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Review article

Whole-body vibration and rehabilitation of chronic diseases: A review of the literature

Konstantina Chanou ✉, Vassilis Gerodimos , Konstantina Karatrantou and Athanasios Jamurtas
[1] University of Thessaly, Department of Physical Education and Sport Science, Karyes, Trikala, Greece

Abstract
The objectives of the study were to review the current literature and findings on the effects of whole-body vibration (WBV) as a training method on performance and its ability to aid in the rehabilitation of chronic diseases (neurological, musculoskeletal or metabolic conditions). Six electronic databases were searched. The combination of the search terminology used included WBV and several neurological, musculoskeletal and metabolic conditions. Twenty six papers were found to be relevant for this review and were included for critical evaluation with regards to sample characteristics, research intervention and methodology. Most studies were conducted on patients diagnosed with neurological conditions (n = 15) while less were performed on patients suffering from musculoskeletal (n = 7) or metabolic (n = 4) disorders. Comparisons were difficult to draw on because of the different pathologies and the differences in the methodology of each study. Some of the observed methodological flaws included limitations in relation to insufficient randomisation, lack of sample homogeneity (size, age variability) and poor blinding in most studies. No consensus could be reached as to whether WBV is more effective than other interventions or no intervention at all, while the additional effects that WBV may have in relation to other interventions could not be assumed. Nevertheless, chronic WBV training seems to only improve strength in neurological patients while balance and mobility improves only in patients suffering from musculoskeletal or metabolic but not from neurological conditions. Although WBV did not prove to be more effective compared to other training methods, it can be used, in some cases, as a less fatiguing and less time-consuming method to enhance physical capabilities. Future research should focus on the effectiveness of WBV in relation to no treatment at all, and to age.

Key words: Exercise, neurological, musculoskeletal, metabolic conditions.

Introduction

Whole-body vibration (WBV) is a recently established training method that has been used to improve neuromuscular performance in healthy individuals (Rehn et al., 2007) and clinical populations (Madou and Cronin, 2008; Pang et al., 2010; Wunderer et al., 2008). In WBV, mechanical stimuli, which are characterized by vertical sinusoidal oscillations, are transmitted from the feet to the rest of the body by use of vibrating platforms (Albasini et al., 2010). The effect of WBV on the human body appears to depend on the interaction of vibration characteristics such as the vibration type (side-to-side alternating vertical oscillation (AV) vs. simultaneous vertical oscillation (SV) vs. multidirectional oscillation), the vibration frequency (Hz) and amplitude (mm), the exercise protocol (session frequency and duration, body position) and the subjects' characteristics (age, gender, training status), (Luo et al., 2005).

The long-term effects of WBV on healthy individuals indicate that muscle strength, power, vertical jumping ability and flexibility may be improved, with greater effects observed on untrained individuals (Rhea et al., 2009). Gait and balance can also be enhanced following WBV in older people (Bautmans et al., 2005; Brogardh et al., 2010). The acute beneficial effects of WBV (that is, following a single session of WBV), are less convincing. It appears that strength, power and balance may be increased (Bosco et al., 1999; 2000; Jacobs and Burns, 2009; Torvinen et al., 2002a), decreased (deRuiter et al., 2003) or remain unchanged (deRuiter et al., 2003; Gerodimos et al., 2010; Torvinen et al., 2002b) depending on the exercise volume and intensity (Luo et al., 2005) while flexibility may be improved (Gerodimos et al., 2010; Jacobs and Burns, 2009).

The mechanism responsible for the effect of the vibration stimulus has not been clearly identified (Mester et al., 2006). Mechanical stimuli referring to muscle length are reflectively transferred through mono- and polysynaptic pathways from the muscle spindles to the central nervous system (Cardinale and Bosco, 2003) for identification and appropriate response selection (Romaiguere et al., 1991). This so called "Tonic Vibration Reflex" appears to be responsible for several peripheral responses among which, is muscular contraction (Eklund and Hegbath, 1966); a reaction potentially justifying the improvement observed in muscle strength (Wunderer et al., 2008). The excitation of the Golgi tendon organs, being responsible for recording changes in the muscle tension, activate a reflex by which the agonist muscle is forced to relax and the antagonist to contract (Lindsay, 1996). Thus, an interaction between agonist and antagonist muscles allows for further movement. The clinical importance of the aforementioned interaction could be exploited in rehabilitation, especially when patients are trained to maintain balance while standing or walking (Madou and Cronin, 2008).

As with any therapeutic intervention, WBV has a risk for harmful effects on the human body when used inappropriately. Its negative effects after chronic exposure in the occupational and industrial settings have long been reported (Buckle and Devereux, 2002; Gerhardsson et al., 2005; Nishiyama et al., 1998). The vibration exposure can be calculated using the "estimated vibration dose value" (eVDV). This value is estimated using the direction, frequency, magnitude and duration of the vibration applied and should not exceed 17, according to the International

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Organization for Standardization (ISO, 2631-1), in order vibration to be considered non-harmful to humans (Merriman and Jackson, 2009).

The opinions regarding the appropriate use of WBV seem to be opposing. Among others, WBV is not suggested as a training method for people suffering from acute inflammation as well as acute cardiovascular and musculoskeletal conditions (Cardinale et al., 2006). This is mainly because of the limited scientific database focused on clinical populations, and, therefore, the unknown possible negative effects that WBV may have on such severe conditions. Nevertheless, its therapeutic use on the aforementioned disorders has been successfully addressed lately. Recent reviews have provided evidence on WBV being a beneficial type of exercise for neurological (Madou and Cronin, 2008; Wunderer et al., 2008) as well as musculoskeletal and metabolic patients.

Specifically, the literature review revealed a decrease in spasticity (Ahlborg et al., 2006; Schyns et al., 2009) and pain levels (Alentorn-Geli et al., 2008; Iwamoto et al., 2005; Johnson et al., 2010; Rittweger et al., 2002) in different clinical populations after chronic WBV exposure, while the results were less clear concerning strength, balance, mobility, gait and motor impairment. Indeed, it appears that balance, mobility and motor impairment either increase (Gusi et al., 2010; Moezy et al., 2008; Rietschel et al., 2008) or have equal effects with the compared interventions (Ahlborg et al., 2006; Arias et al., 2009; Ebersbach et al., 2008; Gusi et al., 2010; Johnson et al., 2010; Schuhfried et al., 2005; Schyns et al., 2009; Van Nes et al., 2006), gait remains unchanged (Ahlborg et al., 2006; Brogardh et al., 2010) or has equal effects with the compared interventions (Ebersbach et al., 2008; Schyns et al., 2009) and strength either remains unchanged (Broekmans et al., 2010; Brogardh et al., 2010; Schyns et al., 2009) or increases (Trans et al., 2009). However, the results from previous studies should be judged with caution, because of methodological inadequacies and the small number of studies (Madou and Cronin, 2008; Wunderer et al., 2008). Thus, carefully designed WBV intervention protocols could be used for rehabilitation purposes and should be implemented in the future to assess their effectiveness.

Therefore, the aims of the current review were: to report clinical conditions where WBV training effects have been examined, to assess the WBV intervention characteristics used in neurological, musculoskeletal and metabolic conditions and analyse the possible therapeutic effects that WBV might have.

Methods

Six electronic databases were searched (Medline, ISI Web of knowledge, Scopus, Academic Search Complete, PEDro and Google Scholar). The search terms used included whole-body vibration, Parkinson's disease, fibromyalgia, stroke, multiple sclerosis, spastic diplegia, spinal cord injury, poliomyelitis, osteoarthritis, low-back pain, anterior cruciate ligament disorder, diabetes, osteoporosis and cystic fibrosis. The search was limited to English, full text research articles on humans. No time restriction was applied to the literature search. All the results relating to local vibration, animal experiments, healthy individuals, children and vibration in relation to industry or occupation were excluded. In addition, abstract forms or papers referring to case studies, unpublished work and topics unrelated to neurological, musculoskeletal and metabolic conditions were also identified and excluded from this review.

Following the application of the inclusion and exclusion criteria, 26 papers were found to be relevant and were critically evaluated and compared with regards to their sample characteristics, research intervention and methodology used. The quality of each study was assessed using the Physiotherapy Evidence Database (PEDro) Scale; a scale which was constructed to assess controlled trials, so as to rapidly provide the best evidence to consumers and clinicians regarding physiotherapy interventions (Sherrington et al., 2000). Twenty two studies were assessed using PEDro scale, while the remaining 4 could not be included in the above assessment because of their design (no control group). All scores were retrieved by PEDro database, with the exception of 4 studies, which were evaluated by the first author. Based on the criteria set by PEDro Scale, each paper was given a score between 0 (no criteria fulfilled) and 10 (all criteria fulfilled), (Table 1). Following Madou et al.'s (2008) example, an average PEDro score was calculated for each of the three target populations as well as a total score. Using 5/10 as the average, studies were classified as below and above average quality (Madou and Cronin, 2008).

Results

Methodological quality

Eighteen studies were randomised-controlled trials (RCT) while 4 were pseudo-RCTs and 4 had a quasi-experimental design (no control group). The quality of the studies in PEDro scale ranged from 2 to 8 for neurological conditions with a mean (SD) 5.00 (1.63), from 3 to 7 for musculoskeletal conditions with a mean (SD) 5.57 (1.27) and from 4 to 5 for metabolic conditions with a mean (SD) 4.50 (0.71). The main limitations in most studies included poor concealed allocation (item 2) and blinding (items 4-6). The scores for each study are presented in Table 1.

Subjects

The included studies explored the long-term effects of WBV on patients diagnosed with musculoskeletal or metabolic conditions and the long-term and acute effects of WBV on neurological patients (Table 2). The severity of the patients' condition varied among studies and their age ranged from 21 to 88 years. Most subjects completed the exercise protocols. Nevertheless, there were studies where some patients withdrew from the program for reasons non-related to the intervention. The drop-out rate was mentioned in most studies (n = 11) with the 85% rule not being fulfilled at all times (n = 1).

Protocols

The WBV training was performed either on an AV (n =

Table 1. Methodological quality scores using PEDro scale.

Reference	Items in PEDro Scale*										
	1	2	3	4	5	6	7	8	9	10	Score†
Neurological conditions											
Ahlborg et al (2006)‡	✓	×	✓	×	×	×	✓	×	×	✓	**4**
Arias et al (2009)§	×	✓	✓	✓	×	✓	✓	×	✓	✓	**7**
Broekmans et al. (2010)‡	✓	×	✓	×	×	×	✓	×	✓	✓	**5**
Brogardh et al. (2010)‖	o	o	o	o	o	o	o	o	o	o	-
Ebersbach et al (2008)‡	✓	✓	✓	×	×	×	×	×	✓	✓	**5**
Haas et al (2006a)‡	✓	×	✓	×	×	✓	✓	×	✓	✓	**6**
Haas et al (2006b)§	×	×	✓	×	×	×	×	×	✓	✓	**3**
Jackson et al (2008)‡	✓	×	✓	×	×	✓	×	×	✓	✓	**5**
Ness et al (2009)‖	o	o	o	o	o	o	o	o	o	o	-
Schuhfried et al (2005)‡	✓	×	✓	×	×	✓	✓	×	✓	✓	**6**
Schyns et al (2009)‡	✓	✓	×	×	×	✓	×	×	×	✓	**4**
Tihanyi et al (2007)‡	✓	✓	✓	×	×	×	✓	×	✓	✓	**6**
Turbanski et al (2005)§	×	×	✓	×	×	×	×	×	✓	×	**2**
van Nes et al (2004)§	×	×	✓	×	×	×	✓	×	✓	✓	**4**
van Nes et al (2006)‡	✓	✓	✓	×	×	✓	✓	✓	✓	✓	**8**
Mean (SD)											**5.00 (1.63)**
Musculoskeletal conditions											
Alentorn-Geli et al (2008)‡	✓	×	✓	×	×	✓	✓	×	✓	✓	**6**
Alentorn-Geli et al (2009)‡	✓	×	✓	×	×	×	✓	×	✓	✓	**5**
Gusi et al (2010)‡	✓	×	✓	×	×	✓	✓	✓	✓	✓	**7**
Johnson et al (2010)‡	✓	×	✓	×	×	×	×	×	×	✓	**3**
Moezy et al (2008)‡	✓	×	✓	×	×	×	✓	×	✓	✓	**5**
Rittweger et al (2002)‡	✓	×	✓	×	×	×	×	×	✓	✓	**4**
Trans et al (2009)‡	✓	✓	✓	×	×	×	×	✓	✓	✓	**6**
Mean (SD)											**5.57 (1.27)**
Metabolic conditions											
Baum et al (2007)§	✓	×	×	×	×	×	✓	✓	✓	✓	**5**
Iwamoto et al (2005)‡	✓	×	✓	×	×	×	×	×	✓	✓	**4**
Rietschel et al (2008)‖	o	o	o	o	o	o	o	o	o	o	-
Roth et al (2008)‖	o	o	o	o	o	o	o	o	o	o	-
Mean (SD)											**4.50 (0.71)**
Total Mean (SD)											**5.14 (1.46)**

* Explenation of Items of PEDro scale: 1 Random allocation, 2 Concealed allocation, 3 Baseline comparability, 4 Blind subjects, 5 Blind therapists, 6 Blind assessors, 7 Adequate follow-up, 8 intention-to-treat analysis, 9 Between group comparisons, 10 Point estimates and variability
† Criteria of PEDro scale: fulfilled (✓), not fulfilled (×), study not assessed (o)
‡ Scores retrieved from PEDro site
§ Scored by the first author
‖ Could not be assessed with PEDro scale because of their design

10) or a SV (n = 11) or a multidirectional (n = 4) vibration (MV) platform while the vibration type was not identified in one study. The duration of the intervention protocols varied from one session (n = 7) to several weeks (n = 19). The vibration parameters differed according to the vibration type that was used. There were studies using an AV platform where lower frequencies, between 2 and 12.5Hz (n = 4) or higher frequencies, between 18Hz and 30Hz (n = 7), were applied. Accordingly, lower frequencies, between 20Hz and 30Hz (n = 8) or higher frequencies, between 35Hz and 50Hz (n = 7), were chosen for SV platforms. Exercise protocols were similar in the reviewed studies in terms of the design. Specifically, in most studies, subjects obtained a static position on the WBV platform (n = 16) while there were few studies where they performed exercise (n = 3) or used a combination of both static and dynamic positions (n = 5) during the vibration. There were also two studies where no specific information on the protocol was presented. The exercise protocols included 1-5 sets of exercise of total training duration between 30s and 5min, except for one study which reported 15min of WBV training (Tables 3-6). In most studies, group allocation involved one WBV and a control group while six studies had no control group. The control intervention included either rest (n = 8), resistance exercise (n = 6) application of transcutaneous electric nerve stimulation (TENS), (n = 1), physiotherapy, (n = 2) or standing on a non-vibrating platform (n = 1).

Effects of WBV

The effects of WBV are presented according to the patients' conditions which were grouped into neurological (n = 15), musculoskeletal (n = 7) and metabolic (n = 4) conditions. Furthermore, the neurological conditions were grouped according to the long-term (Table 3) or acute (Table 4) effects of WBV while the other two conditions involved only long-term effects (Tables 5-6).

Neurological conditions

The literature review identified a large number of studies which were conducted on patients diagnosed with Parkinson's disease (PD), Multiple Sclerosis (MS), stroke, poliomyelitis, cerebral palsy (CP) and spinal cord injury (SCI). The long-term (Table 3) as well as the acute (Table

Table 2. Characteristics of included studies.

Reference	Design*	Condition†	Sample size	Mean age (SD)	PrD‡	F§ (Hz)	D‖ (min)	Control¶
Neurological conditions								
Ahlborg et al. (2006)**	RCT	CP	14	31.2 (6.0)	L	25-40	6	Ex
Arias et al. (2009)††	P-RCT	PD	21	66.7 (8.4)	L	6	10	Placebo
Broekmans et al. (2010)**	RCT	MS	25	47.9 (1.9)	L	25-45	2.5	Rest
Brogardh et al. (2010)**	Q-Ex	Polio	5	64.0 (6.7)	L	25	3.75	No C
Ebersbach et al. (2008)††	RCT	PD	21	73.8 (6.1)	L	25	15	PT
Haas et al. (2006a)‡‡	RCT	PD	68	65.0 (7.8)	A	6±1	5	Rest
Haas et al. (2006b)‡‡	P-RCT	PD	28	63.1 (7.3)	A	6±1	5	Rest
Jackson et al. (2008)††	RCT	MS	15	54.6 (9.6)	A	2/26	0.5	No C
Ness et al. (2009)**	Q-Ex	SCI	17	47.6 (10.2)	L	50	2-4	No C
Schuhfried et al. (2005)‡‡	RCT	MS	12	47.7 (12.5)	A	2-4.4	5	TENS
Schyns et al. (2009)**	RCT	MS	16	47.7 (7.4)	L	40	0.5	No C
Tihanyi et al. (2007)**	RCT	ST	16	58.2 (9.4)	A	20	6	Ex
Turbanski et al. (2005)‡‡	P-RCT	PD	52	69.1 (8.9)	A	6±1	5	Rest
Van Nes et al. (2004)††	P-RCT	ST/H	46	61.2 (10.3)	A	30	7	WBV
Van Nes et al. (2006)††	RCT	ST	53	58.1 (11.4)	L	30	3	Ex
Musculoskeletal conditions								
Alentorn-Geli et al. (2008)**	RCT	FM	24	55.0 (3.0)	L	30	4.5-18	Ex
Alentorn-Geli et al. (2009)**	RCT	FM	33	56.9 (3.3)	L	30	4.5-18	Rest
Gusi et al. (2010)††	RCT	FM	41	52.7 (11.3)	L	12.5	6-12	Rest
Johnson et al. (2010)**	RCT	TKA	16	67.8 (8.0)	L	35	2-18	Ex
Moezy et al. (2008)**	RCT	ACLS	20	23.6 (3.7)	L	30-50	4-16	PT
Rittweger et al. (2002)††	RCT	LBP	50	51.7 (5.8)	L	18	4-7	Ex
Trans et al. (2009) §§	RCT	OA	52	60.4 (9.6)	L	25-30	3-10	Rest
Metabolic conditions								
Baum et al. (2007)**	RCT	D	40	62.7 (5.7)	L	30-35	4	FL/ST
Iwamoto et al. (2005)††	RCT	OP	50	71.3 (8.3)	L	20	4	Rest
Rietschel et al. (2008)††	Q-Ex	CF	10	35.2 (8.3)	L	20-25	9	No C
Roth et al. (2008)††	Q-Ex	CF	8	33.0 (6.6)	L	12	6	No C

*Designs: Randomised-controled trial (RCT); Pseudo- RCT (P-RCT); Quasi-Experimental (Q-Ex)
† Conditions: Celebral Parsy (CP); Parkinson's Disease (PD); Multiple Sclerosis (MS); Poliomyelitis (Polio); Spinal Cord Injury (SCI); Stroke (ST); Healthy (H); Fybromyalgia (FM); (TKA); Anterior Crutiate Ligament Surgury (ACLS); Low-back pain (LBP); Diabetes (D); Osteoporosis (OP); Cystic Fybrosis (CF); Osteoarthritis (OA)
‡ Program Duration (PrD): Long-term (L); Acute (A)
§ Frequency (F)
|| Duration (D)
¶ Conrol group(s): Exercise (Ex); No control (No C); Physiotherapy (PT); whole-body vibration (WBV); Flexibility (FL); Strengthening (ST)
** Platforms using l simultaneous vertical WBV
†† Platforms using side-to-side alternating vertical WBV
‡‡ Platforms using multidirectional WBV
§§ Unidentified WBV platform type

4) effects of WBV on balance (Arias et al., 2009; Ebersbach et al., 2008; Turbanski et al., 2005), motor impairment, gait (Ahlborg et al., 2006; Arias et al., 2009; Ebersbach et al., 2008) and proprioception (Haas et al., 2006b) of patients diagnosed with PD were examined. In most studies, the results showed statistically significant improvement in the aforementioned parameters, irrespectively of the program duration, that is one session (Turbanski et al., 2005; Haas et al., 2006a; 2006b) vs. multiple sessions (Arias et al., 2009; Ebersbach et al., 2008). Furthermore, the type of control group that was used in the study design, that is, rest (Turbanski et al., 2005), placebo (Arias et al., 2009) or other interventions (Ebersbach et al., 2008) did not prove to have significant differences compared to a WBV treatment. Nevertheless, no statistical difference was observed between groups among studies, with the exception of the evaluation in tandem standing, where only the vibration group showed significant improvement compared to a control group (Turbanski et al., 2005). Furthermore, two studies did not reveal any long-term effects of WBV on balance, mobility (Broekmans et al., 2010; Ahlborg et al., 2006) and gait (Ahlborg et al., 2006). Therefore, suggestions on the vibration's effectiveness versus another type of intervention cannot be made. Moreover, WBV had no effect on the knee proprioception of PD patients following one training session of WBV (Haas et al., 2006b).

The acute and long-term effects of WBV on strength (Broekmans et al., 2010; Jackson et al., 2008; Schyns et al., 2009), balance, gait, mobility and spasticity (Broekmans et al., 2010; Schuhfried et al., 2005; Schyns et al., 2009) were evaluated on patients diagnosed with MS. The results showed statistically significant improvement on strength either in acute (Jackson et al., 2008) or chronic WBV exposure (Schyns et al., 2009) even though no between-group significant differences were found. Only in the study of Broekmans et al. (2010), no long-term effects were found on the above variable following twenty weeks of WBV training. Similar results were observed on gait, balance and mobility of MS patients, where no effects (Broekmans et al., 2010) or equal long-term (Schuhfried et al., 2005) and acute (Schyns et al., 2009) effects were found, compared to a control intervention. Reduction of pain levels was also detected in the

Table 3. The long-term effects of WBV on neurological conditions.

Reference	Ability assessed*	Outcome measure†	AT‡	WBV W-G sig§	Control(s) W-G sig**	B-G sig††	Exercise protocol‡‡
Cerebral Palsy							
Ahlborg et al.(2006)	Gait	6-min walk (min)	8 weeks (3d/w)	Ø	Ø	--	V: 1-4 sets, 30-110s + 15-120s rest, SP
	Bal & Mob	TUG (s)		Ø	Ø	--	
	Mot Imp	GMFM (%)		↑	Ø	Ø	Ex: 3 sets, 10-15 reps + 2min rest, 7-10RM
	Strength	CPT 30° (Nm)		Ø (WL), Ø (SL)	↑ (WL), ↑ (SL)	Ø	
		EPT 30° (Nm)		Ø (WL), Ø (SL)	↑ (WL), Ø (SL)	Ø	
	Spasticity	MAS Knee Fx (score)		Ø (WL), Ø (SL)	Ø (WL), Ø (SL)	--	
		MAS Knee Xt (score)		Ø (WL), ↓ (SL)	Ø (WL), Ø (SL)	--	
Multiple Sclerosis							
Broekmans et al.(2010)	Bal & Mob	2-min walk (min)	20 weeks (5d/2w)	Ø	Ø	Ø	V: 1-3 sets, 30-60s + 120s rest, SP, DP
		TUG (s)		Ø	Ø	Ø	
		T-25-fWT (s)		Ø	Ø	Ø	C: rest
	Strength	IMPT (Nm)		Ø (Fx), Ø (Xt)	↓ (Fx), Ø (Xt)	Ø	
		IKPT 60° (Nm)		Ø (Fx), Ø (Xt)	Ø (Fx), Ø (Xt)	Ø	
	Endurance	IKPT 180°/s (J)		Ø (Fx), Ø (Xt)	Ø (Fx), Ø (Xt)	Ø	
Schyns et al. (2009)	Gait	10m walk (m/s)	8 weeks (3d/w)	↑ for V_1 & V_2	N/A	Ø	30s
	Bal & Mob	TUG (s)		↑ for V_1 & V_2	N/A	Ø	V_1: 4weeks V+Ex, 2weeks rest, 4weeks Ex
	Strength	Muscle force max (N)		Ø for V_1 & V_2	N/A	Ø	
	Spasticity	MAS Q, H (score)		Ø for V_1 & V_2	N/A	Ø	
		MSSS-88 (score)		↓ pain for V_1, Ø for V_2	N/A	--	V_2: 4weeks Ex, 2weeks rest, 4weeks V+Ex
				↓ spasm for V_1 &V_2(V+Ex>Ex)	N/A	--	
Parkinson's Disease							
Arias et al. (2009)	Bal & Mob	FRT (mm)	5 weeks	↑	↑	Ø	V: 5sets x 1min +1min rest, SP
		BBS (score)		↑	↑	Ø	
	Mot Imp	UPDRS (score)		↓	↓	Ø	PL: as V without vibration
Brogardh et al. (2010)	Gait	TUG (s)	5 weeks 2d/w	Ø	N/A	N/A	10sessions, 40-60s, 4-10sets, 1min rest, SP No C
		6-min walk (s)		Ø	N/A	N/A	
		CGS/ FGS (s)		Ø	N/A	N/A	
	Strength	IMPT (Nm)		Ø	N/A	N/A	
		IKPT (Nm)		Ø	N/A	N/A	
Ebersbach et al. (2008)	Gait	SWS (s)	3 weeks/ 4 weeks (5d/w)	↓/ maintained	↓/ maintained	Ø	3ses/d, 40min PT (for V&C)
	Bal & Mob	TBS (score)		↑/ maintained	↑/ maintained	Ø	
		Posturgraphy (score)		Ø	Ø		2 ses/d, 15min WBV (for V)
	Mot Imp	UPDRS (score)		↓/ maintained	↓/ maintained	Ø	
Spinal cord injury							
Ness et al. (2009)	Gait	10m walk (m/s)	4 weeks	Speed, Cadence, SSL, WSL: ↑	N/A	N/A	4 x 45s +1min rest, SP No C
Stroke							
Van Nes et al. (2006)	Bal & Mob	BBS (score)	6 weeks/ 12 weeks	↑/ maintained	↑/ maintained	Ø	4x45sec +1min rest between, SP
		RMI (score)		↑/ maintained	↑/ maintained		

* Ability assessed: Balance & Mobility (Bal & Mob); Motor Impairment (Mot Imp)

† Outcome measures: Timed-Up-and-Go test (TUG); Gross Motor Function Measure (GMFM); Concentric Peak Torque (CPT); Eccentric Peak Torque (EPT); Modified Ashworth Scale (MAS); Flexors (Fx); Extensors (Xt); Timed 25-feet walk test (T25-fWT); Quadriceps (Q); Hamstrings (H); Multiple Sclerosis Spasticity Scale (MSSS-88); Stand-walk-sit test (SWS); Tinetti Balance Scale (TBS); Unified Parkinson's Disease Rating Scale (UPDRS); Functional Reach Test (FRT); Berg Balance Scale (BBS); Comfortable gait speed test (CGS); Fast gait speed test (FGS); Maximal isometric peak torque (IMPT); Maximal isokinetic peak torque (IKPT); Rivermead Mobility Index (RMI)

‡ Assessment Time (AT); Days per week (d/w)

§ Whole-body vibration (WBV); Within-group significance (W-G sig); Not statistically significant (Ø); Weak leg step length (WSL); Statistically significant decrease (↓); Strong leg step length (SSL); Statistically significant increase (↑)

** Non applicable (N/A), Not reported (--)

†† Between-group significance (B-G sig)

‡‡ Exercise protocol: Vibration group (V); Repetitions (reps); Exercise (Ex); Static position (SP); Dynamic position (DP); Sessions per day (ses/d); Placebo group (PL)

group that performed 4 weeks of WBV plus exercise followed by 4 weeks of exercise (V_1) in relation to the group that performed 4 weeks of exercise and then 4 weeks of WBV plus exercise (V_2). Furthermore, significant reduction in spasms was observed in both groups (V_1 and V_2), with greater improvements during the WBV plus exercise weeks (Schyns et al., 2009).

Some studies evaluated the acute and long-term effects of WBV on strength (Tihanyi et al., 2007), balance, mobility and posture (Van Nes et al., 2006; 2004) of stroke patients. The results revealed significant improvement of strength in the vibration compared to a control group during acute WBV exposure (Tihanyi et al., 2007). Balance also seems to improve, irrespectively of the

Table 4. The acute effects of WBV on neurological conditions.

Reference	Ability assessed*	Outcome measure†	AT‡	WBV W-G sig§	Control(s) W-G sig**	B-G sig††	Exercise protocol‡‡
Multiple Sclerosis							
Schuhfried et al. 2005)	Bal & Mob	Post sw (sc)	15min	↑ 5.8 (9.7)	↓ -1.2 (6.5)	Ø	V: 5x1min of WBV + 1min rest between PL: 5x1min of TENS + 1min rest between SP
			1 week	↑ 7.0 (5.0)	↑ 0.3 (5.8)	Ø	
			2 weeks	↑ 6.3 (10.1)	↑ 3.8 (2.5)	Ø	
		FRT (mm)	15min	↑ 0.3 (40.1)	↑ -6.1 (33.1)	Ø	
			1 week	↑ 32.8 (71.6)	↑ 34.4 (42.0)	Ø	
			2 weeks	↑ 7.8 (65.4)	↑ 35.3 (64.5)	Ø	
		TUG (s) (csc)	15min	↑ -0.6 (0.6)	↑ 0.1 (0.8)	Ø	
			1 week	↑ -1.0 (1.1)	↑ 0.6 (0.8)	(*)	
			2 weeks	↑ -1.2 (1.1)	↑ -0.3 (0.6)	Ø	
Jackson et al. (2008)	Strength	IPT (Q/H) 2Hz (Nm)	1min	Ø	N/A	Ø	30s, SP
			10min	↑ 108.5 (34.4)/ Ø	N/A	Ø	
			20min	Ø	N/A	Ø	
		IPT (Q/H) 26Hz (Nm) (csc)	1min	Ø	N/A	Ø	
			10min	↑ 111.5 (36.5)/ Ø	N/A	Ø	
			20min	Ø	N/A	Ø	
Parkinson's Disease							
Haas et al. (2006a)	Mot Imp	UPDRS V_1 (sc)	Immed	↓ 16.8% in V_1	--	Ø	V_1: 5x1min + 1min rest (V-REST) V_2: 1min rest + 5x1min (REST-V), SP
		UPDRS V_2 (sc)	Immed	↓ 14.7% in V_2			
Haas et al. (2006b)	Prop	KAng min av (^{0})	Immed	Ø	Ø	Ø	V: 5x1min + 1min rest, 10 extension-flexion cycles, SP
		KAng max av (^{0})	Immed	Ø	Ø	Ø	
Turbanski et al. (2005)	Bal	Post sw NS (cm)	Immed	↓ 14.9%	↓ 7.1%	Ø	V: 5x1min, SP
		Post sw TS (cm)		↓ 24%	Ø	(*)	
Stroke							
Tihanyi et al. (2007)	Strength	EPT Xt (Nm)	Immed	↑ 22,2%	Ø	(*)	V: 5x1min + 1 min rest between, SP
		IPT Xt (Nm)		↑ 36,6%	Ø	(*)	
Van Nes et al. (2004)	Bal	RMS COP (m/s)	Immed	velocity ↓ when eyes closed	Ø	--	V: 1st: BA + FE 2nd: BA + rest +WBV 4x45sec +1min rest between, SP 3rd: BA +rest 4th: BA
				Shift speed ↑	Ø	--	

* Balance & Mobility (Bal & Mob); Motor Impairment (Mot Imp); Proprioception (Prop)
† Postural sway (Post sw); Score (sc); Change score (csc); Functional Reach Test (FRT); Timed-Up-and-Go test (TUG); Isometric peak torque (IPT); Quadriceps (Q); Hamstrings (H); Unified Parkinson's Disease Rating Scale (UPDRS); Knee angles (KAng); Average (av); Vibration followed by rest (V1); Rest followed by vibration (V2); Narrow standing (NS); Tandem standing (TS); Eccentric peak torque (EPT); Extensors (Xt); Isometric peak torque (ITP); Root Mean Square centre of pressure (RMS COP)
‡ Assessment Time (AT); Immediately (Immed)
§ Whole-Body Vibration (WBV); Within-group significance (W-G sig); Statistically significant increase (↑); No significant change (Ø); Statistically significant decrease (↓)
** Between-group significance (B-G sig); Significant difference between groups (*); Change not reported (--)
†† Vibration (V); Placebo (PL); Static position (SP); Balance assessment (BA); Functional evaluation (FE)

program duration, although no between-group differences were observed during chronic exposure (Van Nes et al., 2006) while no information on between-group differences was provided with regards to acute exposure (Van Nes et al., 2004).

One study investigated the long-term effects of WBV on strength, spasticity, gait, mobility and motor impairment of patients with CP (Ahlborg et al., 2006). Fourteen subjects were equally divided into a vibration and an exercise group. The results showed that motor impairment improved only in the vibration group. Spasticity of the extensors of the strong leg decreased in the vibration in relation to the exercise group, though between-group differences were not reported (Ahlborg et al., 2006). Strength improved only in the resistance exercise group, but no between-group differences were identified, while gait and mobility did not improve in either group after eight weeks of training (Ahlborg et al., 2006). It should be noted, however, that Ahlborg et al. (2006) used the Gross Motor Function Measure for the analysis of movement in their patients, which is a tool that has only been validated for use in children (Linder-Lucht et al., 2007). Furthermore, there has been one study examining the long-term effects of WBV on gait in patients diagnosed with SCI. Seventeen patients followed a 4-week WBV training program (4 sets, 45s duration and 60s rest). The results showed significant improvements in gait speed and cadence as well as both legs' step length (Ness & Field-Fote, 2009). Moreover, one study explored the long-term effects of WBV on five patients diagnosed with poliomyelitis and found no statistical significant effect on their strength and gait after five weeks of training (Brogardh et al., 2010). The absence of a control group in the last two studies, however, raises some methodological

Table 5. The long-term effects of WBV on musculoskeletal conditions.

Reference	Ability assessed*	Outcome measure†	AT‡	WBV W-G sig§	Control(s) W-G sig**	B-G sig††	Exercise protocol‡‡
Anterior cruciate ligament surgery							
Moezy et al. (2008)	Prop	AE60°	12 weeks	(*) 3.5 (1.9)/5.9 (3.4)	Ø 0.4 (1.5)/0.5 (1.2)	(*)	C: PT for 12 weeks, V: PT + WBV 3d/w for 4 weeks, DP
		Re/UnAE30°Re/Un		(*) 1.9 (2.9)/4.4 (1.9)	Ø 0.3 (1.6)/0.6 (1.0)	(*)	
	Bal	Post. Stability	(ch sc)				
		EO (sc)		(*) 1.8 (1.2)	(*) 0.2 (0.2)	(*)	
		EC (sc)		(*) 3.2 (1.8)	(*) 0.7 (0.4)	(*)	
Fibromyalgia							
Alentorn-Geli et al. (2009)	Hormonal secretion	IGF-1 (ng/ml)	Immed	Ø	Ø	--	V: 6reps x 6ex x 30s + 3min rest, SP & DP C: as V without vibration
			6 weeks	Ø	Ø	--	
Alentorn-Geli et al. (2008)	Pain	VAS (%)	6 weeks (2d/w)	↓ in V+Ex	Ø in Ex & C	Ø in Ex & C -- in Ex & V	V+Ex: 6reps x 6ex x 30s +3min rest/ex, SP & DP Ex: as V without vibration C: No exercise
	Fatigue			↓ in V+Ex	Ø in Ex & C	Ø in Ex & C -- in Ex & V	
	Stiffness			Ø	Ø	--	
	Depression			Ø	Ø	--	
Gusi et al. (2010)	Bal	Post bal (sc)	12weeks [M (CI)]	↑ 36%	Ø	(*) 0.69 (-1.1 to -0.3)	V: 6 x 30-60s +1min rest, SP C: No exercise
Low back pain							
Rittweger et al. (2002)	Pain	VAS (%)	24 weeks (3d/w)	↓ V	↓ Ex	Ø	V: 2d/w (1-6w), 1d/w (7-12w), + W, SP & DP Ex: 50% max strength +W
	Disability	PDI (sc)		↓ Ex	↓ Ex (Ex>V)	Ø	
	Depression	ADS (sc)		Ø in V	↓ Ex	--	
	Lumbar ROM	Lumbar Fx & Xt (°)		↑ V (Ex > V)	↑ Ex (Ex > V)	(*)	
Osteoarthritis							
Trans et al. (2009)	Strength	IKPT 30° (Nm)	8 weeks	V_1: ↑ 7.6 (3.5 to 11.6)	Ø	(*)	V_1 (WBV), V_2 (Bal): 6-9reps x 30-70s SP C: No exercise
				V_2: Ø	Ø	--	
				V_1 vs V_2: --	--	--	
		IPT Q (Nm)	[M (CI)]	V_1: ↑ 11.9 (1.9 to 22.0)	Ø	(*)	
				V_2: Ø	Ø	--	
				V_1 vs V_2: --	--	--	
		TDPM (s)		V_1: ↓ -0.59 (-1.1 to -0.1)	Ø	--	
	Prop						
Total Knee Arthroplasty							
Johnson et al. (2010)	Strength	IPT Xt (Nm)	4 weeks (3d/w) (ch sc)	↑ (84.3%)	↑ (77.3%)	Ø	V: 3-5ex, 1-3reps, SP & DP Ex : resistance ex
	Mob	TUG (s)		↓ (31%)	↓ (32%)	Ø	
	Pain	VAS M/R (%)		↓ / Ø	Ø / ↓	--	
	ROM	ROM fl/xt (°)		↑ 12 (6) / 4 (3)	↑ 14 (8)/ Ø	--	

* Proprioception (prop); Balance (Bal); Range of motion (ROM); Mobility (Mob)
† Angular error (AE); Reconstructed (Re); Unreconstructed (Un); Postrural (Post); Eyes open (EO); Eyes closed (EC); Score (sc); Insulin-like Growth Factor (IGF-1); Visual Analogue Scale (VAS); Pain Disability Index (PDI); Allgemeine Depressions Skala (ADS); Flexors (Fx); extensors (Xt); W: Weights, Isokinetic peak torque (IKPT); Isometric peak torque (IPT); Threshold for Detection of Passive Movement (TDPM); Timed-up-and-go test (TUG); VAS on movement (VAS M); VAS on rest (VAS R)
‡ Assessment time (AT); Change score (ch sc); Immediately (Immed); Days per week (d/w); Mean (Confidence interval) (M (CI))
§ Whole-body vibration: (WBV); Within-group significance (W-G sig); Significant difference (*); No significant change (Ø), Significant decrease (↓); Significant increase (↑);Vibration+Exercise group (V+Ex); Exercise group (Ex); WBV group (V1); Vibration on balance board group (V2)
|| Control group (C)
¶ Between-group significance (B-G sig)
** Physiotherapy (PT); Dynamic position (DP); Repetitions (reps); exercise (ex); Static position (SP)

concerns and the results should be interpreted with caution.

Musculoskeletal conditions

The review revealed six studies that assessed the long-term effects of WBV on musculoskeletal disorders. In these studies, different pathological conditions were included with different outcome measures (Table 5). The long-term effects of WBV on patients diagnosed with fibromyalgia (FM) were investigated and the results revealed significant improvement in pain and fatigue scores with no between-group differences (Alentorn-Geli et al., 2009). Furthermore, statistical improvement in dynamic balance was also seen (Gusi et al., 2010). There was no

Table 6. The long-term effects of WBV on metabolic conditions.

Reference	Ability assessed*	Outcome measure†	AT‡	WBV W-G sig§	Control(s) W-G sig**	B-G sig††	Exercise protocol‡‡
Cystic Fibrosis							
Rietschel et al. (2008)	Resp cap	FVC (%)	12 weeks	Ø	N/A	N/A	V: 3x3min, 2ses/d,
		FEV1 (%)	(5d/w)	Ø	N/A	N/A	SP
	Mob	CRT (5s)		↑ -1.1 (1.6)	N/A	N/A	No C
	Jump ab	PJF (N)	(ch sc)	↑ in 2-leg jump -122(141)			
				Ø in 1-leg jump	N/A	N/A	
Roth et al. (2008)	Resp cap	FEV_1 (%)	24 weeks	Ø	N/A	N/A	V: 5d/w, 6min for
		Oxygen saturation		Ø	N/A	N/A	range of motion of thorax, spine &
	Cardio cap	SBP (mmHg)		Ø	N/A	N/A	extremities
		DBP (mmHg)		Ø	N/A	N/A	3d/w, 6min
	Jump ab	MP, MF, MV (%)		↑ MP, ↓ MF, ↑ MV for 2-leg jump/ ↑ MF for 1-leg jump	N/A	N/A	+weight for muscle power, DP No C
Diabetes							
Baum et al. (2007)	Strength	IPT Q (Nm)	12 weeks	↑	↑ in Str(14%) Ø in Fl	--	V: 8x30s, DP Str: Strengthening ex Fl: Stretching ex
	Hormonal secretion	Glucose con. (mg/lt)		↓ (6.3%)	↓ in Str (5.6%)	--	
	End cap	HR (b/s)		Ø	Ø	--	
	Cardio cap	OGTT (score)		Ø	↓ in Str & Fl	Ø (Fl, Str)	
		SBP (mmHg)		↓	↓ in Str & Fl (V<Fl<Str)	(*)	
		DBP (mmHg)		Ø	Ø	--	
Osteoporosis							
Iwamoto et al. (2005)	Hormonal secretion	ALP Serum	48 weeks	↓	↓	Ø	ALD+V: 4min, SP
		Ca, P		Ø	Ø	--	ALD: No exercise
	Bone density	LBMD (g/cm^2)		↑	↑	Ø	& V
	Pain	Face scale		↓	↓	(*)	

* Mobility (Mob); Respiratory capacity (Resp cap); Jumping ability (Jump ab); cardiovascular capacity (cardio cap);
† Forced Vital Capacity (FVC); Forced Expiratory Volume in 1sec (FEV1); Chair Rising Test (CRT); Peak Jump force (PJF); Systolic Blood Pressure (SBP); Diastolic Blood Pressure (DBP); Muscle Power (MP); Muscle Force (MF); Muscle velocity (MV); Isometric peak force (IPT); Quadriceps (Q); Concentration (con); Heart Rate (HR); Bits per second (b/s); Oral Glucose Tolerance Test (OGTT); Serum alkaline phosphatase (ALP); Calcium (Ca); Phosphorus (P); Alendronate (ALN); Lumbar Bone Mineral Density (LBMD)
‡ Days per week (d/w); change score (ch sc)
§ Whole-body vibration (WBV); within-group significance (W-G sig); No significant change (Ø); significant increase (↑); significant decrease (↓)
|| Non Aplicable (N/A), Strength group (Str); Flexibility group (Fl); Significant difference (*)
¶ Between-group significance (B-G sig); Not reported (--)
** Vibration group (V); Sessions per day (ses/d); Static position (SP); Dynamic position (DP)

effect on the stiffness and depression levels of FM patients (Alentorn-Geli et al., 2009) as well as the secretion of the Insulin-like Growth Factor (Alentorn-Geli et al., 2008).

The long-term effects of WBV on patients with low-back pain (LBP) were also explored (Rittweger et al., 2002). The results showed that pain sensation as well as the patients' impression on their disability was decreased, irrespectively of the intervention (vibration vs. exercise). The depression levels were improved only in the exercise group. The lumbar range of motion was increased with greater values observed in the exercise than the vibration group. It should be noted, however, that the exercise group was assessed on the same device on which training occurred while the vibration group performed only the assessment procedure on that device. Familiarization could be a confounding factor that could have affected the results.

Pathologies like osteoarthritis (OA) and relevant surgical treatments or anterior cruciate ligament (ACL) injury have also been studied. Trans et al. (2009) examined the long-term effects of vibration on women suffering from OA utilising two different platforms: a WBV platform vs. a balance with built-in vibration platform. The results indicate that muscle strength was significantly increased in the group that trained on a WBV platform while proprioception was significantly improved in the group that performed exercise on a balance platform with built-in vibration. Nevertheless, Trans et al. (2009) claimed that the protocols used in both groups were well-matched; an assumption that may be questioned since two different platforms were used, therefore, dosage similarities should not be assumed without further research.

Johnson et al. (2010) examined the long-term effect of WBV following a 4-week exercise protocol on patients having undergone total knee arthroplasty (TKA)

due to OA. The results revealed improvement in strength and mobility irrespectively of the protocol used (physiotherapy plus vibration or physiotherapy only). These results indicate that vibration does not result in greater improvements in relation to physiotherapy only. Furthermore, a reduction in pain at rest in the physiotherapy group and in pain during movement in the physiotherapy plus vibration group was found (Johnson et al., 2010). Moezy et al. (2008) examined the long-term effects of WBV on athletes having undergone ACL reconstruction surgery and found that balance and proprioception were significantly improved when physiotherapy was combined with WBV compared to physiotherapy alone. Based on the current information from the literature, there is no evidence to support that WBV training is not more effective compared to physiotherapy alone regarding strength, balance, mobility and proprioception of ACL patients. This is in contrast to research conducted on a healthy older population where WBV seems to further improve balance in relation to physiotherapy alone (Bruyere et al., 2005). Furthermore, the above results do not agree with a large body of research where the positive effects on balance have been demonstrated on healthy individuals (Bogaerts et al., 2007; Gusi et al., 2006; Spiliopoulou et al., 2010; Verschueren et al., 2004). It should be noted, however, that the protocols used in healthy populations differ in terms of frequency and duration. Therefore, higher frequencies and longer durations could induce a therapeutic effect. In addition, patients' lifestyle, environment, physical conditioning prior to the beginning of the program as well as the influence of other factors such as drugs, diet, mental state etc. should also be taken into consideration while designing an exercise program and interpreting the results.

Metabolic conditions

Only a few studies (n = 4) have looked at the long-term effects of WBV on metabolic conditions (Table 6). Specifically, the long-term effects of WBV on a small sample of patients with cystic fibrosis (CF) were examined using an AV platform (Rietschel et al., 2008; Roth et al., 2008). Both studies found no effects of WBV on the patients' lung function. However, Rietschel et al. (2008) found a statistically significant improvement in patients' muscle force, power and flexibility and Roth et al. (2008) found a significant increase in jumping ability and performance in the chair rise test. It should be noted, however, that none of the studies used a control group, thus, raising questions about the study's methodological validity.

The review of the literature found only one study that examined the long-term effects of WBV on patients suffering from type 2 diabetes. Baum et al. (2007) allocated 40 patients into 3 groups: 1) a vibration group, which performed dynamic exercise on a vertical vibration platform (30-35 Hz, 2 mm) for 12 weeks, 2) an exercise group, which performed resistance exercise, and 3) a stretching group, which performed stretching exercises for the same time period. They found that muscle strength increased in the vibration and exercise but not in the stretching group. Furthermore, systolic blood pressure decreased in all groups, while a significant reduction was observed in glucose concentration in the vibration and exercise groups.

Iwamoto et al. (2005) examined the long-term effects of WBV on osteoporotic women who received alendronate, a biphosphonate drug used for osteoporosis. Half (n = 25) of the women receiving alendronate also followed a 48-week training protocol on a side-to-side alternating vibration platform (20 Hz, 0.7-4.2 mm). The results showed that the calcium and phosphorus serum levels were not affected by WBV and that bone density of the lumbar spine was increased in both groups. It can be, therefore, assumed that WBV was not more effective than alendronate itself. Nevertheless, the potential low frequency of exercise (once a week) could be a factor responsible for the aforementioned results. Future research should focus on dose-response parameters.

Discussion

Methodological quality

Methodological quality is considered a very significant criterion for the inclusion or exclusion of studies in systematic reviews, so as to provide reliable outcomes. The use of this criterion provides strength in the present review. The quality evaluation was performed by the use of a standardised model, the PEDro scale, proposed as a rapid and accurate tool for clinicians (Maher et al., 2003).

Most of the reviewed studies were of high quality (18 RCTs and 4 pseudo-RCTs). The mean PEDro score was above average for either neurological or musculoskeletal conditions but not for metabolic conditions, providing a total score of 5.14±1.46. Nevertheless, only a few studies presented a sound research design, that is, a score ≥ 7, and methodological rigour, that is, fulfilling at least one of the blinding factors, based on PEDro scale (Arias et al., 2009; Gusi et al., 2010; Van Nes et al., 2004). Comparisons were, therefore, difficult to make, because of the different conditions that have been assessed.

Methodological limitations included insufficient randomisation (Arias et al., 2009; Haas et al., 2006b; Turbanski et al., 2005; Van Nes et al., 2004), lack of sample homogeneity (size, age variability) and poor blinding (Ahlborg et al., 2006; Alentorn-Geli et al., 2009; Baum et al., 2007; Broekmans et al., 2010; Ebersbach et al., 2008; Haas et al., 2006b; Johnson et al., 2010; Rittweger et al., 2002; Trans et al., 2009; Turbanski et al., 2005; van Nes et al., 2004). Indeed, there were studies where the sample size was small (Ahlborg et al., 2006; Johnson et al., 2010; Schuhfried et al., 2005; Tihanyi et al., 2007) or no control group was used (Brogardh et al., 2010; Jackson et al., 2008; Ness and Field-Fote 2009; Rietschel et al., 2008; Roth et al., 2008; Schyns et al., 2009), the sample's age varied (Haas et al., 2006b; Jackson et al., 2008; Ness and Field-Fote, 2009) and the severity of the condition differed (Jackson et al., 2008). Furthermore, most researchers faced practical complications with regards to blinding factors, that is, a difficulty in determining similar intervention parameters (frequency, duration) either among groups or assessors. This is a limitation which could negatively impact the PEDro scale scores. In order to address "blinding" sufficiently, placebo interventions were used in two studies, with participants

either standing on the platform without vibration (Arias et al., 2009) or using TENS to simulate the vibration (Schuhfried et al., 2005).

Factors affecting WBV outcomes

There is a large number of factors identified which could produce a WBV effect. Those are grouped into the vibration characteristics (vibration type, vibration frequency and amplitude, eVDV) and the subjects' characteristics.

WBV characteristics: The information regarding dose-response of WBV parameters (frequency, amplitude, duration, eVDV) in pathological populations is rather limited. Indeed, there is only one study which explored the acute effects of WBV using either 2Hz or 26Hz and did not find any significant differences in strength of MS patients between the two frequencies (Jackson et al., 2008). Furthermore, there is no research to compare different amplitudes or durations in pathological populations. Moreover, the eVDV index has not been examined in any of the reviewed studies, although its importance is highly stressed in ISO guidelines (Merriman and Jackson, 2009). It is, therefore, not known whether WBV training is harmful for the pathological populations that have been examined. It is important to note, however, that the focus of ISO health guidelines lies on chronic exposures of healthy adults to daily vibration and may, consequently, have limited value when assessing risk associated with exposures in clinical populations (Merriman and Jackson, 2009). For example, there is evidence to support that WBV, exceeding the safety values mentioned earlier, can relieve pain in LBP rather than cause it. It is, therefore, necessary to modify the ISO standards and include information on vibration within the rehabilitation field (Rittweger, 2010). Despite the fact that no serious side effects have been reported in any of the reviewed studies, it is essential for researchers in the future to calculate eVDV so as to provide clinicians with information on the appropriateness of WBV on pathological populations.

The type of vibration used while training may also be considered a possible factor influencing WBV effects. In the reviewed studies, three different vibration types have been used: the AV (n = 10), the SV (n = 11) and the MV (n = 4). In the literature, comparisons only between AV and SV platforms have been identified in healthy populations. The results show that SV proves to be more effective than AV, regarding the enhancement of muscular performance, probably due to the greater frequencies that are used in these platforms (Marin and Rhea, 2010). Similar conclusions in patient populations are not easy to make. Indeed, the results of the current review are inconsistent, irrespectively of the vibration type. Specifically, either no significant effects (4SV vs. 4AV), positive effects (3SV vs. 2AV) or positive effects with no between-group differences (4SV vs. 4A) were identified regarding the under study variables. This disparity in the results could be attributed to the different pathologies that have been examined, the different variables that have been measured and the different assessment tools that have been used to evaluate the same variables (e.g. balance). It is possible that different pathologies respond differently to WBV, therefore, future research using consistency in the assessment tools might provide comparable results.

Subjects' characteristics: The use of WBV for therapeutic purposes has only recently been examined, with neurological conditions being the main focus in a population consisting of young adults (20-34 years), young middle-aged (35-44 years), middle-aged (45-64 years) and/or older subjects (> 64 years) according to Shephard's age classification (Shephard, 1998). It is difficult to reach conclusions regarding the effects of WBV in relation to the sample's age. In the current review, only a few studies explored the WBV effects on defined age groups. Indeed, in most studies selected age groups included a combination of middle-aged and older subjects (n = 10) while only a few studies included solely adults (n = 4) or middle-aged (n = 5) participants. No research studies investigated older patients. The results from either population groups are controversial with studies reporting no effect (n = 3), statistically significant effect (n = 4) or significant effect with no between-group differences (n = 7). It is, therefore, possible that the large variation observed in the samples' age for the majority of the reviewed studies, explain the controversial results. Since WBV exercise seems to be more beneficial in healthy aged adults in relation to younger adults (Vipond et al., 2008), future research should focus on the exploration of WBV in relation to age, in pathological populations.

WBV effects

In the current review, the acute as well as the long-term effects of WBV on neurological conditions have been investigated. Furthermore, only studies exploring the long-term effects of WBV on patients diagnosed with musculoskeletal and metabolic conditions have been identified in the literature. Physical capabilities such as strength, gait, balance and mobility have been examined. Variables such as proprioception, spasticity, motor impairment, cardiovascular performance and respiration have also been reported.

Strength and power: There is no consensus in the literature with regards to the long-term effects of WBV on strength. All studies apart from Trans et al.'s (2009) used SV platforms and reported no effects of WBV on patients' strength (Broekmans et al., 2010; Brogardh et al., 2010; Schyns et al., 2009) or whenever there was an effect, it was not statistically significant between groups (Ahlborg et al., 2006; Johnson et al., 2010). Only in one study, strength has been improved irrespectively of the intervention used, that is, a resistance, flexibility, stretching or WBV exercise (Baum et al., 2007). Furthermore, in the study of Trans et al. (2009), strength was improved significantly in the WBV and not in the balance group, in relation to a control group, although information on the comparison between interventions was not provided. Moreover, Roth et al. (2008), in their study on CF patients, claimed to have assessed power and lung function using two different intervention protocols (12 Hz and 26 Hz), both of which were applied in the same 6-month period. Nevertheless, it seems impossible to distinguish the effectiveness of each protocol on power and lung function due to methodological inadequacy. A few studies revealed positive acute effects on strength either in high

(26 Hz) or low (2 Hz) frequency (Jackson et al., 2008) using AV or only in the vibration in relation to an exercise group (Tihanyi et al., 2007). Therefore, the positive effects of either acute or chronic exposure of WBV vs. other interventions on strength could not be established. Future, more concise research, in terms of the methodology used, is necessary. Moreover, further research on the effects of WBV on strength and power of different pathological populations, using an AV platform is essential. This stems from the fact that SV has been proved to have a higher eVDV and a greater transmission of mechanical energy to the head, thus, having greater health risks than AV (Abercromby et al., 2007).

Gait, balance and mobility: With regards to gait, during long-term exposure, no effects or positive effects with no between-group differences have been observed on MS, SCI and PD patients, independently of the platform type and the protocol used. It should be noted, however, that the lack of effects could be attributed to the program duration which was not over eight weeks long. It can, therefore, be assumed, that gait cannot be affected to a greater extent by WBV compared to other interventions, during chronic exposure. Future research should explore the effects of WBV on gait following exercise protocols of longer duration. Furthermore, since no study referring to the acute effects of WBV on gait has been identified, research focusing on the acute effects of WBV on gait of PD, MS, CP and SCI patients as well as on patients diagnosed with musculoskeletal or metabolic conditions, should also be conducted in order to identify possible differences in relation to the program duration.

Research referring to the long-term effects of WBV on balance, mobility and motor impairment of several clinical populations, revealed that, in most studies, WBV had equal effects on the parameters that were examined compared to alternative interventions (Ahlborg et al., 2006; Arias et al., 2009; Ebersbach et al., 2008; Gusi et al., 2010; Johnson et al., 2010; Schuhfried et al., 2005; Schyns et al., 2009; Van Nes et al., 2006). This lack of differences was evident, irrespectively of the vibration type and the program duration. Only three studies (two referring to musculoskeletal and one in metabolic conditions) identified statistically significant improvement in balance of patients with FM (Gusi et al., 2010) and ACLS (Moezy et al., 2008) as well as mobility of patients with CF (Rietschel et al., 2008). The number of studies conducted on several clinical populations is rather limited; it is therefore, not clear whether WBV is more effective than any other exercise intervention or a control condition. It may be assumed, however, that WBV might produce greater positive effects in musculoskeletal compared to neurological conditions, concerning balance. Furthermore, the results with regards to the acute effects of WBV on balance are not clear since there are occasions in which it improves in relation to the control group, e.g. tandem standing (Turbanski et al., 2005) or both groups improve equally (Schuhfried et al., 2005), e.g. narrow standing (Turbanski et al., 2005). Further research on neurological as well as on musculoskeletal and metabolic conditions would provide more objective conclusions.

Spasticity, pain and fatigue: WBV appears to have positive long-term effects on decreasing spasticity (Ahlborg et al., 2006; Schyns et al., 2009). The limited data on this topic indicates that WBV may be successfully used to reduce muscle spasms. Pain also seems to be reduced in conditions such as MS, LBP, FM, TKA and osteoporosis (Alentorn-Geli et al., 2008; Iwamoto et al., 2005; Johnson et al., 2010; Rittweger et al., 2002). The results are more evident in FM since the combination of vibration and exercise appears to have greater effects than exercise alone (Alentorn-Geli et al., 2008). The rather limited data on the effects of WBV on proprioception, depression and fatigue levels of patients suffering from specific pathological conditions as well as several methodological flaws do not allow one to reach solid conclusions. Nevertheless, it can be assumed that WBV can be used as a less fatiguing and less time-consuming training method since it seems to reduce fatigue levels (Alentorn-Geli et al., 2008) and produce positive effects in less training time (30s-5min) than conventional exercise. The above assumption is of great clinical importance considering that in rehabilitation, therapists seek to improve their patients' physical condition with minimum cost of energy.

Respiratory and cardiovascular capacity, hormonal secretions and bone density: The long-term effects of WBV on the respiratory and cardiovascular capacity have only been examined in metabolic conditions, where no effects on WBV were identified with regards to respiration (Rietschel et al., 2008; Roth et al., 2008) and cardiovascular parameters (Baum et al., 2007; Roth et al., 2008). Systolic blood pressure was found to be reduced irrespectively of the intervention, with the vibration group being less improved than the other two treatments (flexibility and strengthening training), (Baum et al., 2007). Furthermore, assumptions regarding hormonal secretion and bone density cannot be made. Although it seems that there are positive effects of WBV on the above parameters, there is not much evidence to support that vibration is better compared to drugs (Iwamoto et al., 2005) or other exercise interventions (Baum et al., 2007). Similar results derive from research in healthy populations as well. Indeed, there is rather limited data regarding the long-term effects of WBV on the hormonal system, presenting increase in parathormone (Martin et al., 2009) or no changes in hormones such as testosterone and cortisol (Kvorning et al., 2006). The only exception is growth hormone which seems to show a greater response due to a combination of weight training and WBV training protocol (Kvorning et al., 2006). Conflicting evidence also exist in relation to bone density, which seems to improve in healthy elderly (Gusi et al., 2006; Verschueren et al., 2004) while it remains unchanged in young adults (Torvinen et al., 2003). Therefore, further research in relation to chronic exposure of patients on WBV is needed, before reaching a conclusion.

Although the results regarding the additional effect that WBV has on other interventions are quite clear, this is not the case in studies where no intervention at all was used. Indeed, irrespectively of the program duration and the vibration type used, the results of some studies showed no significant effect (n = 3) or positive effects but no between-group differences (n = 3) when WBV was compared to no intervention. Similar results were derived from healthy populations' studies where the positive ef-

fects of WBV in relation to no intervention at all could also not be established (Bautmans et al., 2005; Cheung et al., 2007; Delecluse et al., 2005).

Conclusion

In summary, chronic WBV training seems to only improve strength in neurological patients, while balance and mobility improves only in patients suffering from musculoskeletal or metabolic conditions. The additional effects that WBV may have in relation to other interventions could not be assumed. The results regarding the comparison to no intervention (resting control group) are less clear. There are studies where WBV has no effect, equal effects or differs statistically from the control group, irrespectively of the program duration and the vibration type, on the under study parameters. Although WBV did not prove to be more effective compared to other training methods, it can be used as a safe, less fatiguing and less time-consuming type of exercise for patients with neurologic conditions compared to other more demanding interventions. Future research should, therefore, focus on whether WBV is an effective training method compared to no treatment at all, as well as on its relation to age, that is whether the examined parameters respond differently to WBV according to the participants' age. The settlement of methodological issues and the development of well-designed safe protocols should also be taken into consideration for the establishment of comparable results.

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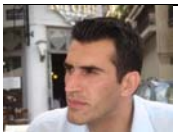
Key points

- Chronic WBV training seems to only improve strength in neurological patients while balance and mobility improves only in patients suffering from musculoskeletal or metabolic conditions.
- WBV did not prove to be more effective than other interventions, while the positive effects of WBV in relation to no intervention at all could not be established.
- No consensus could be reached as to which vibration type is more effective.
- WBV training could be used as a safe, less fatiguing and less time-consuming type of exercise for patients with neurologic conditions instead of other more demanding interventions.

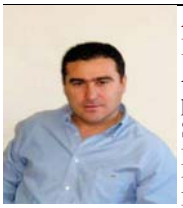
AUTHORS BIOGRAPHY

Konstantina CHANOU
Employment
Private Physiotherapist, Trikala, Greece
Degree
PhD
Research interests
Physiotherapy management, Mckenzie, exercise in elderly, vibration training.
E-mail: konchanou@gmail.com



Vassilis GERODIMOS
Employment
Assistant Professor, University of Thessaly, Department of Physical Education and Sport Science, Trikala, Greece
Degree
PhD
Research interests
Muscular adaptations to exercise physical conditioning and evaluation in health and sports
E-mail: bgerom@pe.uth.gr

Konstantina KARATRANTOU
Employment
PhD student, University of Thessaly, Department of Physical Education and Sport Science, Trikala, Greece
Degree
MSc
Research interests
Vibration training, evaluation Of Performance
E-mail: kokaratr@pe.uth.gr



Athanasios JAMURTAS
Employment
Assoc. Prof., University of Thessaly, Department of Physical Education and Sport Science, Trikala, Greece
Degree
PhD
Research interests
Metabolic aspects of exercise, exercise-induced oxidative stress, muscle damage and inflammation
E-mail: ajamurt@pe.uth.gr

✉ **Konstantina Chanou**
University of Thessaly, Department of Physical Education and Sport Science, Karyes, 421 00, Trikala, Greece