N = 19*)	Completing participants (N = 15)
Age (years, mean, and SD)	63.53 SD 8.32	63.80 SD 9.40
Age onset polio (years, mean, and SD)	3.55 SD 4.03	3.70 SD 4.80
PPS diagnosis (yes/no)	18/1	14/1
Gender (male/female)	8/11	6/9
Race/Ethnicity		
African-American/Black	2 (1 mixed)	1
Asian/Pacific islander	1	1
Hispanic/Latino	2	2
Native American	1 (mixed)	0
White	13	11
Walking status		
Full time	12	11
Part time	6	3
Not able to walk	1	1
Use of orthoses		
None	13	9
1 AFO	2	2
B AFOs	1	1
1 KAFO	1	1
B KAFOs	1	1
Not applicable	1	1
Use of assistive devices		
None	12	8
1 Cane/Walking stick	3	3
2 Canes	2	2
B Canadian crutches	1	1
Not applicable	1	1
Working status		
Full time	6	5
Part time	4	2
Retired	9	8

*Two females withdrew from original 21 who consented, prior to data collection.

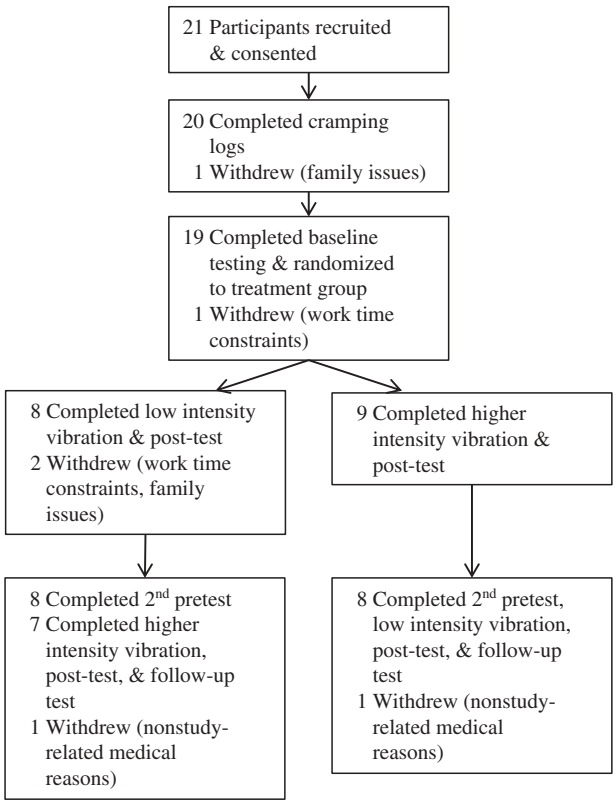

Figure 1. Study flow diagram with attrition.

Design

This study used a crossover exploratory experimental intervention design, with order of interventions randomized using a random number table. There was a 2-week washout period between intervention blocks and a 2-week follow-up period following termination of last intervention block and post-intervention testing. There was no control group due to an anticipated small sample size. The WBV intervention was not compared to "normal" or "standard-of-care" physical therapy because these participants who are in the chronic phase of this neurological condition of PPS tend to seek episodic care to address specific issues, including but not limited to, balance training, gait training with new devices, or pain management (Bruno, 2002; Halstead, 2011; Quiben, 2013) (Figure 2).

Interventions

Individuals participated in eight WBV sessions in two 4-week blocks. Participants stood on the vibration platform with knees slightly flexed and body weight as evenly distributed as possible between the two LEs. Knee flexion up to 30 deg has been reported to allow sufficient damping of the mechanical energy

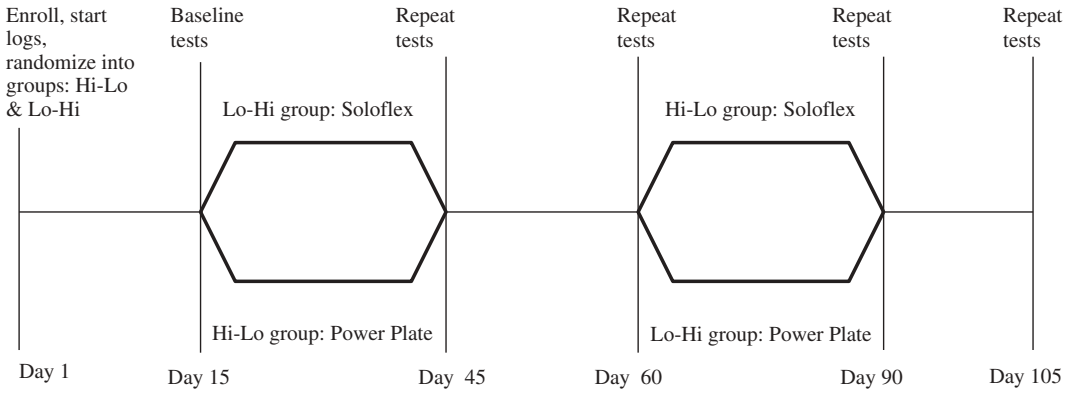

Figure 2. Crossover experimental design with intervention blocks and testing schedule.

transmission by the LEs into the upper body and head to avoid negative side effects (Abercromby et al., 2007). Upper extremity support was available to participants, as needed, for stepping up and down from the platforms and during vibration. Participants removed their orthoses, shoes, or both, wearing socks only on their feet to maximize sensory and mechanical input from the vibration. Individuals, who were unable to stand, sat in a wheelchair or chair positioned next to the platform, with their feet on the platform, leaning forward onto distal thighs to enhance LE weight bearing. No participants were participating in skilled physical therapy services during the study. They were encouraged to continue their normal daily activities, including work, volunteer activities, walking programs, exercise, and so on.

Individuals were randomly assigned into one of two intervention groups with one group participating in low intensity WBV 4-week block of eight sessions first (group Lo–Hi), and higher intensity WBV 4-week block of eight sessions, second. The second group participated in both WBV intervention blocks in the reverse order (group Hi–Lo). The low intensity (peak-to-peak amplitude 4.53 mm, 24 Hz, unit of gravity of Earth [*g*] force 2.21) intervention was provided by the Soloflex (Hillsboro, OR 97124, USA), a relatively small unit that is usable within the home. This force was the Soloflex's lowest setting, labeled "acceleration-load" 0.3*g*. The amplitude and vibration frequency are linked together on this unit, in that the lower the amplitude, the lower the frequency, and the higher the amplitude, the higher the frequency. The higher intensity (peak-to-peak amplitude 8.82 mm, 35 Hz, *g* force 2.76) intervention was provided by the Power Plate Pro 5 (Performance Health Systems, LLC, Northbrook, IL 60062, USA) a commercial grade WBV device that can be found in health clubs for more aggressive workouts in shorter time periods. The Power Plate amplitude setting that was used was termed "low" amplitude, although this amplitude was almost twice the amplitude of the Soloflex lowest setting. The Power Plate amplitude and vibration frequency can be set independently of each other. Both platforms provide vertical synchronous vibration. Amplitudes, frequencies, and *g* forces of the two platforms were measured by a Trigno tri-axial accelerometer (Delsys, Inc. Natick, MA, 01760, USA).

Due to the huge variations of frequencies and magnitudes seen in the WBV intervention studies in the neurologic populations (del Pozo-Cruz et al., 2012), studies measuring the effects of WBV with bone mineral density in post-menopausal women (Bruyere et al., 2005; Gómez-Cabello et al., 2012; Slatkovska, Alibhai, Beyene, and Cheung, 2010; von Stengel, Kemmler, Engelke, and Kalender, 2011), older adults (Bruyere et al., 2005; Ma et al., 2016; Sitjà-Rabert et al., 2012), and people with fibromyalgia (Collado-Mateo et al., 2015) were explored due to most of the current study's population being of similar ages, having difficulties in performing "typical" weight-bearing exercises, and having issues related to pain and fatigue. In these review studies, 10–40 Hz (most in 30–35 Hz) vibration frequencies, with 1–8 mm amplitude, and variable *g* forces were used (Bruyere et al., 2005; Collado-Mateo et al., 2015; del Pozo-Cruz et al., 2012; Gómez-Cabello et al., 2012; Ma et al., 2016; Sitjà-Rabert et al., 2012; Slatkovska, Alibhai, Beyene, and Cheung, 2010; von Stengel, Kemmler, Engelke, and Kalender, 2011).

Two different vibration platforms were used for the following reasons: (1) Power Plate can be found in some health clubs; (2) Soloflex is cheaper, portable, and therefore, amenable to home use, when thinking ahead to future studies; (3) least intensive setting on the Power Plate is more intense than most of the Soloflex settings, and principal investigator was concerned

about how the people with PPS would tolerate the intensity levels of the Power Plate, even at its lowest setting; and (4) the investigators wanted to study two very different levels of intensity due to the large variety of settings seen in the current literature and the diversity of clinical presentations and symptoms of people with PPS. Although two different brands of vibration platforms were used, the *g* forces, Hz, and amplitudes of each were measured with a separate accelerometer as reported above. One machine could not be used with the selected intensities, particularly considering the potential exacerbation of PPS symptoms in the targeted study population.

Participants started with 1-min standing with vibration on, 1-min sitting with no vibration, with this sequence repeating 10 times for 10 total minutes of vibration per session, gradually increasing to 2-min increments of vibration, 1-min rests, for 20 total minutes (Brogårdh, Flansbjer, and Lexell, 2010; Collado-Mateo et al., 2015; del Pozo-Cruz et al., 2012; Ness and Field-Fote, 2009). Fifteen seconds were added to each vibration bout so that each session of 10 bouts increased by 2.5 min until 20-min maximum was attained, if no increased PPS symptoms were reported when asked. Participants were expected to be able to increase to the goal of 20 min at the fifth session, thereby having sessions five through eight at 20 min. Blood pressure and heart rate were measured before and after each vibration session. Rating of perceived exertion (RPE) was measured after each session.

Outcome measures

Two licensed PTs (one primary and one back-up), blinded to intervention order, performed all outcome measure testing before and after each 4-week intervention block per vibration platform and 2 weeks following the last testing session. A 2-week washout period was scheduled in between the two 4-week vibration intervention blocks. Each participant completed daily muscle cramping logs 2 weeks prior to start of all testing and vibration, continuing throughout the entire study period, including washout and follow-up weeks (approximately 3 months total).

Measures used were at the participation, activity, and body structure and function domains of the International Classification of Function, Disability, and Health (World Health Organization, 2002) and were selected based upon common symptoms or problems experienced by people with PPS. At the participation level, fatigue was measured by the FSS (Horemans, Nollet, Beelen, and Lankhorst, 2004; Krupp, LaRocca, Muir-Nash, and Steinberg, 1989); pain interference was measured by the BPI (McDowell, 2006; Mendoza et al., 2004); and sleep quality was measured by the PSQI (Buysse et al., 1989). At the activity level, gait speed was measured by the 10-mWT, with acceleration and deceleration zones allowed beyond 10 m (Flansbjer and Lexell, 2010). Gait endurance was measured by the 2 mWT rather than the 6-min walk test to avoid unnecessary testing fatigue per recommendations by Stolwijk-Swüste et al. (2008). Sleep ability (i.e., latency, duration, efficiency, and disturbances) was measured with the PSQI. Participants were allowed to use their orthoses, assistive devices, or both for the gait measures. At the body structure and function level, LE muscle strength was tested by HHD using the Microfet 2 (Hoggan Scientific, LLC, Salt Lake City, UT 84104, USA) and MMT. Strength of hip flexors, extensors, and abductors; knee extensors and flexors; and ankle dorsiflexors and plantarflexors were measured in standard testing positions. The "break" test method was used for MMT once active movement against gravity through full passive range of motion occurred (Hislop, Avers, and Brown, 2013; Horemans, Beelen, et al., 2004; Nollet and Beelen, 1999). Also at the body structure and function level, muscle cramping was measured by participant completion of daily cramping logs, and pain severity was measured by the BPI. Blood pressure and heart rate were measured before and after each intervention session, and Borg's RPE (Voorn et al., 2014) was measured after each session.

Data analysis

Descriptive statistics and Mann–Whitney *U* tests were performed to examine significant differences between intervention groups for the demographic variables and pre-intervention outcome measures. Change scores were also computed for each intervention. For between-subject differences, nonparametric Mann–Whitney *U* tests were conducted between the high intensity and low intensity conditions on measures at pretest, post-test, and follow-up. Nonparametric Wilcoxon signed-rank tests were also conducted to examine the within-subject change between pretests and posttests, while Friedman's analysis of variance test was conducted to examine the change in time from pretest to follow-up since there were a total of five testing sessions to avoid committing a Type I error with multiple Wilcoxon signed-rank tests. Within-subject differences were tested for all participants and split by group (Portney and Watkins, 2000). Nonparametric tests were exclusively used due to the small sample size and a lack of normality. The Statistical Package for Social Sciences (SPSS) v.23 (IBM Corporation,

Armonk, New York 10504-1722, USA) was used for all analyses.

Results

Participants who began with the higher intensity intervention (group Hi–Lo) improved in walking speed as measured in meters per second ($Z = -2.38$, $p = 0.017$, Cohen's $d = -1.294$). However, when the Hi–Lo and Lo–Hi groups were combined, walking speed improvement was not significant ($p = 0.087$). BPI pain severity significantly improved ($Z = -1.97$, $p = 0.049$, Cohen's $d = 0.60$), and BPI pain interference approached significant improvement ($Z = -1.92$, $p = 0.055$, Cohen's $d = 0.81$) after higher intensity vibration intervention, regardless of treatment order. There were no significant changes in 2 mWT, PSQI, or FSS. There were no significant differences in demographic variables between participants who completed and did not complete the study or between the two intervention groups. There were no intervention order effects. There were no significant differences in any of the measures post 2-week washout or follow-up period. See Table 2 for results from primary outcome measures of full sample. There were no study-related adverse events.

For other outcome measures, no significant changes were found in LE muscle strength in either MMT or HHD between pre and post-testing from either intervention block or at follow-up testing. There were no significant changes in blood pressure or heart rate immediately after each intervention session. There were no changes in prevalence of muscle cramping between intervention and nonintervention days. RPE was not significantly different and was reported from 6 (no exertion at all) to 13 (somewhat hard) with per session group means of 7.13-7.73 (extremely light) immediately following each lower intensity intervention and 6 (no exertion at all) to 19 (extremely hard) with per session group means of 9.40-9.80 (very light) immediately following each higher intensity session.

Although 12 of the total sample of participants (eight of those completing the study) were able to walk without equipment of any kind, all had asymmetry of muscle bulk in their LEs, and all except for one male without PPS demonstrated muscle paresis in one or more muscle group tested. Most of the participants were able to progress to the total of 20 min per session at the scheduled fifth of eight sessions. However, one participant had under-controlled hypertension and was referred back to his prescribing physician. He resumed the intervention after his medications were changed and blood pressure was well controlled. Another participant felt like the higher intensity vibration was too intense for him in standing, and he chose the sitting protocol for the remainder of his sessions, although he was one of the more physically active individuals. He sat in a standard chair with two pillows in the seat to elevate his hips and leaned forward onto his distal thighs to facilitate weight bearing through his LEs. One participant was unable to stand at all during normal functional activities and during the study; therefore, he utilized the sitting protocol throughout. His motorized wheelchair had a seat elevator, and he moved his hips to the front edge of the cushion and leaned his upper body onto his thighs. Gait measures had a total sample size of 14, rather than 15, due to this participant's inability to walk.

Discussion

The aim of this study was to explore the feasibility of WBV as a means of weight-bearing exercise in people with PPS through limited-efficacy testing (Bowen et al., 2009). Although the effects of WBV on gait and LE strength have previously been reported (Brogårdh, Flansbjer, and Lexell, 2010), this study was the first to address other symptoms with which people with PPS can present, i.e., fatigue, pain, sleep disturbances, and muscle cramping. The null hypothesis was rejected with respect to pain severity and walking speed; however, it was accepted for the other measures in the participation, activity, and body structure and function domains.

When establishing feasibility, the first concern should likely be that of safety and tolerance of the intervention. There were no study-related adverse events in this study. Similar to the findings by Brogårdh, Flansbjer, and Lexell (2010), no change in muscle strength occurred. However, maintenance of strength and prevention of increased muscle cramping indicate that the WBV was not overly fatiguing for the muscles of these participants with or without PPS. Nonsignificant changes in vital signs and RPE indicate that real and perceived exertion were not excessive (Voorn et al., 2014). The WBV did not worsen their other symptoms of fatigue and sleep disturbances and, in fact, appeared to help with pain severity as measured by BPI, $p = 0.049$, at least in the short term. A *post hoc* power analysis was conducted to determine the achieved power from this sample. The associated *p*-value, Cohen's *dz* values, and sample size were used for the calculations. The power for BPI pain severity was 0.800, so the existing sample size appears to allow adequate power for this measure. The minimum clinically important difference (MCID) for pain in people with PPS has not been reported. However, the MCID of BPI pain severity reported for people with fibromyalgia is 2.2 points or a 34% reduction (Mease et al., 2011), while our study's groups showed a 0.61–0.83 point or 19-24% reduction. BPI pain interference approached

Table 2. Results from primary outcome measures.

Measure	Lo–Hi group $n = 6$ Mean (median) and SD Range	Hi–Lo group $n = 9$ Mean (median) and SD Range	Between-subject differences p (d)	Within-subject differences p (dz *and eta squared)*
10 mWT (m/s)				
Pre-Lo	1.13 (1.23) SD 0.52 0.30–1.92	1.23 (1.11) SD 0.44 0.76–1.89	0.885 (0.20)	
Post-Lo	1.24 (0.99) SD 0.49 0.87–2.09	1.25 (1.08) SD 0.50 0.79–2.00	0.728 (0.02)	0.410 (0.25)
Pre-Hi	1.32 (1.07) SD 0.51 0.86–2.11	1.11 (1.03) SD 0.39 0.69–1.82	0.346 (0.46)	
Post-Hi	1.24 (1.09) SD 0.49 0.76–1.96	1.27 (1.17) SD 0.47 0.82–2.08	0.698 (0.06)	0.087 (0.52)
Follow-up	1.31 (1.09) SD 0.48 0.84–2.00	1.23 (1.15) SD 0.43 0.78–1.92	0.747 (0.18)	Lo int: 0.458 (0.04) Hi int: 0.353 (0.11)
2 MWT (m)				
Pre-Lo	137.01 (130.84) SD 49.65 74.24–219.18	138.73 (128.93) SD 46.20 90.25–214.99	0.834 (0.04)	
Post-Lo	137.36 (121.76) SD 52.97 87.29–228.63	144.38 (125.37) SD 52.30 89.00–218.04	0.655 (0.13)	0.650 (0.23)
Pre-Hi	147.97 (138.95) SD 49.27 89.32–219.95	128.49 (115.50) SD 51.59 81.66–220.70	0.443 (0.39)	
Post-Hi	136.08 (117.09) SD 55.07 81.95–217.28	141.36 (134.46) SD 49.89 89.29–211.77	0.796 (0.10)	0.279 (0.14)
Follow-up	143.48 (120.92) SD 52.82 94.54–220.25	140.36 (126.60) SD 47.27 93.40–214.20	0.796 (0.06)	Lo int: 0.794 (0.10) Hi int: 0.083 (0.08)
BPI Interference				
Pre-Lo	3.97 (4.29) SD 2.55 0.00–7.43	3.05 (2.93) SD 3.13 0.00–6.71	0.554 (0.32)	
Post-Lo	2.81 (2.50) SD 2.80 0.00–6.57	2.43 (2.21) SD 2.37 0.00–5.57	0.747 (0.15)	0.093 (0.55)
Pre-Hi	3.14 (2.50) SD 3.14 0.29–7.57	3.62 (3.57) SD 2.50 0.00–7.57	0.796 (0.17)	
Post-Hi	2.26 (0.00) SD 3.09 0.00–5.86	2.39 (2.57) SD 2.40 0.00–5.14	0.862 (0.05)	0.055 (0.81)
Follow-up	2.41 (1.75) SD 2.81 0.00–6.14	3.08 (3.00) SD 2.97 0.00–6.71	0.924 (0.23)	Lo int: 0.549 (0.12) Hi int: 0.091 (0.21)
Severity				
Pre-Lo	3.59 (3.63) SD 1.70 1.00–6.00	1.92 (1.50) SD 2.24 0.00–5.25	0.135 (0.84)	
Post-Lo	2.88 (2.38) SD 2.87 0.00–7.00	2.46 (2.50) SD 2.26 0.00–5.75	0.686 (0.16)	0.678 (0.18)
Pre-Hi	3.29 (2.75) SD 2.57 0.75–7.25	3.44 (3.50) SD 1.74 0.00–5.50	0.795 (0.07)	
Post-Hi	2.68 (0.13) SD 3.63 0.00–7.25	2.61 (2.50) SD 2.65 0.00–5.75	0.674 (0.02)	*0.049* (0.60)*
Follow-up	6.16 (3.19) SD 8.57 0.00–18.25	2.68 (3.75) SD 2.37 0.00–5.25	0.565 (0.55)	Lo int: 0.469 (0.09) Hi int: 0.419 (0.06)
PSQI				
Pre-Lo	7.00 (7.00) SD 2.74 4.00–11.00	6.33 (6.00) SD 1.53 5.00–8.00	0.880 (0.30)	
Post-Lo	6.50 (6.50) SD 2.08 4.00–9.00	6.00 (6.00) SD 2.83 4.00–8.00	0.814 (0.20)	0.357 (0.20)
Pre-Hi	7.50 (8.00) SD 1.73 5.00–9.00	9.00 (9.00) SD 3.00 6.00–12.00	0.368 (0.61)	
Post-Hi	9.00 (11.00) SD 4.36 4.00–12.00	6.33 (6.00) SD 1.53 5.00–8.00	0.513 (0.82)	0.673 (0.18)
Follow-up	9.71 (9.00) SD 3.25 4.00–12.00	6.75 (6.00) SD 3.20 5.00–9.00	0.092 (0.92)	Lo int: 0.108 (0.08) Hi int: 0.783 (0.03)
FSS				
Pre-Lo	41.40 (36.00) SD 11.19 31.00–54.00	34.67 (41.00) SD 23.16 9.00–54.00	1.000 (0.37)	
Post-Lo	38.50 (38.00) SD 17.99 22.00–56.00	26.00 (26.00) SD 24.04 9.00–43.00	0.355 (0.59)	0.416 (0.56)
Pre-Hi	38.00 (36.50) SD 16.99 23.00–56.00	35.00 (45.00) SD 22.72 9.00–51.00	0.724 (0.15)	
Post-Hi	40.67 (35.00) SD 25.97 18.00–69.00	36.00 (46.00) SD 23.64 9.00–53.00	0.827 (0.19)	0.225 (0.24)
Follow-up	28.71 (27.00) SD 16.95 15.00–39.00	40.25 (38.00) SD 17.89 21.00–55.00	0.324 (0.66)	Lo int: 0.678 (0.14) Hi int: 0.534 (0.09)

*Indicates a significant difference. All follow-up p-values are from Friedman's ANOVA.
Lo–Hi group: Low intensity intervention first, higher intensity intervention second.
Hi–Lo group: Higher intensity intervention first, lower intensity intervention second.
Lo int: Low intensity protocol.
Hi int: Higher intensity protocol.

significance at $p = 0.055$, but the *post hoc* analysis showed it to have insufficient power at 0.603.

Because of the number of symptoms reported by people with PPS, both from the literature and clinical patient reports, the participants had surprisingly few complaints or concerns during the interventions. All of the participants, except for one (as described earlier), were able to progress to the maximum time according to the protocol, although one chose the sitting protocol for the remainder of his higher intensity sessions. Conversely, a third participant who used a motorized wheelchair for "95%" of his locomotion and reportedly stood less than 20 min total in a typical day had no difficulty tolerating the higher intensity intervention in standing. Some of the people described commuting times of more than 1 h each direction to participate. Additionally, from their recorded comments, one person had her work demands approximately double due to an unanticipated change in her position at work, and another babysat her two preschool grandchildren for 2 weeks full time during the course of the study. However, there were no significant increases in fatigue, even with our study's small sample size. All participants, except for one, were able to independently get on and off the WBV platforms. None of them required more than 1-min rest in between vibration bouts. Therefore, the dose (i.e., frequency and intensity) of the intervention did not appear to be too intense for the participants (Bowen et al., 2009).

Orthoses were not used during vibration sessions due to variability of design and support, with their use decreasing the vibratory input into the limb. Some individuals were initially apprehensive about standing without their orthoses, but they were able to hold onto the handles of the Power Plate or the grab bar mounted on the wall next to the Soloflex for support or balance. They were instructed to evenly distribute their weight as much as possible, and their attempts to do so were observed by the PT. Muscle electromyography amplitude effects have been found to be similar between paretic and nonparetic LEs in people with chronic stroke during WBV (Liao et al., 2014; Liao et al., 2015). Therefore, attention to paretic limb positioning for weight bearing on the vibration platform appears to be important. Participants attempted to stand with knees minimally flexed; however, a few could stand and weight bear only with knee or knees locked into full extension due to their weakness and nonuse of LE orthoses. Due to their weakness, most would have been unable to attain or maintain recommended static knee flexion positions of 30 deg or more for maximal muscle recruitment (Abercromby et al., 2007; Di Giaminiani et al., 2013). A rolled cuff weight was placed under the heel of one participant with a significant plantarflexion contracture to improve her ability to weight bear through the limb. The described limb positioning adaptations to accommodate severe paresis or contractures occurred to allow optimal implementation of the intervention protocol (Bowen et al., 2009).

Although there was significant acceptability (potential participant interest) in the study (Bowen et al., 2009), the perceived barrier of the time and expense of commuting to a university research lab in the Texas Medical Center was the most frequent reason given for choosing not to participate or terminating participation once enrolled. In fact, the one-way commute time was longer than the intervention time for most of the participants. Parking was compensated, but mileage, gas, or public transportation was not reimbursed. Recruitment and retention may have been enhanced if the interventions could have been administered in their homes. Therefore, the primary limitation of this study was the small sample size due to recruitment challenges. This limitation is a significant challenge to the focus area of practicality in feasibility studies (Bowen et al., 2009). The principal investigator did not record numbers of invitations to participate or telephone or electronic mail inquiries about the study. Now, the number of people who chose to participate versus declined, once inclusion and exclusion criteria were reviewed, is unknown. People had been approached during personal contact in the polio out-patient clinic, and flyers had been sent through support groups. Forty-one participants will be needed for an efficacy trial, assuming a moderate effect size ($dz = 0.40$), as determined by G*Power (Heinrich-Heine-University Düsseldorf, 40204 Düsseldorf, Germany). This number, although challenging, may be feasible and practical when recruiting from a large urban area, especially if barriers to participation, such as home-based rather than lab-based intervention, can be employed.

For such a small sample size, a moderate amount of heterogeneity of participants existed, based upon demographic and pre-intervention testing data (Tables 1 and 2). However, clinic out-patients who were experiencing active functional declines with acute symptoms of PPS were not invited to participate in this study. The Hi–Lo group had twice as many people who worked full time, walked full time, or both, as did the Lo–Hi group. However, the Hi–Lo group also had 2.5 times as many people who used assistive devices, LE orthoses, or both. Although walking speed between the two groups was not significantly different at baseline, only the Hi–Lo group significantly improved speed after the higher intensity intervention. The investigators have no answers as to why the group with opposite treatment order did not similarly increase gait speed. When follow-up analyses were performed to determine who seemed to respond more favorably to WBV, there were no clear trends.

The significant increase in walking velocity of the Hi–Lo group (p = 0.017, *post hoc* power analysis = 0.990) was different than that reported in the small study by Brogårdh, Flansbjer, and Lexell (2010) with WBV and people with PPS. They did not report the platform's g force, but their vibration frequency, amplitude, and time on the platform each were less than both the high and low intensity protocols for the current study, although their intervention lasted 5 weeks as compared to this study's two 4-week intervention blocks. Their lack of intervention effects was similar to that of the current study's lower intensity vibration intervention. Although the MCID of the 10 mWT for people with PPS has not been reported, the 0.16 mean improvement by the Hi–Lo group is consistent with or higher than the MCIDs reported for people with spinal cord injury, stroke, or older adults (Rehabilitation Measures Database, 2014).

Could the faster gait speed be related to pain reduction? Possibly a short-term reduction in pain severity or pain interference contributed to the faster walking speeds in these participants with PPS. WBV has improved pain in people with chronic low back pain (del Pozo-Cruz et al., 2011; Rittweger et al., 2002), fibromyalgia (Collado-Mateo et al., 2015), knee osteoarthritis (Zafar, Alghadir, Anwer, and Al-Eisa, 2015), and exercise-induced muscle soreness (Kosar, Candow, and Putland, 2012; Lau and Nosaka, 2011). People with PPS frequently have pain from various causes, including those listed above, and both groups significantly improved in pain severity after the higher intensity intervention, with only the Hi–Lo group also significantly improving in gait speed. The relationship between the impairment of pain and functional gait speed is likely quite complex.

The present study's protocol attempted to address the benefits of weight-bearing exercise by mimicking parameters used in WBV studies addressing bone density, older adults, fibromyalgia, or people with neurologic conditions (Bruyere et al., 2005; Collado-Mateo et al., 2015; del Pozo-Cruz et al., 2012; Gómez-Cabello et al., 2012; Ma et al., 2016; Sitjà-Rabert et al., 2012; Slatkovska, Alibhai, Beyene, and Cheung, 2010; von Stengel, Kemmler, Engelke, and Kalender, 2011). Because much variability in WBV parameters exist in the literature, twice a week interventions were selected to be similar to patient participation in outpatient PT or independent exercise in a gym, while avoiding undue burden or fatigue to participants.

The study strengths include the randomized treatment order assigned to each participant in the crossover experimental design. Two experienced PT assessors who were blinded to participant group assignment, vibration intensity, and platform being used conducted all the testing. The participants were unable to be blinded to treatment intensity due to its inherent sensory input. Our results suggest that the low intensity intervention, which caused no significant changes in pain severity, gait speed, and other areas measured, could be considered for use in a sham treatment group for a future randomized controlled trial. The principal investigator conducted all screening, informed consent processes, and most interventions. The biggest study limitation is its small sample size. Therefore, results must be interpreted cautiously. No significant changes at follow-up testing suggest that treatment duration may have been insufficient to cause long-term effects. Further research with larger sample sizes, as determined by power analyses, and a control group is necessary in order to determine ways to reduce intervention burdens of time and expense for longer term effectiveness and efficacy studies, addressing potential wellness benefits of WBV with muscle health, bone density preservation, pain management, and functional mobility.

Conclusions

Preliminary results of this exploratory study indicate WBV to be a safe, tolerable, and feasible form of weight-bearing exercise for people with PPS. Short-term changes in pain and gait speed for some individuals are encouraging for polio survivors who have limited methods to exercise. This study has attempted to answer the first big question of a feasibility study, "Can it work?" (Bowen et al., 2009), with "Yes, it can." Further research with more participants and a control group needs to be done to examine long-term use and efficacy of WBV in people with PPS and other neurological conditions, addressing reduction of barriers to exercise participation to be able to answer the question, "Does it work?" (Bowen et al., 2009).

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Declaration of interest

The authors report no conflicts of interest.

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