Full Title:

Effects of whole body vibration on sensorimotor performance in individuals with Parkinson's disease: a systematic review

Authors:

Ricky WK Lau,[1] Tilda Teo,[1,2] Felix Yu,[1] Raymond CK Chung,[1] Marco YC Pang[1]

Affiliations:

1. Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong.
2. Inpatient Therapy Services, St Andrew's Community Hospital, Singapore.

Corresponding author:

Dr. Marco YC Pang, Associate Professor, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong. Fax: 852-2330-8656, Telephone: 852-2766-7156, Email: Marco.Pang@inet.polyu.edu.hk

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Abstract

Background. Prior studies have shown that whole body vibration (WBV) has beneficial effects on neuromuscular performance in older adults and may also be a viable treatment option for individuals with Parkinson's disease (PD).

Purpose. This systematic review was aimed at determining whether WBV improves sensorimotor performance in people with PD.

Data sources. MEDLINE, CINAHL, EMBASE, the Cochrane Database of Systematic Reviews, and the Physiotherapy Evidence Database (last search in April 2010).

Study selection. Randomized and non-randomized controlled studies examining the effects of WBV in individuals with PD were selected. Six studies fulfilled the selection criteria and were included in this review.

Data extraction. The PEDro score was used to evaluate methodological quality. The effects of WBV on various sensorimotor outcomes were noted.

Data synthesis. Methodological quality was rated as good for one study (PEDro = 6), fair for four studies (PEDro = 4-5), and poor for one study (PEDro = 2). Two studies reported that WBV treatment led to a significant improvement in tremor and rigidity as measured on the Unified Parkinson's Disease Rating Scale (UPDRS) in comparison with no intervention. The findings on other UPDRS cluster scores were conflicting, however. Two studies showed that longer-term WBV (3-5 weeks) did not result in better sensorimotor outcomes than those achieved with conventional exercise training.

Limitations. The studies reviewed are limited by their methodological weaknesses and small heterogeneous samples.

Conclusion. There is insufficient evidence to prove or refute the effectiveness of WBV to enhance sensorimotor performance in PD (i.e., grade D recommendation). More good-quality trials are required to establish the clinical efficacy of WBV in improving sensorimotor function in PD.

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INTRODUCTION

Individuals with Parkinson's disease (PD) are prone to falls.[1,2] People with PD typically suffer from varying degrees of muscular weakness, mobility deficits, postural instability, and other motor impairments (e.g. rigidity, tremors), all of which render them highly susceptible to falls.[3] Falls often lead to detrimental consequences that can be both psychological (i.e. fear of falling)[4] and physical (i.e. fragility fractures) in nature.[5,6] Researchers have therefore continued to search for intervention strategies that are effective in modifying fall-related risk factors.

Focal muscle vibration has been used in neurological rehabilitation for a long time.[7] The vibration signals activate the sensory receptors (i.e. muscle spindles), thereby inducing reflex muscle activation (i.e. tonic vibration reflex)[8] and potentially result in muscle strength benefits. Moreover, vibration signal delivery also constitutes a form of sensory stimulation. The combination of increased sensory input and muscle activation may lead to the enhancement of other neuromotor functions such as balance and gait. A recent study has shown that a 3-day focal muscle vibration program on the quadriceps muscle can effectively improve stance control and leg muscle power in older adults.[9] It has also been demonstrated that rhythmic vibrations applied to trunk muscles can enhance gait velocity in patients with PD.[10] These findings point to the potential use of vibratory stimulation in patients with deficits in sensorimotor function.

Over the past decade, whole body vibration (WBV) therapy has gained popularity in the rehabilitation of various populations. In WBV, the vibratory signals are delivered via a vibratory platform or chair to expose a larger part of the body to the stimulation. In addition to its potential benefits for bone health due to the effect of mechanical loading,[11,12] various studies have found that WBV is effective in improving muscle strength and postural control in older adults.[12-22] It is thus easy to see why researchers have increasingly focused their attention on establishing the clinical efficacy of WBV in patients with different chronic conditions (e.g. stroke, type II diabetes, cerebral palsy, etc.)[23-30] who often sustain deficits in various aspects of sensorimotor function and are thus highly susceptible to physical deconditioning and falls.

People with PD may be potential beneficiaries of WBV in view of the many neuromotor deficits commonly observed in this group. A systematic review of the literature examining the effects of such therapy on sensorimotor performance in people with PD was considered a timely endeavor given the increased level of research interest shown in the application of WBV in this population over the past few years.

METHOD

Research question and study selection criteria

The PICO method[31] was used to define the four major components of the research question: P (patient) = patients with PD; I (intervention) = WBV; C (comparison) = conventional therapy or no intervention; O (outcome) = sensorimotor performance. This systematic review was thus aimed at answering the following question: does WBV therapy lead to better sensorimotor performance outcomes in people with PD than those achieved through conventional therapy or no intervention?

The eligibility criteria for article selection were formulated on the basis of the foregoing study question. Studies were required to meet the following inclusion criteria: (1) randomized or non-randomized controlled studies that investigated the effects of WBV in individuals with PD; (2) they included a measure of sensorimotor performance (e.g. leg muscle strength, balance ability, gait) as one of the outcome measures; and (3) English publications. The exclusion criteria were as follows: (1) studies reported in books, as they are considered a secondary source of information; (2) theses and dissertations; and (3) reports published as conference proceedings, as these may not have undergone a formal peer-review process.

Data sources and searches

An extensive literature search of electronic databases including MEDLINE (1950-April 27, 2010), the Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982-April 27, 2010), and the Excerpta Medica database (EMBASE) (1980-April 27, 2010) was undertaken to identify relevant articles. The combination of the following key terms was used to perform the literature search: (1) exp Parkinson Disease/ or parkinson disease.mp., (2) parkinsonian disorders.mp. or exp Parkinsonian Disorders/, (3) parkinsonism.mp., (4) parki*.mp., (5) whole body vibration.mp., (6) exp Vibration/ or vibration.mp., (7) vibratory.mp., (8) exp Postural Balance/ or balance.mp., (9) rehabilitation.mp. or exp Rehabilitation/, (10) exp Physical Therapy Modalities/ or physiotherapy.mp.. The Cochrane Library Database of Systematic Reviews and the Physiotherapy Evidence Database[32] were also searched (the last search being performed on April 27, 2010) using the keyword “vibration”. The reference list of each selected article was examined thoroughly to identify other potential articles that might fulfill our criteria. A forward search using the Science Citation Index was also conducted to identify and examine all subsequent articles that referenced the selected articles. Moreover, experts in the field were contacted to identify any additional trials.

Data extraction and quality assessment

The literature search, data extraction and quality assessment procedures were performed by two independent research personnel who are both experienced rehabilitation practitioners and are actively involved in research. The titles and abstracts of the selected articles generated by the search strategy described above were first screened to eliminate irrelevant articles. The full text of each of the remaining papers was then reviewed to determine eligibility.

The PEDro scale was used to evaluate the scientific rigor of the studies selected (Table 2).[33] It consists of 11 items, with the first item assessing external validity (i.e. the eligibility criteria are clearly specified) to which a YES or NO response is designated. One point was given for each of the other 10 items evaluating external validity. The PEDro scores ranged from 0 to 10, with a higher score representing superior methodological quality (9-10: excellent; 6-8: good; 4-5: fair; < 4: poor).[34] The level of evidence reported in each article was determined according to the PEDro score and guidelines set by the Oxford Center for Evidence-Based Medicine (e.g. level 1b = good-quality randomized controlled trial; level 2b = poor-quality randomized controlled trial).[31] The opinion of the principal investigator was sought if the data extracted and the PEDro ratings given by the two independent researchers were different.

Data synthesis and analysis

Kappa statistics were used to assess agreement between the two raters on article selection and PEDro ratings. **For each selected article, the effects of WBV on various sensorimotor outcomes were noted.** Based on the overall evidence reported in the selected articles, a grade recommendation was given for identified outcomes (e.g. A=consistent level 1 studies; B=consistent level 2 studies or extrapolations from level 1 studies; C=level 4 studies or extrapolations from level 2 or 3 studies; D=level 5 evidence or troublingly inconsistent or inconclusive studies at any level) as described by the Oxford Center for Evidence-Based Medicine.[31] In view of the limited number of studies using the same outcome measures and the vast differences in the WBV protocols adopted (see the Results section below), meta-analysis was deemed inappropriate.

RESULTS

The aforementioned search strategy yielded 6,533 articles (Figure 1). After initially screening the titles and abstracts, eighteen articles were identified as potentially relevant.[10,35-51] After reading the full text of each of these papers, twelve more studies were eliminated (Figure 1).[10,35-45] This process resulted in a total of six studies fulfilling all the selection criteria and thus being included in the review (Table 1).[46-51] The level of inter-rater agreement for article screening after reading the titles and abstracts was good (kappa = 0.75), while that for article selection after reading the full text of each of the remaining papers was excellent (kappa = 1.00).

Methodological quality and levels of evidence

The level of inter-rater agreement for PEDro ratings was good (kappa = 0.76) (Table 1). Overall, only one study was considered a good-quality trial (PEDro ≥ 6).[47] None of the studies used intent-to-treat analysis. Blinding of the assessors was implemented in only three studies[47,49] and three studies had small sample sizes (n = 21-28).[48-50] Therefore, after considering the methodological weaknesses of the selected studies, only that of Haas et al.[47] was classified as level 1b, with the rest being assigned to level 2b.[46,48-51]

Subject characteristics

Individuals with idiopathic PD were the target population in all selected studies (Table 2).[46-51] The sample size varied from 21 to 68, with the mean age ranging from 63 to 73 years.

The Hoehn and Yahr stage indicated considerable heterogeneity in terms of the severity of PD among subjects. For example, Haas et al.[46,47] examined patients with both relatively mild disabilities (Hoehn and Yahr stage II) and severe disabilities (Hoehn and Yahr stage IV).

Training protocol

There were a number of differences in the WBV training protocols adopted across the six studies included in the review (Table 3). A vibrating platform was used to deliver the WBV treatment in all studies other than that of King et al.[51], who used a physioacoustic system consisting of a reclining chair equipped with several speakers and a computer that produced sound vibrations. When sitting in the chair, the legs, lower back, and upper back of the subject came into contact with the surface of the chair, exposing a large part of the body to the vibration.

Four studies specifically assessed the immediate effects of only a single session of WBV.[46-48] In contrast, the experimental group observed by Ebersbach et al.[49] underwent two WBV sessions per day five days a week for three weeks, and the outcomes were measured before and after the three-week training period. Arias et al.[50] implemented a WBV program consisting of 12 sessions spread over a five-week period before carrying out intra-session (i.e. assessing the effects of a single session) and end-of-program evaluations (i.e. assessing the effects of the five-week program). With regard to the parameters of the vibration signals, four of the studies employed a frequency of 6 Hz[46-48,50], whereas one used 25 Hz.[49] The amplitude of the signals also varied from 3 mm[46-48] to as high as 14 mm.[49] King et al. did not report the frequency or amplitude of the vibration signals generated by the physioacoustic system they used.[51]

Effect on sensorimotor performance

Motor impairments (Unified Parkinson's Disease Rating Scale)

Four studies employed the motor examination of the Unified Parkinson's Disease Rating Scale (UPDRS) to assess the effects of WBV on motor impairment (Table 4).[47,49,50] Haas et al.[47] assessed the immediate effects of a single session of WBV (five one-minute bouts). It was found that the UPDRS score fell significantly immediately following the treatment condition, whereas no significant change was observed in the control condition. Among the different symptom clusters, improvements were found in tremor, rigidity, bradykinesia, and gait and posture following WBV, but no improvement was observed in cranial symptoms. In a study with a crossover design, King et al.[51] also assessed the immediate effects of a single session of WBV (five one-minute bouts). Significantly greater reductions were found in UPDRS rigidity and tremor scores after WBV in comparison with those experienced during the control period. In contrast, Ebersbach et al.[49] and Arias et al.[50] showed that a longer-term WBV program (3-5 weeks) was not superior to conventional exercises in improving the UPDRS motor score.

Balance

Several studies specifically measured balance (Table 4). Turbanski et al.[46] and Ebersbach et al.,[49] for example, both assessed the extent of postural sway in patients standing on a movable platform. The former study used the linear displacement of the pivot of the tiltboard as the outcome,[46] whereas the latter employed the sum of the displacements of the platform in the anterior-posterior and medial-lateral directions to obtain an objective body sway value.[49] Turbanski et al.[46] claimed that the WBV group experienced a significantly greater improvement in postural sway in tandem standing (i.e. one foot was placed in front of the other) than did the controls after a single WBV session. However, examination of their data showed that the trend in the change in postural sway during the treatment period was very similar to, if not less marked than, that observed during the control period. Ebersbach et al.,[49] on the other hand, found that the WBV group experienced a significant reduction in postural sway but reported no significant change in the conventional therapy group. **However, the significant group × time interaction did not reach statistical significance ($p = 0.093$).** In addition to the aforementioned posturography tests, Ebersbach et al.[49] and Arias et al.[50] also employed various clinical measures of functional balance to evaluate balance ability (e.g. the Tinetti balance test, the Berg balance test, functional reach). Neither study found any difference between the WBV and comparison groups on these functional balance measures.

Mobility tasks

Three studies evaluated the effect of WBV on mobility tasks (Table 4).[49-51] King et al.[51] found that a brief WBV session had no significant treatment effect on gait velocity. Their findings on step length were also inconsistent. Group A, the first to receive WBV, experienced no significant change in step length after WBV. Intriguingly, Group B, which received WBV after the rest period, experienced a significant increase in step length.[51] None of the mobility parameters (e.g. the Timed-Up-and-Go test, the 10 meter walk test, and the stand-walk-sit test) measured by Ebersbach et al.[49] and Arias et al.[50] showed any significant treatment effect following multiple sessions of WBV in comparison with the conventional therapy group.

Proprioception

Only one study assessed the effects of WBV on sensory functioning (Table 4).[48] Haas et al.[48] assessed the proprioceptive function of the knee joint by asking the subjects to reproduce a slowly oscillating target course (0.25 Hz, amplitude: ±10°) involving unilateral repetitive knee extension and flexion movement. The average maximum and minimum knee angles of the movement series were used as the outcome measures to represent the quality of proprioception. In addition, they also analyzed knee joint movement velocity to indicate timing deficits. No significant changes were found in these variables following a single session of WBV.[48]

Pegboard task

Arias et al.[50] employed the Purdue pegboard test to assess manual dexterity, with the mean number of pegs introduced into the holes being used as the outcome measure. No significant treatment effect was reported. On the other hand, King et al.[51] used a timed pegboard task to assess bradykinesia. Subjects were required to place the pegs into the holes with randomly positioned slots as quickly as they could. In one of the treatment groups, the performance improvement in this pegboard task after the control period was very similar to that observed after the WBV treatment period that followed. It was thus difficult to determine whether the change in performance was due to the practice effect/maturation or was attributable to the effect of the vibration treatment itself.

Adverse events

Haas et al.[47,48] explicitly stated that no adverse effects are associated with WBV, whereas none of the other studies reported on whether any adverse events occurred during or after WBV treatment.

DISCUSSION

Training protocol

There was great variation in the training protocols adopted in the selected studies. While most studies used a vibrating platform to deliver the WBV treatment,[46-50] King et al.[51] used the physioacoustic system. A similar system was also used in a recent study by Zheng et al.[52], who found that a 6-month vibration treatment program was effective in improving mobility and reducing bone turnover in a group of frail older adults. Presumably, this system may be more suitable for more severely disabled individuals who cannot tolerate standing on a vibrating platform. In addition, the physioacoustic system may allow for more uniform delivery of stimulation to the body than is possible using a vibrating platform, as a large part of the body surface is in contact with the chair. Although it was claimed that the sound waves created by the physioacoustic system are physically similar to mechanical vibration,[52] whether they produce the same physiological effects remains uncertain.

Effects of a single session of WBV

Five studies [46-48,50,51] investigated the immediate effects of a single session of WBV in people with PD (i.e. acute effects). The results were mixed. There was no evidence to suggest that WBV can improve performance in proprioception.[46] Significantly better outcomes reflected in UPDRS tremor and rigidity scores (compared with no intervention) were reported by Haas et al.[47] (level 1b) and King et al.[51] (level 2b), but the methods they used to deliver vibration were different (vibrating platform vs physioacoustic chair). The results on other UPDRS subscales were conflicting.[47,50,51] Arias et al.[50] showed that the WBV group recorded a similar gain in sensorimotor performance (i.e. functional reach, Timed-Up-and-Go test, etc.) to that experienced by the placebo group (which performed the same exercises without vibration). Therefore, it cannot be ruled out that the beneficial effects of WBV observed by Haas et al.[47] and King et al.[51] could be related to the placebo effect associated with this form of treatment. Studies on the acute effects of WBV in young adults[53-56] and patients with chronic neurological conditions[23,27,28] have also produced conflicting results. Presumably, the discrepancies in the reported outcomes are related to differences in the subjects' characteristics and in the WBV protocols and outcome measures employed.

The mechanisms underlying the reported improvements in postural sway and the UPDRS motor score in people with PD are not clear.[46,47] It is likely that a number of physiological systems are involved, as previous studies conducted among other populations have demonstrated the influence of WBV on neuromuscular,[18-22] vascular,[57] and hormonal systems.[58] For example, it is known that WBV may affect the concentration of several neurotransmitters.[53,58,59] It cannot be ruled out that WBV may have an effect on the dopaminergic system, which may contribute to the observed improvement in neuromuscular performance. Some form of neuroplastic change may also be involved, as it has been shown that focal muscle vibration can induce long-lasting plastic changes in the motor cortex.[60] Increased neuromuscular efficiency may account for these improvements. It has been proposed that WBV may enhance activity of the agonist muscles, but inhibit that of the antagonist muscles, thus leading to the optimized coordination of muscle synergies.[24,61]

In summary, evidence of the acute effects of WBV on sensorimotor performance remains inconclusive (Table 5). Considering the conflicting results and the methodological flaws in the studies reviewed here, only a grade D recommendation (i.e. inconsistent evidence at any level) can be given for the use of a brief session of WBV to improve sensorimotor performance in people with PD.

Effects of multiple sessions of WBV

Both Ebersbach et al.[49] and Arias et al.[50] (both level 2b) investigated the effects of multiple WBV sessions on the UPDRS score and other aspects of sensorimotor performance (i.e. chronic effects).[49,50] In contrast with a good number of WBV studies conducted among elderly populations demonstrating the positive effects of longer-term WBV on balance performance and leg muscle strength,[8,15-21] neither study provides sufficient evidence to demonstrate that WBV treatment is any better than standard balance training[49] or control exercises without vibration.[50] It is possible that differences in the WBV protocols employed in these studies partially account for these discrepancies in results. For example, the duration of training in most of the studies carried out among older adults was between six weeks and a year, longer than the treatment periods adopted by Ebersbach et al.[49] and Arias et al.[50] (three and five weeks, respectively). Disabled patients may require a longer, more intense training program to obtain the optimal treatment effect, which would explain why WBV (of 6-8 weeks) also failed to induce a significant treatment effect in patients with other types of neurological conditions (e.g. stroke, cerebral palsy).[22,25] Moreover, both of the aforementioned studies employed small samples (21 subjects) (Table 2)[49,50] and their resulting reduced statistical power renders it difficult to detect any significant between-group difference in treatment outcomes.

In summary, only two fair-quality studies examined the effects of long-term WBV and neither showed any significant results in comparison with conventional exercises, except that there was a tendency for the WBV group to have more improvement on the posturography test as shown by Ebersbach et al (Table 5). In view of the lack of good-quality studies and the inconsistent findings, only a grade D recommendation can be given for the use of long-term WBV to improve sensorimotor performance in people with PD.

How does the evidence for WBV compare with that for the use of other physiotherapy interventions among people with PD? Keus et al.[40] performed an evidence-based analysis of physiotherapy in PD and made several specific treatment recommendations based on evidence from more than two moderate-quality controlled trials (grade B recommendation) including the use of cueing strategies (e.g. auditory, visual, tactile, cognitive) to improve walking, the application of cognitive movement strategies to improve the performance of transfers, the use of balance training combined with lower limb strength training to improve balance, and flexibility and resistance exercises designed to improve joint mobility and muscle power. Overall, research evidence supporting the use of WBV to improve sensorimotor function in people with PD is not as well established as that on the benefits of other common physiotherapy interventions.

Safety and adverse events

Safety has to be taken into consideration, as prior studies show that occupational exposure to WBV is related to vestibular problems,[62] circulation disorders,[63] and lower back pain.[64] The peak vertical accelerations of the vibration platform depend on the theoretical relationship (peak acceleration = $4\pi^2 \times \text{frequency}^2 \times \text{amplitude}$).[65] At certain stimulation frequencies and amplitudes, the vibrations may be amplified as they are transmitted through the body.[65] For example, vibration (10-20 Hz) with peak accelerations at one unit of g (Earth's gravitational constant) measured at the level of the vibration platform could be amplified to more than 2-3 g when measured at the hip if the amplitude is greater than 0.5 mm.[65] Hence, there is a potential hazard if a high-amplitude protocol is adopted for individuals with very low bone mass, as the applied load may be too much for fragile bone tissue to withstand.[65] It is thus critical that the WBV protocol (signal frequency, amplitude, and duration of exposure) be selected carefully and reported clearly, as osteoporosis is also prevalent among patients with PD.[66]

The protocols employed in each of the studies considered in this review varied. According to the aforementioned theoretical relationship, the protocol adopted by Ebersbach et al.[49] (25 Hz, 7-14 mm) would yield peak accelerations ranging from 17.6 g to 35.2 g. Although the signals would attenuate as the vibration is transmitted through the body,[65] the possibility of amplification of signals associated with the use of a high-amplitude vibration may raise some concerns.

No significant adverse effects were reported in any of the studies selected, however. Previous studies carried out among elderly populations[15-22] and individuals with different types of chronic conditions[23-30] show that it is rare for adverse events to be associated with WBV therapy. The reported side-effects are mainly limited to muscle soreness, headaches, knee pain, and joint effusion.[15-22] If present, these side-effects usually subside as training progresses. It seems reasonable to suggest that brief daily exposure to WBV is feasible and safe for individuals with PD, but further study is required.

Limitations of the included studies

The first observation to make here is that good-quality experimental studies are lacking in this area of research. Second, because three of the studies selected for review were conducted by the same group of investigators and two of these studies had unblinded assessors,[46-48] their results must be interpreted with caution. Finally, several of the studies selected suffered from reduced statistical power due to their small samples, which were also quite heterogeneous. All of these factors may partially explain the insignificant findings.

Limitations of the systematic review

The dramatically different treatment protocols and outcome measures employed in the studies reviewed make it difficult to compare their results directly. This also partly explains why meta-analysis could not be performed. The exclusion of articles written in other languages may also have led to bias in the results of the review. For example, we cannot rule out the possibility that publications in other languages may have reached very different results to those reported in the articles we reviewed.

Implications for clinical practice

This review found conflicting results concerning the acute effects of a single session of WBV. Two studies (one level 1b, one level 2b) reported that a single WBV session had a positive effect on tremor and rigidity,[47,51] but this could have been due to the placebo effect.[49,50] Only two level 2b studies investigated the effects of longer-term WBV (up to 3-5 weeks) and reported unremarkable results.[49,50] Overall, there is insufficient evidence to prove or refute the effectiveness of WBV to improve sensorimotor function in PD.

Implications for research

Many research questions concerning the use of WBV in people with PD remain unanswered. First, more good-quality studies are needed to determine the acute and chronic effects of different WBV protocols on sensorimotor performance in individuals with PD. Second, future studies should consider incorporating bone health outcomes (e.g. bone density, bone turnover), as it has been shown that WBV has a positive influence on hip bone density in older women.[11] Third, it remains to be determined whether the benefits of WBV, if any, are maintained following termination of treatment. It is also important to establish the neurophysiological mechanisms underlying the sensorimotor improvement observed after WBV.

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Table 1. Methodological quality using the PEDro scale

Criterion	Study					
	Turbanski [46]	Haas[47]	Haas[48]	Ebersbach[49]	Arias [50]	King [51]
Eligibility Criteria	No	No	No	No	Yes	No
Random Allocation	0	1	0	1	0	1
Concealed Allocation	0	0	0	0	0	0
Baseline Comparability	0	1	1	1	1	0
Blinded Subjects	0	0	0	0	1	0
Blinded Therapists	0	0	0	0	0	0
Blinded Assessors	0	1	0	1	1	0
Adequate follow-up	1	1	1	0	1	1
Intention-to-treat analysis	0	0	0	0	0	0
Between group comparisons	1	1	1	1	0	1
Point estimates and variability	0	1	1	1	1	1
Total	**2**	**6**	**4**	**5**	**5**	**4**

Table 2. Study design and subject characteristics

Study	Level of evidence	Study design	Subject characteristics			Severity of disease			Duration of disease (years)
			Sample Size	Age	Gender	UPDRS III motor score (pre-test)	Hoehn and Yahr Stage	Dosage of L-dopa (mg/d)	
Turbanski[46]	2b	Non-randomized controlled trial	Patients with idiopathic PD (n=52) WBV, n=26 CON, n=26	69.1±8.9	F=14 M=38	40.0±11.2	III-IV	494±192	8.5±0.7
Haas[47]	1b	RCT with cross-over	Patients with idiopathic PD (n=68)	65.0±7.8	F=15 M=53	29.9±11.9	II-IV	325±122	5.9±4.9
Haas[48]	2b	Non-randomized controlled trial	Patients with idiopathic PD (n=28) WBV, n=19 CON, n=9	63.1±7.3	NR	NR	II-IV	357±139	NR
Ebersbach[49]	2b	RCT	Patients with idiopathic PD (n=21) WBV, n=10 CON, n=11	WBV:72.5±6.0 CON: 75.0±6.8	F=14 M=7	WBV: 23.0±4.9 CON: 25.9±8.1	NR	WBV: 532±226 CON: 600± 207	WBV: 7.0±3.3 CON: 7.5±2.7
Arias[50]	2b	Non-randomized controlled trial	Patients with idiopathic PD (n=21) WBV, n= 10 CON, n=11	WBV: 66.9±11.1 CON: 66.6±5.6	F=9 M=12	WBV: 24.8±7.1 CON: 30.5±7.1	NR	NR	NR
King[51]	2b	RCT with cross-over	Patients with idiopathic PD (n=40)	65.4±9.9	F=15 M=25	NR	NR	NR	6.8±4.8

[a]CON = control group; F = female; M = male; NR = not reported; PD = Parkinson's disease; RCT = randomized controlled trial; WBV = whole body vibration group.

[b] Mean±SD presented unless indicated otherwise

Table 3. Training protocol

Study	Protocol for WBV group							Protocol for comparison group
	WBV treatment						Additional treatment	
	Frequency of sessions × duration of program	Number of vibration bouts x duration per bout	Rest between bouts	Frequency and amplitude of vibration signals	Device	Posture		
Turbanski[46]	Single session	5 bouts × 1 min	NR	6Hz, 3mm	ZEPTOR-med system (Vertical)	Not mentioned	None	Moderate walk for 15 mins
Haas[47]	Single session	5 bouts× 1 min	60s	6Hz, 3mm	ZEPTOR-med system, Scisens (Vertical)	Standing on the platform with slightly flexed knees	None	No specific intervention
Haas[48]	Single session	5 bouts× 1 min	60s	6Hz, 3mm	Srt-medical system (Vertical)	Standing on the platform with shoes and slightly flexed knees	None	Rest of 15 mins
Ebersbach[49]	5/week × 3 weeks	2 bouts × 15mins	NR	25Hz, 7-14mm	Galileo (left-right alternating)	Standing on the platform with slightly flexed knees and hips	Standard therapy (3×40 mins relaxation techniques, speech therapy, occupational therapy, release maneuvers for freezing patients)	Standard therapy and conventional balance training (exercises on a tilt board)
Arias[50]	Total of 12 sessions over 5 weeks on non-consecutive days	5 bouts × 1 min	60s	6H amplitude: NR	Fit Massage (left-right alternating)	Standing on the platform with feet apart and knees slightly bent	None	Standing on the platform without vibration, with equal weight-bearing on the two sides
King[51]	Single session	5 bouts x 1 min	60s	NR	Physioacoustic chair	Sitting in the chair, lower legs, thighs, buttocks, lower back, and upper back in contact with surface of the chair	None	Rest

[a] mins = minutes; NR= not reported; WBV = whole body vibration

Table 4. Effects of whole body vibration therapy on sensorimotor performance

Study	UPDRS	Other measures of sensorimotor performance	Adverse effects
Turbanski[46]		**Postural sway in side-by-side standing: NS** **Postural sway in tandem standing: WBV group had significantly more improvement than the control group (p=0.04).**	NR
Haas[47]	**UPDRS III motor score and cluster (tremor, rigidity, gait and posture, bradykinesia): significant improvement following WBV (p<0.01), but no significant change following the control condition.** **UPDRS cranial symptoms cluster score: NS.**		No adverse effects
Haas[48]		**<u>Proprioception performance in knee</u>** **Maximum knee angle, minimum knee angle, movement frequency: NS**	No adverse effects
Ebersbach[49]	**<u>Immediately after termination of the 3-week treatment:</u>** **UPDRS III Score: NS** **<u>4-week follow-up:</u>** **UPDRS III Score: No significant decline in performance for both the WBV and control groups.**	**<u>Immediately after termination of the 3-week treatment:</u>** **Tinetti balance score, Time to walk 10 m, Stand-walk-sit, Pull test score: NS** **Posturography (sway, mm): Tendency for WBV group to have lower sway (p=0.093).** **<u>4-week follow-up:</u>** **Tinetti balance score, Time to walk 10 m, Stand-walk-sit, Pull test score: No significant decline in performance for both the WBV and control groups.** **Posturography (sway, mm): Tendency for WBV group to have lower sway (p=0.093).**	NR

Arias[50]	<u>**Effects of multiple sessions**</u> **UPDRS III score: NS.** **UPDRS total score: NS.**	<u>**Effect of a single session:**</u> **Timed-up-and -Go test, functional reach, pegboard test: NS** <u>**Effect of multiple sessions:**</u> **Timed-up-and -Go test, functional reach, Berg balance test, pegboard test: NS.**	NR
King[51]	**Rigidity:** **Group A: significant improvement after WBV (p=0.049), no significant change after rest period (p=0.141). Group B: significant improvement following both rest period (p=0.003) and WBV (p<0.001).** **Tremor:** **Group A: Significant improvement following WBV (p<0.001), tremor remained lower than baseline value after rest period (p=0.021).** **Group B: No significant change across assessments.** **Other UPDRS clusters: NS**	**Step length:** **Group A: No significant change across assessments.** **Group B: Post-vibration value significantly improved compared with baseline, but only differed slightly from post-rest value (p≈0.05)** **Gait velocity: NS** **Pegboard task:** **Group A: significant improvement following WBV and rest period (p=0.008), no significant change after rest period (p=0.565).** **Group B: significant improvement following both rest period (p=0.039) and WBV (p<0.001).**	

[a]NR = not reported; NS = no significant effect when compared with control/conventional therapy; UPDRS = Unified Parkinson’s Disease Rating Scale

[b]In King et al.[51]:GroupA= received WBV first, followed by a rest period; Group B = received a rest period first, followed by WBV.

Table 5. Summary of main findings

Acute effects of WBV (a single session)

- Two studies (level 1b and level 2b) reported significant results on UPDRS tremor and rigidity scores in favor of WBV in comparison with no intervention.
- Conflicting results on other UPDRS cluster scores.
- No evidence that WBV is effective in improving knee proprioception and other clinical measures of sensorimotor performance (balance, mobility).

Chronic effects of WBV (multiple sessions over 3-5 weeks)

- Two level 2b studies reported no significant effect on UPDRS motor score in comparison with conventional exercises.
- Only one level 2b study showed that WBV had tendency to improve performance on the dynamic posturography test, but not on other clinical measures of gait and balance in comparison with conventional exercises.

Overall conclusion

- None of the studied outcomes provides adequate evidence to support the use of WBV in PD as current “best practice”.

Figure 1. Flow diagram of article selection process