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The Effects of Whole Body Vibration on Physical and Physiological Capability in Special Populations

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Abstract: The objective of this article was to systematically review the effects of whole body vibration (WBV) loading parameters on the elderly, postmenopausal women and neurological patients. Ten databases were searched for clinical trials using WBV training in special populations. To assess the methodological quality, the PEDro score was used. To compare effects, effects were converted into percentage changes and effect sizes. Four clinical and 10 randomized clinical trial papers were included. The average PEDro score was 4.93 (±1.59). With 60-second intervention and 60-second rest periods, the most frequent vibratory stimulation loading parameters used were 3–6 Hz and 3 mm amplitude for multiple sclerosis and Parkinson's disease patients, and 30 Hz and 3–5 mm amplitude for all other conditions. Balance, stability and functional performance significantly improved ($p < 0.05$) in all special population WBV intervention groups as compared with the control groups. Bone mass density and isometric leg strength improvements were also reported. WBV provides alternative and/or additional therapeutic interventions to improve physical and functional performance. The specific loading parameters and the value of WBV as compared with conventional interventions need to be the source of future research.

Key words: elderly, multiple sclerosis, Parkinson's disease, whole body vibration

Introduction

Whole body vibration (WBV), applied with a diversity of equipment, has been recognized by many researchers as a possible means to increase physical performance [1–10], function [9,11,12] and hormone production [13–15], and to improve physiological properties such as bone structure [9,10,16]. More recently, it is claimed by an increasing number of researchers to support rehabilitation of elderly people [11,12] and patients with neurological diseases and disorders [17–22]. This phenomenon is not new, as in the 16th century, a Japanese book, *Sau-Tsai-Tou-Hoei*, discussed the use of percussion, vibration and pressure on health [23,24]. Furthermore, in 1808, John Barclay wrote *The Muscular Motion of the Human Body*, in which he reported a case of muscular spasm cured by vibration [25].

The mechanism responsible for WBV benefits is not conclusive [26,27]. It seems generally accepted, however, that WBV stimulates subcutaneous proprioceptors, which influences the γ-loop, increasing/decreasing muscle spindle sensitivity. WBV probably activates muscle spindle activity to cause muscle contraction via α-afferent and α-efferent pathways and, depending on the position of the subject on the platform, may activate Golgi tendon organs and thus muscle activity such as tonic vibration reflex [28,29] and even antagonist vibration reflexes [30]. The latter may be of clinical importance for the treatment of decreased neuromuscular activity after stroke or may be caused by diseases such as multiple sclerosis, where antagonistic activity of the m. tibialis anterior is of the greatest importance to maintain balance and stability while standing and walking.

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Exposure to WBV, however, has also been reported to have negative effects on the human body [31–34]. Therefore, it is important to be cognizant of those loading parameters used in the application of WBV that are beneficial for improving physical performance and function. Frequency, amplitude, direction and exposure time, as well as the position and activity of the subject on the WBV equipment, have to be considered, as well as the applied type of vibration. The aim of this review, therefore, is to critique the research in this area that has used WBV with special populations, particularly with regard to patients with neurological disease. Short- and long-term physical and physiological effects after WBV, with or without conventional training, are discussed with the intent of giving insight as to whether WBV is of any clinical and functional benefit to these populations and, if so, identifying loading parameters that can be safely used with these populations.

Methods

Strategy for literature search

To find the literature on this topic, the following electronic databases were searched: ProQuest, IngentaConnect, Meditext, MEDLINE, Proquest5000, PubMed, SPORTDISCUS, Web of Science, Health and Medical Complete, as well as Google Scholar. The following key words were used in different compositions: whole body vibrations and therapy (303), stroke (59), Parkinson (22), multiple sclerosis (1), elderly (124), women bone density (42), cerebral palsy (26), neurological (96). One reviewer carried out the selection of articles in two consecutive screening phases. The first phase consisted of selecting articles based on the title and abstract. The second phase involved applying the selection criteria to the full-text articles.

The following selection criteria for inclusion in this study were used: (1) the studies used WBV as a training method for treatment; (2) the studies were written in English, German or Dutch, with the abstract in English and were published in a peer-reviewed journal; and/or (3) the study provided additional information on an aspect of WBV as an intervention method. All articles reporting occupational health risks from exposure to WBV were excluded. Thus, 14 articles from 1997 to 2007 were included.

Evaluation of methodological quality

The PEDro Methodological Quality Scale was used to evaluate the quality of the individual studies included in this systematic review. The PEDro scale is designed to help users of the PEDro database quickly identify which of the randomized clinical trials indexed on the PEDro database are likely to be internally valid (items 2–9) and could have sufficient statistical information to make their results interpretable (items 10–11) [35,36].

Two reviewers independently performed the evaluation of the methodological quality of each study. Any differences in scoring by the independent reviewers were evaluated, discussed and rescored, resulting in an overall score for methodological quality. Therefore, each paper was given a score between 0 and 10. By averaging the score, a raw split into two categories seemed to be the best possible criterion to decide whether a paper should be regarded as of above- or below-average quality. Studies that scored the highest used a randomized controlled trial research design. Randomized studies with an experimental and control group have more statistical power than studies with an experimental group only. Some limitations of the literature in this area included small sample sizes, sample homogeneity, poor blinding (of subjects, treatment providers and assessors), and no or limited randomization of subjects.

Evaluation of effects

Effect sizes (ES) were calculated for the few studies that provided enough statistical data (Table 1). The Cohen scale was used to quantify ES. Cohen [37] categorized ES into trivial (< 0.2), small (< 0.41), moderate (0.41–0.7),

Table 1. Total number of studies and participants, specified by sex and topic of research

	Spastic diplegia	Elderly	Postmenopausal women	Parkinson's disease	Multiple sclerosis	Stroke patients	Total
Male	8	47	0	147	3	56	261
Female	6	47	188	57	9	43	350
Total	14	94	188	204	12	99	611
WBV	7	63	69	178	6	50	373
CON	0	20	53	26	6	49	154
RES	7	11	66	0	0	0	84
Studies (*n*)	1	3	3	4	1	2	14
Participants/Study	14	31.3	62.67	51	12	49.5	43.6

WBV = whole body vibration; CON = control; RES = resistance training.

and large (>0.71). Using ES as a means to present the magnitude of the training effect has several advantages. As it is a standard unit for measuring and reporting changes, it is possible to compare different methods and training effects within and between studies, and single studies have greater impact because of normalization. By using this approach, it is possible to distinguish between statistical significance and clinical relevance. Several authors stated that the effects of WBV were not significant without presenting any data pre- or post-test. As readers should be able to decide for themselves whether an effect is of clinical relevance and interest, we were interested in the magnitude of the effect. Others only presented percentage change. Calculating percentage changes does not take into consideration the variance of improvements among subjects and, therefore, these changes are not unconditionally comparable, either within or across studies. ES account for this variation.

Results and Discussion

PEDro score

The 14 papers selected had an average PEDro score of 4.64 ± 1.74. Nine papers [6,10–12,14,17,19,38,39] were assessed in PEDro, and the authors assessed the five remaining papers (Table 2).

Design and training duration

Two studies used a crossover design (Haas et al [18,40]), two studies (Roelants et al [6] and Verschueren et al [10]) used three groups (experimental, control and resistance training), and one study (Hoos [41]) had no control group. van Nes et al [21] used two groups with different characteristics (control group were healthy adults). All other studies used a control group and implemented a pre-test–post-test design with randomized allocation to the groups.

In terms of intervention duration, five studies [18–20,39,40] were short-term (one intervention only) and nine long-term in duration. Six [11,12,17,21,38,41] of these studies were between 6 and 8 weeks in duration, and three studies [6,10,38] had a substantial intervention period ranging from 24 to 37 weeks (Table 2).

Sample size and characteristics

The average sample size (Table 2) was 43.64 ± 25.43. The largest specific population studied was postmenopausal women (89 subjects) [6] and the smallest sample size was used by Hoos (Parkinson's disease patients, nine subjects) [41]. The control and experimental groups ranged in size from six subjects in each group in a pilot study by Schuhfried et al [19] to a study that used 68 subjects [18] in a pre-test–post-test design where the subjects acted as their own controls. All other groups used samples sizes between 22 and 27 participants for their interventions. The specific number of males and females, as well as the numbers in the experimental and control groups, are listed in Table 1. Obviously, statistical power will vary according to sample size and design, but no studies reported their statistical power.

The subject dropout rate during the interventions should not exceed 15% [42]. Using WBV on the elderly, Bruyere et al [12] reported that 22 subjects started in the experimental group, but only 16 participants were assessed after 6 weeks, which equated to a 26% dropout rate. Twenty of the 22 subjects, however, were included in the intention-to-treat analysis. Bautmans et al [11] reported that three participants (23.1%) from the experimental group did not finish the study. Runge et al [38] reported five dropouts from the initial 39 participants (12.8%), which were not included in the analysis. Roelants et al [6] reported dropout rates of 20% (six participants) from the WBV group, 30% (nine participants) from the resistance training group, and 17.9% (five participants) from the control group. Gusi et al [14] reported that 28.5% of the participants (four from the experimental and four from the control group) did not finish the study. After all had participated in the second of three assessments, van Nes et al [39] had one dropout with shoulder pain in the WBV group, who was not linked to the intervention, and two dropouts in the ETM (exercise therapy on music)/CON group, because one had a second cerebral infarction and the other refused to continue.

One study [12] did not report the reason for dropout, and five studies [6,11,14,38,39] reported health reasons for stopping, in which one case [38] possibly was because of vibration training. Ahlborg et al [17] reported no dropout, but one participant had to reduce the training owing to training loads being too demanding. In two studies [6,12], lost participants were included in the analysis. In summary, 24 of 373 participants (6.4%) were lost from the experimental groups, nine of 84 participants (10.7%) from the resistance-training groups, and 11 of 154 participants (7.1%) from the control groups.

WBV devices

Five different WBV devices were used. The major differences in these devices were the frequency range, amplitude, and the type of vibratory stimulation.

The Power Plate (Power Plate International Ltd., Northbrook, IL, USA; http://www.powerplate.com) uses a frequency of 30–50 Hz and amplitude of 1.7–5 mm. The NEMES (Elite Sport Services, Athens, Greece; http://www.bosco-system.com) uses a frequency of 20–55 Hz and amplitude of 4 mm. The Fitvibe (Fitvibe, a division of GymnaUniphy NV, Bilzen, Belgium; http://www.fitvibe.com) uses a frequency of 20–60 Hz and amplitude of 2–4 mm. These three devises use one platform and vertical sinusoidal vibration.

The ZEPTORmed (Scisens GmbH, Frankfurt, Germany; http://www.scisens.com/index.php) uses a frequency

Table 2. General overview of parameters, methods and design of papers with special populations

Reference	PEDro	Sample	Random	Control	Population	Weeks	Frequency	Amplitude	Load*	Work (seconds/set)
Ahlborg et al [17]	4	14	Yes	Yes	Spastic diplegia	8	40	4	1	110
Bautmans et al [11]	7	24	Yes	Yes	Elderly	6	40	5	2	60
Bruyere et al [12]	6	36	Yes	Yes	Elderly	6	26	3	1	60
Gusi et al [14]	5	28	Yes	Yes	Postmenopausal	37	12.6	3	1	60
Haas et al [40]	3	75	No	Yes	Parkinson		6	3	1	60
Haas et al [18]	5	68	Yes	Yes	Parkinson		6	3	1	60
Hoos [41]	2	9	No	No	Parkinson	8	60	2	1	90
Roelants et al [7]	4	89	Yes	Yes	Postmenopausal	24	40	2.5	2	60
Runge et al [38]	2	34	Yes	Yes	Elderly	8	27	7	1	120
Schuhfried et al [19]	6	12	Yes	Yes	MS patients		3	3	1	60
Turbanski et al [20]	4	52	No	Yes	Parkinson		6	3	1	60
van Nes et al [21]	4	46	No	Yes	Stroke patients		30	3	1	45
van Nes et al [39]	8	53	Yes	Yes	Stroke patients	6	30	3	1	45
Verschueren et al [10]	5	71	Yes	Yes	Postmenopausal	24	40	2.5	2	60
Average	4.64	43.64				14.1	26.2	3.36		67.86
SD	1.74	25.43				10.7	16.6	1.17		21.69

*1 = standing on whole body vibration device, and 2 = dynamic exercises on whole body vibration device. MS = multiple sclerosis; SD = standard deviation.

Table 3. Special populations and vibration equipment used

	Spastic diplegia	Elderly	Postmenopausal women	Parkinson's disease	Multiple sclerosis	Stroke patients	Studies (*n*)
NEMES	1						1
Power Plate		1	2				3
Fitvibe				1			1
Galileo		2	1			2	5
ZEPTORmed				3	1		4
Total	1	3	3	4	1	2	14

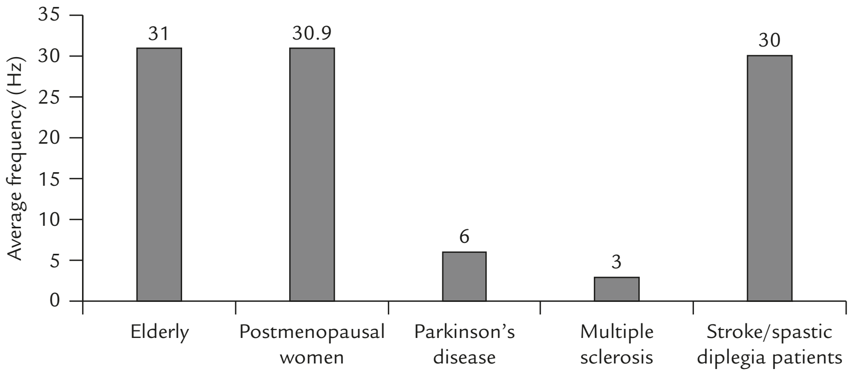

Figure 1. Most frequently used whole body vibration frequencies in different special populations.

of 1–12 Hz and amplitude of 3 mm. The Galileo900/2000 (Novotec Medical GmbH, Pforzheim, Germany; http://www.galileo-training.com/index.php) uses a frequency of 5–30 Hz and amplitude of 0–6.4 mm. These two devices use different vibration platforms. The vibratory stimulation of the ZEPTORmed is stochastic in nature, multidirectional (a combination of horizontal, vertical and tilted) and applied through two plates. The platform of the Galileo provides a sinusoidal vibration by tilting one platform on a mid-axis (effective amplitude, 0–6.4 mm). The amplitude of the latter depends on the feet position distance from this mid-axis. The different vibration devices and the populations that used these devices are listed in Table 3.

Vibratory loading parameters

Frequency

The average vibration frequency used in all the selected studies was 26.9 Hz (range, 3–60 Hz). The highest mean frequencies (30–31 Hz; range, 10–40 Hz) reported in the studies were used for the elderly, postmenopausal and stroke patients (Figure 1). The lowest frequencies (3–6 Hz) were used for Parkinson's disease and multiple sclerosis patients, except for Hoos [41], who used a range of frequencies from 30 Hz to 60 Hz for Parkinson's disease sufferers, which was the exception to the other papers and was not included in the analysis presented in Figure 1.

Amplitude

The amplitude was rather similar in all studies (mean, 3.36 mm; range, 2–7 mm). In studies with Parkinson's disease and multiple sclerosis patients, 3 mm amplitude was used except for Hoos [41], who used 2 mm. The amplitude used for the elderly group was on average 5 mm. The most frequently used frequencies for each of the populations are summarized in Figure 1.

Intervention duration and rest periods

With regard to the intervention durations, all studies, except two, used WBV intervention times of 45–60 seconds per set (average, ~68 seconds). The two exceptions were Ahlborg et al [17] and Runge et al [38] who used WBV durations of 110 seconds and 120 seconds, respectively (Table 2). The rest period between sets of vibrations was 60 seconds in seven of 14 studies. Roelants et al [6] and Verschueren et al [10] used decreasing rest periods between sets, from initially 60 seconds to finally 5 seconds at the end of the first 12 weeks and only 5 seconds' rest for the remaining 12 weeks. Bruyere et al [12] used 90 seconds and Hoos [41] 30 seconds; Ahlborg et al [17], Runge et al [38] and Turbanski et al [20] did not specify their rest periods between sets. For most of the studies, the number of WBV sets performed ranged between two and six sets. Two exceptions to these loading parameters were Roelants et al [6] and

Verschueren et al [10], who used 27 sets of 60 seconds WBV at the end of their 24-week study.

Additional loading

The participants carried no additional load and did not move when standing on the platform in all but three studies (Bautmans et al [11], Roelants et al [6], Verschueren et al [10]), in which they performed dynamic exercises such as different variations of squats whilst being vibrated.

Assessed variables

Twenty-nine different dependent variables were assessed in the 14 studies, of which only eight variables/properties were reported in two or more papers. The most commonly reported variables were: timed up-and-go (TUG); balance (combined with scores from centre of pressure score, sway recovery score and 30-second chair rising test); sit and reach (combination of sit-and-reach test, and functional reach test); bone mass density (BMD); isometric strength; Tinetti test; functional ability (combination of gait and walking scores); and isotonic strength. BMD was the most important variable assessed for postmenopausal women.

Intervention effects: ES and percentage changes

The variables of most interest and that were most assessed were body balance, TUG, stability (chair sit and reach/functional reach test) and BMD, but most papers failed in presenting comparable data. To determine the magnitude of effects, the results should be converted into ES, but most papers did not supply enough information to calculate ES. Seven papers presented percentages only. One paper [21] reported small but significant positive effects presented in a graph without exact data. All others presented intervention effects in tables, reporting changes of the mean and standard deviations, which could be converted into ES and/or percentage change.

All intervention effects are listed in two tables (Tables 4 and 5). Table 4 presents the results of long-term studies and Table 5 the results of short-term interventions. If possible, changes are presented as ES as well as percentage change. Percentage change of a variable can indicate a certain tendency if this variable is presented in a number of papers. In Figure 2, eight studies that assessed balance are presented. All papers reported improvement of balance in the intervention group (average ES and percentage change).

WBV and training efficacy of different equipment

Beneficial effects were reported with all named WBV devices (Figure 3). The major limitation, when comparing the efficacy of different devices, is that some equipment were only used in the treatment of a specific group of subjects. For example, ZEPTORmed was used in studies with patients suffering from Parkinson's disease (intervention parameters: 6 Hz with 3 mm amplitude, stochastic) and multiple sclerosis (intervention parameters: 3 Hz with 3 mm amplitude, stochastic). The Fitvibe was used in patients with Parkinson's disease in a long-term study with different parameters (60 Hz, 2 mm amplitude, vertical sinusoidal) but similar beneficial effects. The Galileo, NEMES and Power Plate were used in similar groups of participants. With the elderly, Galileo (10–25 Hz, 3 mm amplitude, vertical with a tilting plate; Bruyere et al [12]) resulted in greater improvements than the Power Plate (30–40 Hz, 2–5 mm amplitude, vertical sinusoidal; Bautmans et al [11]). With postmenopausal women, the improvements with the Galileo (12.6 Hz, 3 mm amplitude, vertical with a tilting plate) [14] were less compared with the effects using NEMES and Power Plate (35–40 Hz, 1.27–2.5 mm amplitude, vertical sinusoidal) [6,10]. Using different equipment in a design with which similar special population subgroups are studied would offer insight as to whether different WBV devices offered superior treatment effects for specific populations.

Effects in subgroups of special populations

To determine which subgroup found WBV most beneficial, the effects of three groups of variables, i.e. function (sit and reach, and functional reach test) and gait, TUG, and body balance, were compared and presented in a graph (Figure 4). As not all results could be converted into ES, the results in Figure 4 are presented in percentage change. The average score for each variable in each subgroup was calculated. Although there are limitations to such a comparison, it seems that the elderly benefit to a higher degree from WBV training, as well as patients with Parkinson's disease and postmenopausal women (TUG was not tested in these two groups). Patients with spastic diplegia did not improve in TUG (0%, therefore not visible), and in functional performance, a negative effect of –2.1% was observed. The reader needs to be cognizant that most of the percentage changes in Figure 4 were calculated from short-term interventions, but similar and higher effects have been reported in long-term intervention protocols (Gusi et al [14], van Nes et al [39], Roelants et al [6], Verschueren et al [10]).

Effects of WBV on body balance, functional performance, BMD, stability and gait, muscular strength, and power

This section summarizes those WBV loading parameters that have the greatest influence on body balance, stability and gait, TUG, BMD, muscular strength (isometric and dynamic), and power. It should be kept in mind that in most cases, there is a paucity of research investigating the influence of WBV on these variables in special populations, so some of the conclusions made by the authors must be read with this in mind. Figure 5 shows the average effects on three functional performances and BMD, found in studies mentioned in this section.

Table 4. Overview of training effects of studies using long-term interventions utilizing whole body vibration (WBV) in special populations

Reference	Subjects	Age/Sex	Design	Parameters	Device	Characteristics	Assessments	% WBV	% CON	% RES	ES WBV	ES CON/RES
Ahlborg et al [17]	Spastic diplegia	Age = 32	RCT	F = 35–40 Hz	5 = NEMES	Static	Walking test	–2.3		10.23		
	n = 14	Male = 8	Long-term	A = 4 mm		Standing knee 130º flexed	TUG	0		–6.7		
	WBV = 7	Female = 6	8 wk	Vibr. = 360 s		Body weight	GMFM	1		–1		
	RES = 7		3/wk	Rest included		RES = 3 × 7–10 RM						
			PEDro = 6			Rest = 2 m						
Bautmans et al [11]	Elderly	Age = 77.5	RCT	F = 30–40 Hz	3 = Power Plate	Static	Sit and reach	13.8		14.3	0.42	0.35
	n = 24	Male = 15	Long-term	A = 2–5 mm		Standing	30 s chair stand	43.9		1.2	0.44	0.03
	WBV = 13	Female = 9	6 wk	Vibr. =		Body weight	Balance	3.7		–10.7	0.04	–0.54
	RES = 11	Dropouts = 3	3/wk	2 × 30–60 s		Six positions	Gait	0.4		0.4	0.14	0.19
			PEDro = 7	Rest = 30–60 s		RES = no WBV	TUG	18		3.3	0.6	0.08
							Leg extension power	90.1		27.7	1.11	0.31
Bruyere et al [12]	Elderly	Age = 81.9	RCT	F = 10–26 Hz	4 = Galileo	Static	Gait score	39.3	0		0.96	0
	n = 42	Male = 11	Long-term	A = 3 mm		Standing	Balance	40.7	–0.04		0.97	–0.09
	WBV = 22	Female = 31	6 wk	Vibr. = 4 × 60 s		Body weight	TUG	30.2	–8.3		0.67	–0.09
	CON = 20	Dropouts = 6	3/wk	Rest = 90 s		CON = 10 m therapy	SF36 function	86.9	7.8		1.16	0.08
			PEDro = 6				SF36 pain	26	–7.2		1.13	–0.11
Gusi et al [14]	Postmenopausal women	Age = 66	RCT	F = 12.6 Hz	4	Static	BMD spine	–1.05	–1.2		–0.08	–0.08
	n = 28		Long-term	A = 3 mm		Standing knee 130º	BMD femur	2.5	–1.2		0.2	–0.15
	WBV = 14		37 wk	Vibr. = 6 × 60 s		Body weight	BMD hip	6.3	1		0.36	0.08
	CON = 14		3/wk	Rest = 60 s		CON = walking	Balance	28.7	–4.4		0.53	–0.13
			PEDro = 5									
Hoos [41]	PD	Age = 66.9	CT	F = 30–60 s	2 = Fitvibe	Static	UPDRS	6				
	n = 9	Male = 6	Long-term	A = 2 mm		Standing	Tremor rest	33.3				
		Female = 3	8 wk	Vibr. =		Body weight	Tremor action	16.7				
			2/wk	1 × 90 s		Four positions	Gait/Posture	22.2				
			PEDro = 2	1 × 45 s		No CON						
				Rest = 30 s								
Roelants et al [7]	Postmenopausal female	Age = 64.2	RCT	F = 35–40 Hz	3	Dynamic	12 wk:					
	n = 89	Dropouts:	Long-term	A = 1.7–2.5 mm		Six squat exercises	Max isometric	12.4	–4.3	16.8		
		n = 20	24 wk	Vibr. =			Max dynamic	12.1	?	12.5		

	WBV = 30	WBV = 6	3/wk	18 × 60 s (wk 12)		Body weight	Isokinetic strength					
	CON = 29	CON = 9	PEDro = 4	27 × 60 s (wk 24)		RES: 60 m	– extension speed					
	RES = 30	RES = 5		Rest = 5 s		4 × 12–8 RM	1–20% of	< 7.4	No data	No data		
							isometric strength					
							– extension speed					
							40–60% of	0	No data	No data		
							isometric strength					
							CMJ					
							24 wk:					
							General < 12 wk	16	–?	12		
Runge	Elderly	Age = 67	RCT	F = 27 Hz	4	Static	Chair rising test	18	0			
et al [38]	n = 39	Male = 23	Long-term	A = 3.5–6.4 mm		Standing (bended	(five repetitions					
		Female = 11	8 wk	Vibr. = 3 × 120 s		knees and hip)	timed)					
		Dropouts = 5	3/wk	Rest = ?		Body weight						
			PEDro = 4			WBV = CON						
van Nes	Stroke patients	Age = 61.1	RCT	F = 30 Hz	4	Static	Seven different					
et al [39]	n = 53	Male = 30	Long-term	A = 3 mm		Standing knee	scales:					
	WBV = 27	Female = 23	6 wk	Vibr. = 4 × 45 s		135°	Balance scale	85.4	89.5		1.38	1.14
	ETM/CON = 26	Dropouts:	5/wk	Rest = 60 s		Body weight						
		WBV = 1	PEDro = 8			CON = ETM						
		ETM/CON = 2				4 × 45 s/60 s rest						
Verschueren	Postmenopausal	Age = 66	RCT	F = 35–40 Hz	3	Dynamic	24 wk:					
et al [10]	female	Dropouts	Long-term	A = 1.7–2.5 mm		Six squat exercises	Max isometric	13.4	–3.2	14.5	0.82	–0.18/0.77
	n = 71		24 wk	Vibr. =		Body weight	Max dynamic	16.9	2	9.8	0.51	0.11/0.54
	WBV = 25		3/wk	18 × 60 s (wk 12)		RES: 60 m	BMD hip	0.9	–0.7	–0.59	0.59	–0.05/–0.05
	RES = 22		PEDro = 7	27 × 60 s (wk 24)		4 × 12–8 RM	BMD L1–L4	–0.3	0.4	0.1	–0.02	0.03/0.01
	CON = 24 (23)			Rest = 5 s			Postural sway:					
							(1) Arm abducted					–0.43
							A–P	15.6%	–11.7		0.15	–0.18
							M–L	9.1%	–5.1		0.33	
							(2) Arm anteflected					
							A–P	4.4%	–1.35		0.15	–0.05
							M–L	12.8%	–4.8		0.35	–0.18

CON = control group; RES = resistance training; ES = effect size; RCT = randomized clinical trial; F = frequency; A = amplitude; Vibr. = vibration; RM = repetition maximum; TUG = timed up-and-go; GMFM = gross motor function measure; SF36 = Short-Form 36 health survey questionnaire; BMD = body mass density; PD = Parkinson's disease; CT = clinical trial; UPDRS = Unified Parkinson's Disease Rating Scale; Max = maximum; CMJ = counter movement jump; ETM = exercise therapy on music; A–P = from anterior to posterior; M–L = from medial to lateral.

Table 5. Overview of training effects of studies using short-term interventions utilizing whole body vibration (WBV) in special populations

Author	Subjects	Age/Sex	Design	Parameters	Device	Characteristics	Assessments	Effect WBV	Effect CON	Effect RES	ES WBV	ES CON/RES
Haas et al [40]	PD n = 75 25 (–L-Dopa) 50 (+L-Dopa	Age = unknown Male = ? Female = ?	CT Short-term PEDro = 4	F = 6 Hz A = 3 mm Vibr. = 5 × 60 s Rest = ?	1 = ZEPTORmed	Static Standing Body weight Knee angle (?)	30 s balance test on platform	26% overall				
Haas et al [18]	PD n = 68 (34 per group)	Age = 65 Male Female	RCT cross over design Short-term PEDro = 7	F = 6 Hz A = 3 mm Vibr. = 5 × 60 s Rest = 60 s	1	Static Standing Body weight Knee angle (?)	UPDRS Tremor Rigidity Gait/Posture	14–16% 25% 24% 15%	 0% 0% 0%			
Schuhfried et al [19]	MS patients n = 12 WBV = 6 CON = 6	Age = 47.7 Male = 3 Female = 9	RCT Short-term PEDro = 6	F = 3 Hz A = 3 mm Vibr. = 5 × 60 s Rest = 60 s	1	Static Standing with min. flexed knee Body weight CON = TENS 5 × 60 s/60 s	1 week post: SOT TUG FRT	 9.90% 10.90% 10%	 0.40% –7.5% 10.50%		 1.35 0.77 0.53	 0.02 –0.15 0.48
Turbanski et al [20]	PD n = 52 WBV = 26 CON = 26	Age = 69.1 Male = 38 Female = 14	CT Short-term PEDro = 4	F = 6 Hz A = 3 mm Vibr. = 5 × 60 s Rest = ?	1	Static Standing on platform	32 s postural sway: Narrow stand Tandem stand	 14.90% 24%	 7.10% 11.30%			
van Nes et al [21]	Stroke patients n = 46 WBV = 23 CON = 23 (healthy)	Age = 58.1 Male = 13 Female = 10 Age CON = 63.9	CT Short-term PEDro = 4	F = 30 Hz A = 3 mm Vibr. = 4 × 45 s Rest = 60 s	4	Static Standing min. flexed knees Body weight	COP velocity	Sign. + ?%				

CON = control group; RES = resistance training; ES = effect size; PD = Parkinson's disease; CT = clinical trial; F = frequency; A = amplitude; Vibr. = vibration; RCT = randomized clinical trial; UPDRS = Unified Parkinson's Disease Rating Scale; MS = multiple sclerosis; TENS = transcutaneous electrical nerve stimulation; SOT = sensory organization test; TUG = timed up-and-go; FRT = functional reach test; COP = centre of pressure.

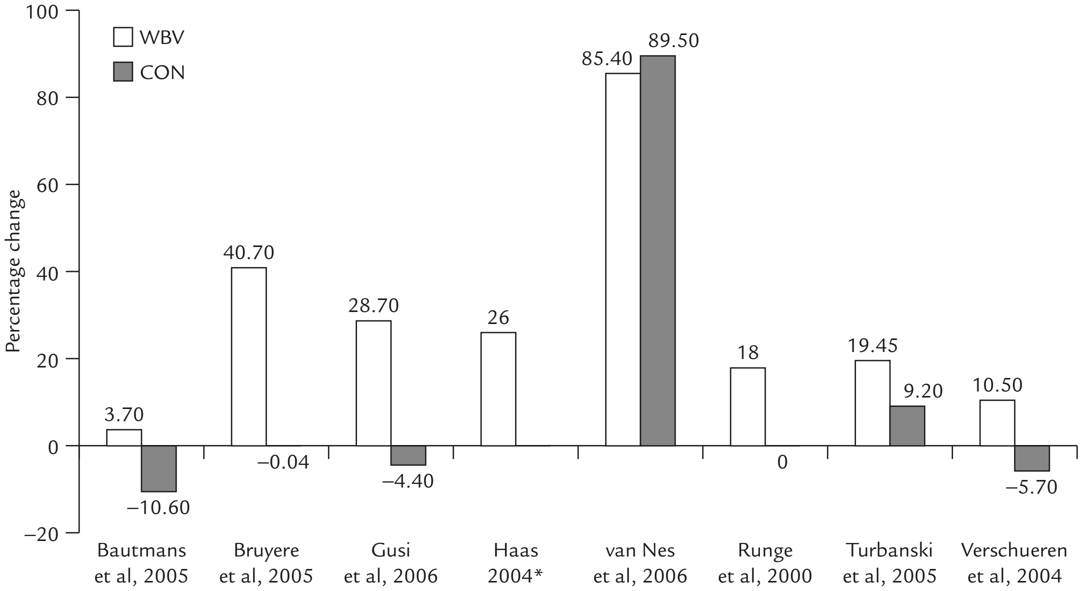

Figure 2. Percentage change in body balance in separate studies using whole body vibration (WBV). CON = control group. *No control group.

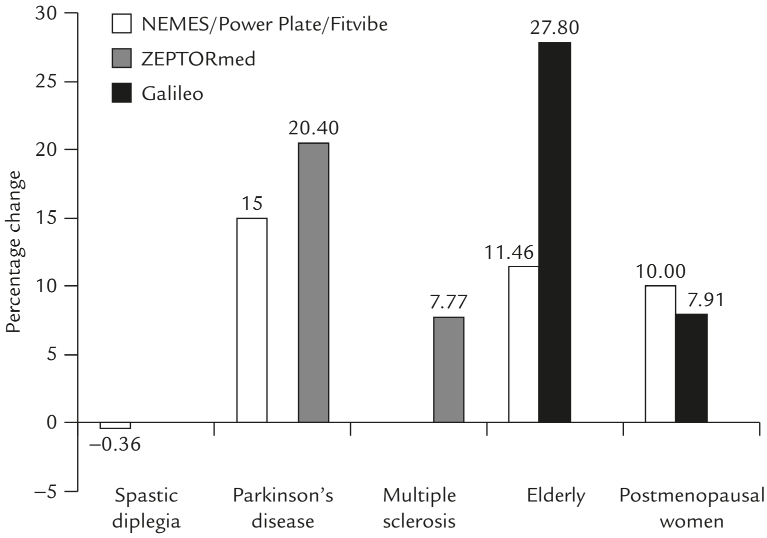

Figure 3. Average percentage change of dependent variables using different whole body vibration devices in different special populations.

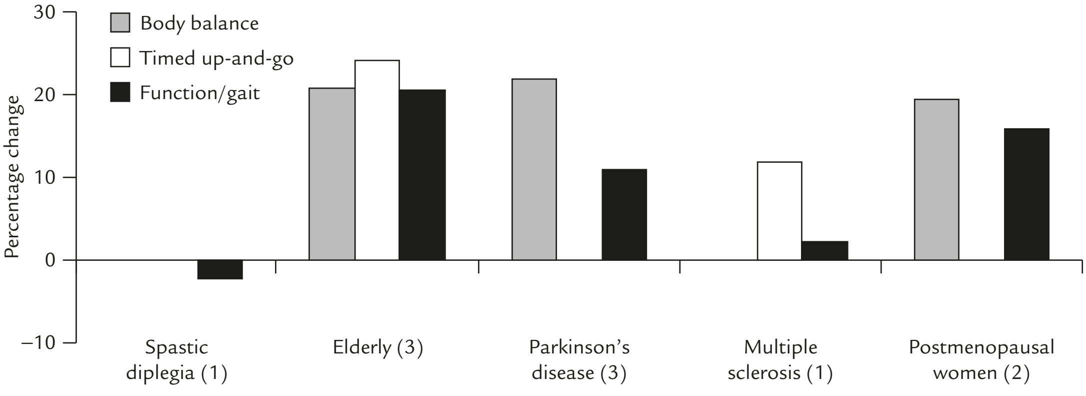

Figure 4. Average percentage change of three subgroups of dependent variables in different special populations (number of studies shown in parentheses).

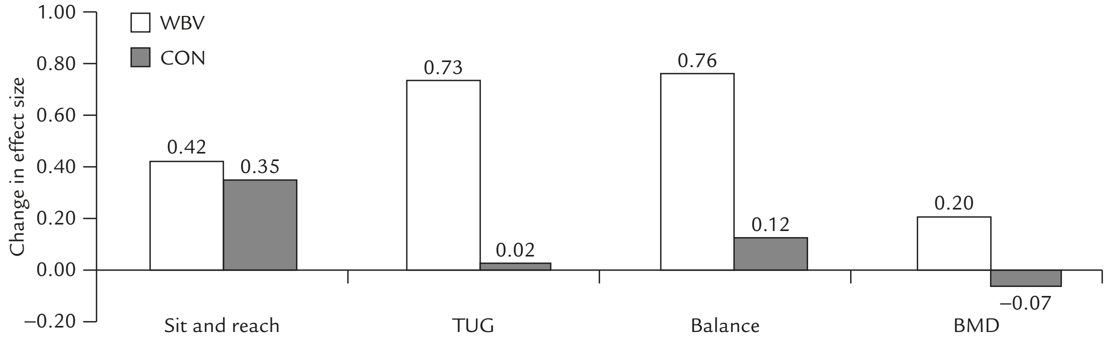

Figure 5. Change in effect size of whole body vibration (WBV) *vs.* control group (CON) for three functional performances and bone mass density (BMD). TUG = timed up-and-go.

Body balance

1. Assessments: Body balance is a variable consisting of several underlying properties. Proprioception, equilibrium and selective muscle control determine body balance in a standing position. Body balance was assessed in eight of 14 papers with a variety of tests. The Berg Balance Scale [43] is regarded as the gold standard for balance and consists of 14 different tests. Only van Nes et al [39] used the complete test. Others used single tests derived from this scale, like the standardized 30-second standing test on an unstable platform (Haas et al [40]), the timed five repetitions chair rising test (Runge et al [38]), and two different postural sway tests (Turbanski et al [20]). The Tinetti test [43], also known as Performance Oriented Mobility Assessment, was used by Bautmans et al [11] and Bruyere et al [12], and consists of 17 test items, one of which is a body balance test in different standing positions.
2. Effects: The training effects reported in the different papers show great variation. Compared with the control groups, balance improved to a greater degree after WBV intervention as reported in eight out of eight studies. van Nes et al [39] reported in both the WBV and control groups extreme high post-test improvements (85.4% and 89.5%, respectively) with a slightly better score for the control group. The results were derived from the Berg Balance Scale, which could explain the magnitude. Converted into ES, however, the WBV application seemed to have a greater effect (ES, 1.38 *vs.* 1.14 in WBV and control groups, respectively) on body balance. Although Bautmans et al [11] reported only a small positive effect (ES, 0.04) in the intervention group, the control group showed a decrease in body balance (ES, –0.52).
3. Loading parameters: Comparing the effect with the frequency used, frequencies around 30 Hz seemed to be most effective in combination with 3 mm amplitude. The intervention time in most studies was 60 seconds, with 60 seconds' rest between sets. The number of sets varied from two (Bautmans et al [11]) to six sets. Only Verschueren et al [10] used 18 sets in the first 12 weeks and up to 27 sets in the last 12 weeks of the study, with only 5 seconds' rest between sets. Although most parameters improved after 24 weeks of the intervention, an identical intervention protocol used by Roelants et al [6] showed no additional increase in effects during the second 12 weeks of intervention. Verschueren et al [10] did not assess the variables after the first 12 weeks.

Stability and gait

1. Assessments: Bautmans et al [11] and Bruyere et al [12] investigated the effects of WBV on stability and gait as they were interested in decreasing the risk of falling in the elderly. The Tinetti test was also used to assess gait. To test gait, the same procedure as in the TUG test was used, only this time the assessors evaluated the start of the walking, stride length and width, stride frequency, and continuity, and after a 360º turn, returning to the chair and sitting down. The quality of execution was rewarded with 0 (unstable), 1 (stable) or 2 points (very stable).

   The 30-second chair rising test and sit-and-reach test were regarded to represent functional stability, with no separate assessment for stability presented. In the 30-second chair rising test, the number of repetitions performed in 30 seconds was recorded. In the sit-and-reach test, the distance a subject could reach forward, without standing up from the chair, was measured in centimetres.
2. Effects: Bautmans et al [11] found no difference between the intervention and control/resistance groups, but both groups improved similarly at 0.4% (ES, 0.14). Bruyere et al [12] reported an increased gait score of 39.3% (ES, 0.92) in the intervention group and no effects in the control group. Bautmans et al [11] reported improvements in the reach tests for the intervention group (ES, 0.42; percentage change, 13.8%) but not significantly more than for the control/resistance group (ES, 0.35; percentage change, 14.3%).
3. Loading parameters: Both studies used similar amplitudes (~3 mm) but differed regarding the frequency

(Bautmans et al [11], 30–40 Hz; Bruyere et al [12], 10–26 Hz). For each of the six dynamic exercises, Bautmans et al [11] chose intervention times of two times 30–60 seconds with 30–60 seconds' rest in between. Bruyere et al [12] used four sets of 60 seconds (standing on the platform) with 90 seconds' rest between sets.

TUG

1. Assessments: The functional performance of most interest in people with neurological diseases or pathology is the ability to stand up and walk (TUG) without assistance. The test, which represents this ability very specifically, was developed by Mathias et al [44] in 1986 and was replaced in 1991 by the currently used TUG test of Podsiadlo et al [45]. The subject sits on a chair of normal height (54 cm) with armrests and is allowed to use his normal aids. On command, the subject stands up, walks 3 m, turns, walks back, and sits down on the chair again. The total time taken is recorded.
2. Effects: For TUG, Schuhfried et al [19] reported an improvement from 9.2 seconds pre-test to 8.1 seconds with WBV (control group, no change), and Bruyere et al [12] from 36.4 seconds pre-test to 25.4 seconds (control group, from 31.3 to 33.9 seconds). Bautmans et al [11] reported an improvement of 2.7 seconds in the WBV group (pre-test score, 15 seconds) and 0.5 seconds (pre-test, 14.8 seconds) in the control group. On converting into ES (percentage change), Schuhfried et al [19] reported improvements of ES 0.92 (12%), Bruyere et al [12] of ES 0.67 (30.2%) and Bautmans et al [11] of ES 0.6 (18%) with WBV. Schuhfried et al [19] reported no changes in the control group, Bruyere et al [12] reported a decreased performance of ES –0.09 (–8.3%) and Bautmans et al [11] a trivial improvement of ES 0.08 (3.3%). Ahlborg et al [17] reported that the WBV group did not change and the control group had a decreased TUG of 1 second (pre-test, 15 seconds) or –6.7%. In absolute values, a time of ≤ 14 seconds is regarded as a good result [43], whereas times over 14 seconds indicate an increased risk of fall. For this specific variable, it might be more informative sometimes to report absolute values.
3. Loading parameters: Figure 6 shows the effects of vibration frequency used in various studies on TUG. Because the pre-test scores were very heterogeneous and only limited data were presented, it is not possible to conclude which parameters are the most effective. The greatest improvements were reported in the elderly [11,12] with 10–26 Hz [12] and 30–40 Hz [11], 30–60 seconds' vibration, and 90 and 30–60 seconds' rest between sets, respectively. Schuhfried et al [19] reported improvements with 3 Hz and five times 60 seconds' intervention with 60 seconds' rest. All studies used amplitudes of 2.5–3 mm. Ahlborg et al [17] reported no effects using 40 Hz (8 weeks intervention on spastic diplegia [17]), and provided no specification on amplitude and rest between vibration sets.

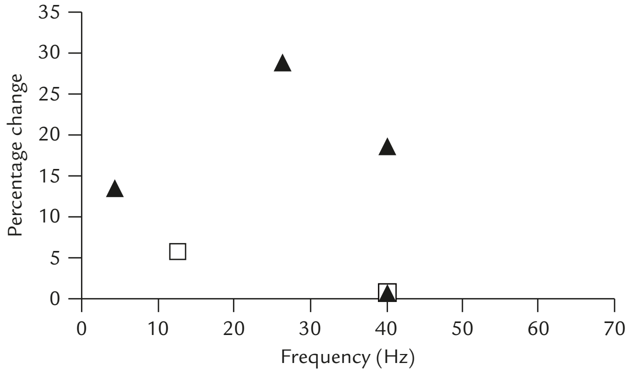

Figure 6. Whole body vibration frequency effect on timed up-and-go (▲) and bone mass density (□).

BMD

1. Assessments: In postmenopausal women, a decrease in BMD [46,47] (osteoporosis) is observed, causing increased risk of bone fractures. Physical weight bearing exercises and various physical activities [48–50] have proven to be an effective tool to prevent osteoporosis. Gusi et al [14] measured BMD in g.cm^2 and assessed it with dual energy X-ray absorptiometry (DXA) of the hip and lumbar spine. Verschueren et al [10] also determined real BMD of the total hip and the total body by DXA using the QDR-4500A device (Hologic, Waltham, MA, USA) [51]. They used standard positioning with anteroposterior scanning of the right proximal femur.
2. Effects: Two studies (Gusi et al [14], Verschueren et al [10]) reported that BMD increased more with WBV than with resistance training alone, but more in the lower body than in the spine (Figures 6 and 7). Only Verschueren et al [10] reported a significant increase in BMD of the lower body. Gusi et al [14] reported an ES of 0.36 compared with 0.59 by Verschueren et al [10] The study of Gusi et al [14], however, was only 6 weeks in duration, whereas Verschueren et al [10] used a 24-week treatment period.
3. Loading parameters: Gusi et al [14] used six sets of 60 seconds with 60 seconds' rest between sets, and Verschueren et al [10] used up to 27 sets of 60 seconds (week 24). The latter used only 5 seconds' rest between sets during the last 12 of 24 weeks and a frequency of 40 Hz, whereas Gusi et al [14] used 12.6 Hz. Both used comparable amplitudes (3 mm and 2.5 mm, respectively).

Muscular strength and power

1. Assessments: To assess strength, Verschueren et al [10] and Roelants et al [6] used a motor-driven dynamometer (REV9000; Technogym Systems, Gambettola, Italy),

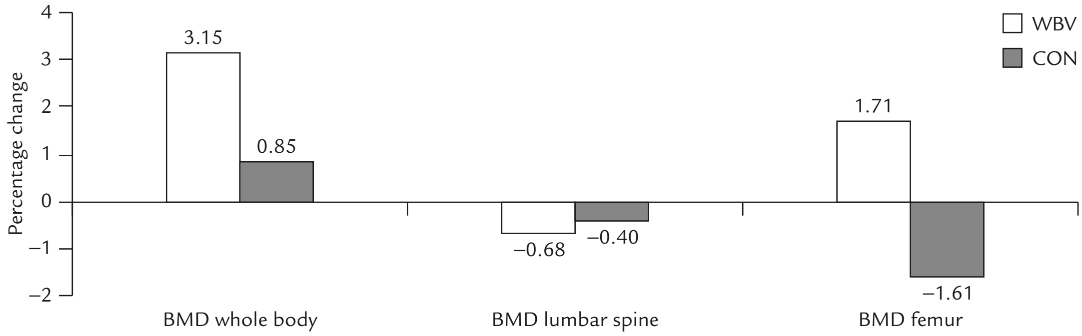

Figure 7. Percentage change in bone mass density (BMD) of the whole body vibration (WBV) and control/resistance training (CON) groups.

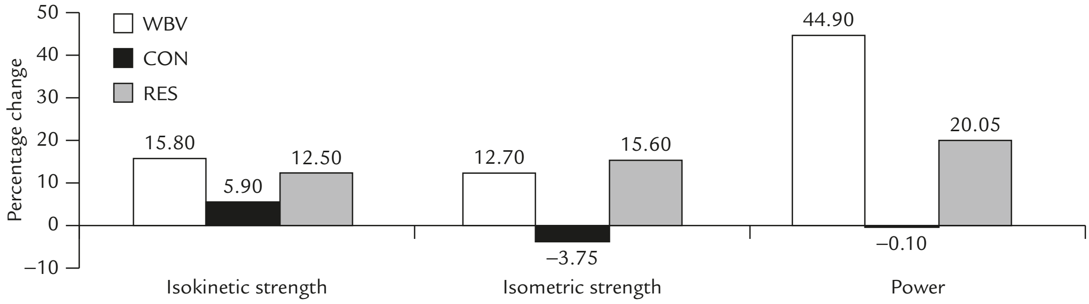

Figure 8. Whole body vibration (WBV) and effects on strength and power. CON = control group; RES = resistance training group.

an isokinetic device. Knee extension strength was tested at a velocity of 100º/second, starting at a knee angle of 90º and ending at 160º. Four consecutive extensions were performed, with a passive return to flexion after each extension. The maximum strength was determined as the peak torque (N.m.). At a knee angle of 130º, the maximum isometric strength was determined twice. The isometric contractions lasted 3 seconds with a 2-minute rest between the two attempts.

Bautmans et al [11] also used an isokinetic device, the Aristokin (Lode, Groningen, The Netherlands), a linear isokinetic multi-joint dynamometer. Closed chain bilateral leg extension kinetics were evaluated at 40 cm/s and 60 cm/s. Power (W), force (N), work (J) and explosivity (N/s) were determined according to the protocol described by Bautmans et al [11]. Strength was expressed in force (N) and power (W). Power was also assessed by Roelants et al [6] using the counter movement jump, and effects were reported as difference in jump height (mm).

2. Effects: It seems obvious that vibration training improves isometric and isokinetic strength and, to a higher degree, muscular power (Figure 8). Roelants et al [6] and Verschueren et al [10] both used the same parameters in two 24-week studies on postmenopausal women. Besides a control group, they had also included a resistance-training group (RES). Verschueren et al [10] presented the effects after 24 weeks; Roelants et al [6] presented the effects after 12 weeks and after 24 weeks. The effects after 12 weeks however did not differ much from the effects reported after 24 weeks. Verschueren et al [10] provided data for isometric and isotonic strength, which could be converted into ES. With the WBV, RES and control groups, they reported improvements in isometric strength of ES 0.82, 0.77 and –0.18 (13.4%, 14.5% and –3.2%), respectively, and in isotonic strength of ES 0.51, 0.54 and 0.11 (16.9%, 0.8% and 2%), respectively. Roelants et al [6] only reported percentage changes. Isometric strength results after 24 weeks were 12.45%, 16.8% and –4.3% in the WBV, RES and control groups, respectively, and isokinetic strength improved 15.8% and 12.5% in the WBV and RES groups, respectively, whereas the control group did not change significantly (no data presented) (Figure 8).

Besides Roelants et al [6], only Bautmans et al [11] tested for power. In percentage change, Bautmans et al [11] reported substantial but not significant increases of 73.7% in the WBV group compared with 28.15% in the RES group. In terms of ES, the effects were 1.07 and 0.37 for the WBV and RES groups, respectively. Roelants et al [6] reported a significant increase in counter movement jump of 16% and 12.1% for both the WBV and RES groups, respectively, but no significant difference between groups. No significant changes were reported in the control group.

3. Loading parameters: All three studies used similar amplitudes (around 3 mm) and frequencies. Bautmans et al [11] used 30–40 Hz, while Verschueren et al [10] and Roelants et al [6] used 35–40 Hz. In the last 12 weeks of the study, participants in the studies of Verschueren et al [10]/Roelants et al [6,10] were exposed to WBV during 27 sets of 60 seconds with only 5 seconds' rest between sets. Bautmans et al [11] used 12 sets of 30–60 seconds and 30–60 seconds' rest between sets. Although power increased more in the study by Bautmans et al [11], it is not possible with these limited data to conclude which parameters were superior.

Conclusion and Recommendations

In studies with neurological patients and the elderly, WBV seems to have positive effects. Based on this review, WBV has proven to have more beneficial effects on balance, stability and gait, strength, and physical and physiological properties as compared with conventional treatment (resistance training and physiotherapy).

The parameters used for patients with Parkinson's disease (three of the four studies on Parkinson's disease were from the same research group) and multiple sclerosis tend to be in the low-frequency, low-amplitude region, of similar amplitude (3 mm), but of a shorter intervention time per set (45 seconds versus 60 seconds in most other studies); in a study with stroke patients, 30 Hz was used. The reason for choosing these parameters is not reported, probably because other researchers used similar parameters.

For future research, the following research questions may be of interest. In neurological patients, the optimal frequency and intervention time could be an important topic, of which the application of stochastic versus non-stochastic vibration is one of the heavily discussed matters. In addition, effects of different types of vibrations applied to the whole body or directly to the target area, and the different types of equipment used should be further studied. The equipment covered by the studies reviewed in this article represents only a small number of devices available on the market. Each machine applies different and, as the manufacturers claim, unique mechanical stimuli to the participants. As so many different devices are currently used in clinical settings and also made available to the public as an easy way to build up physical and functional improvements, researchers should focus not only on what has been used in other studies, but also on what the optimum parameters are.

When presenting results, all means and variances from pre- and post-tests should be presented in tables as quantitative values, ES, and percentage change. Using only graphical presentation should be avoided.

The number of studies on participants with neurological pathologies and diseases is very limited, especially with regard to multiple sclerosis and Parkinson's disease. A great research field lies ahead for all researchers who are interested in and concerned with the problems occurring within these groups of patients.

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