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Review article

Effect of Whole-Body Vibration Therapy on Health-Related Physical Fitness in Children and Adolescents With Disabilities: A Systematic Review

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ABSTRACT

Purpose: To summarize the current literature regarding the effects of whole-body vibration (WBV) therapy on the health-related physical fitness of children and adolescents with disabilities.
Methods: A literature search using MEDLINE–PubMed, SPORT DISCUS, and EMBASE databases was conducted up to August 2013. A total of 22 articles were included in this review (eight randomized controlled trials, four non–randomized controlled trials, three case reports, and seven reviews).
Results: Most of the studies showed positive effects of WBV on health-related physical fitness in children and adolescents with disabilities. Overall, 10–20 minutes at least three times per week, for a minimum of 26 weeks, with high frequency (between 15 and 35 Hz) and low amplitude (no more than 4 mm of peak-to-peak displacement) might be an appropriate protocol to achieve improvement in body composition and muscular strength.
Conclusions: Because no serious adverse events have been observed, WBV might be defined as a safe treatment to be applied in children and adolescents with disabling conditions. Further research is recommended to explore the minimum dose of exposure to WBV required to elicit an optimal response in children and adolescents for improving health-related physical fitness. These may be translated into a more specific WBV protocol.

IMPLICATIONS AND CONTRIBUTION

The effects of whole-body vibration therapy on health-related physical fitness in children and adolescents with disabilities are unclear. Whole-body vibration therapy may be an efficient, safe, and easily adhered-to method from participants and families for improving health in populations with special needs. Efforts are needed to clarify the most effective intervention protocol.

Physical activity (PA) and physical fitness are important issues to be considered throughout childhood and adolescence to achieve optimal development. Both have an important role in body composition, and therefore in health during growth in persons with [1,2] and without disabilities [3,4]. Physical activity is associated with reduced mortality [5], it protects against overweight and/or obesity, and it prevents the development of osteopenia or osteoporosis and future fractures in the elderly [6]. Therefore, PA has been reported as one of the best non-pharmacological ways to improve health.

Longitudinal studies showed that physical fitness in adulthood is conditioned by what was achieved during childhood and adolescence [7–9]. Persons with disabilities such as Down syndrome (DS), Duchenne muscular dystrophy (DMD), cerebral palsy (CP), and osteogenesis imperfecta are characterized as having low physical fitness and an increased risk of osteoporosis [10–14].

Nowadays, vibration treatment is receiving attention for improving certain aspects of body composition such as bone mass [15]. It can be applied to humans through several methods; directly to the muscle belly of the tendon of the muscle by a

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Conflicts of Interest: The authors declare that they have no conflicts of interest that may affect the contents of this work.

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vibration unit (punctual system), by gripping a vibration dumbbell or pulley system (segmental vibration), and by standing on a vibration platform. The latter, whole-body vibration (WBV), uses high-frequency mechanical stimuli, which are generated by a vibrating platform and transmitted through the body, where they load the bone and stimulate sensory receptors. WBV is considered a weight-bearing exercise. Over the past decade, the use of WBV has become an issue of growing interest as training and therapy methods [16–24]. In fact, in recent years, WBV has become the most popular vibration treatment in the world. Different exercises can be performed on a vibration platform, but WBV is not exercise per se, although it induces improvement in physical fitness. WBV has shown physiological benefits in healthy [25] and disabled populations [6,26,27], and researchers have investigated acute [28,29] and chronic adaptations [30,31].

WBV therapy may be applied while standing or exercising on the platform. The vibrations are characterized by parameters such as direction, amplitude, velocity, and frequency, which can be combined to generate different treatment protocols and intensities [32]. Vibration platforms deliver vibration over a range of frequencies (5–90 Hz) and amplitudes (also known as displacements), even up to 10 mm, generating a perturbation of gravitational field that can reach 15 g. To avoid confusion, and as recommended by the International Society of Musculoskeletal and Neuronal Interactions, in this review we use the term “peak-to-peak displacement” (the displacement from the lowest to the highest position) to indicate the extent of the vibration, and not the term “amplitude” (the maximum displacement from equilibrium) [32]. There are two main types of vibration platform: (1) vertical, also known as synchronous vibration (displacing perpendicularly to the floor); and (2) oscillating or side-alternating vibration (rotating over a horizontal axis).

According to the American College of Sports Medicine, health-related physical fitness includes body composition, cardiorespiratory fitness, flexibility, muscular strength, and muscular endurance [33]. There is evidence that WBV treatment improves both strength and power [17,24,34,35], has an impact on motoneuron excitability and/or fast twitch fiber recruitment [21], produces gains in maximal strength [31], increases bone formation [36], and improves muscle function [37–39]. However, not all studies have found the same positive effects using WBV treatment [19,21,27,40]. The use of different protocols in terms of frequency, amplitude, and number of sessions explains discrepancies in results among studies. The type of vibration device used (vertical or synchronous vibration and pivot/wobble or side-alternating vibration) also complicates comparison between studies. It has been argued that side-alternating vibration would evoke rotational movements around the hip and lumbosacral joints [41]; this movement reduces vibration transmission to the trunk. Evidence suggests that greater peak acceleration levels can be tolerated in the side-alternating as opposed to the synchronous vibration mode [42]. However, whether these different mechanisms for inducing vibration offer similar physiological or performance effects is unclear and requires further study. Some efforts has been made to review the literature concerning the effects of WBV treatment on strength [18], power performance [43], and speed [44]; on the health of persons with CP [10]; and on different parameters of bone health in the general population [45,46]. Similarly, some information has focused on whether the current interest in vibration as an exercise modality is only the result of unduly perceived exertion, or whether it can really constitute a physiological training stimulus [47]. Although some of these reviews included studies with children and adolescents [10,44–47], and one even pointed out that WBV could be more effective for adolescents and children with compromised bones than for postmenopausal women or young adults [45], knowledge about the effects of WBV treatment on health-related physical fitness in children and adolescents with certain disabilities is unclear. Therefore, the purpose of this review was to summarize the current literature regarding the effects of WBV on the health-related physical fitness of children and adolescents with disabilities, to clarify concepts and establish future lines of action and research in this field.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-analyses statement was used as a guideline for reporting results from published studies [48]. Journal articles were identified by searching electronic databases, scanning reference lists of articles, examining tables from earlier systematic reviews, and consultation with experts in the field. When possible, limits were applied for humans and ages. This search was applied to MEDLINE–PubMed, SPORT Discus, and EMBASE up to August 2013. Two investigators independently examined each database to obtain the potential publications. The keywords used to identify the articles on the topic of this review were “children” and “adolescents,” to restrict the population in this review; these terms were combined with the following keywords: “whole-body vibration,” “vibration therapy,” “vibration training,” “disabilities,” “body composition,” “physical fitness,” “lean mass,” “bone mass,” “fat mass,” “aerobic fitness,” and “muscle strength.” The search strategy was also modified for each database and explored, when possible, to maximize sensitivity and produce a comprehensive search. Terms were searched for title, abstract, and subject heading. Two reviewers independently evaluated all studies. Both authors examined titles and abstracts, and obtained in full relevant articles that were assessed against the inclusion and exclusion criteria described below. Inter-reviewer disagreements were resolved by consensus. A third reviewer resolved disagreements.

Criteria for inclusion were as follows:

- Types of study: randomized and nonrandomized controlled trials (except three case report studies) studying the effects of WBV on health-related physical fitness in children and adolescents with disabilities. Moreover, meta-analyses and systematic reviews were also included to study the background of this topic.
- Type of intervention: trials studying the effects of WBV on health-related physical fitness.
- Types of outcome measures: health-related physical fitness and/or body composition and skill-related physical fitness.

Exclusion criteria consisted of (1) studies in languages other than English; (2) studies investigating the acute effects of WBV; (3) studies including participants with an average age of ≥19 years; (4) studies without physical fitness or body composition as their main topic; (5) unpublished data; and (6) studies with animals. No statistical analyses or meta-analyses were conducted in this review.

Searches identified 309 potentially relevant articles; four additional articles were identified through reference lists and journals, and by asking experts. After a review of titles and abstracts, the total was reduced to 32. Of those articles, 22 were selected to be included in this review. Seven articles were reviews used to study the background, and 15 met the selection criteria and were included in this review (Figure 1).

The characteristics of each study are summarized throughout in different sections and in detail by specific tables using the PICO format [48]: patients or participants (P), intervention (I), comparison or control group (C), and outcomes (O).

Assessment of methodological quality

Two reviewers independently determined the methodological quality of each study using a modified version of the criteria list proposed by Van Tulder et al. [49]. Consequently, the following nine criteria were evaluated: (1) randomization method; (2) concealed treatment allocation; (3) baseline similarity of study groups regarding the most important prognostic variables; (4) blinding of assessors as to the study protocol; (5) co-interventions; (6) compliance; (7) dropout rate; (8) timing of the outcome assessment; and (9) intention-to-treat analysis. Adequate methods of randomization were, for instance, a computer-generated random number table and the use of sealed envelopes. Methods of allocation using date of birth or date of admission were not accepted as appropriate. Concealed treatment allocation had to be accomplished through random assignment generated by an independent person not responsible for determining the eligibility of the subjects. Compliance to the interventions, determined by training diaries, could not be <75%. The dropout rate was considered acceptable up to 25% for follow-up <6 months and up to 30% for follow-up >6 months. The timing of outcome assessment had to be identical for all study groups and for all outcome measurements. The nine criteria for the assessment of the methodological quality were scored as positive (“yes”), negative (“no”), or unclear (“unknown”) in case of inadequate reporting. Each criterion that was scored positive contributed 1 point to the summary quality score, ranging from 0 to 9 points. According to Van Tulder et al., studies were considered to be of high methodological quality if they adequately fulfilled at least five of nine of the quality criteria.

Results and Discussion

Methodological quality

Table 1 shows details of the methodological quality assessment of the 15 selected studies. The average summary quality score was 4.1 (range, 1–8) out of 9. Seven studies of high methodological quality adequately fulfilled the defined inclusion criteria [50–56]. The rest of the studies did not reach a score of 5, but they were also included in this review because of the small number of studies; therefore, the data should be interpreted cautiously.

Effects of whole-body vibration therapy on health-related physical fitness in children and adolescents with disabilities

Table 2 summarizes studies concerning WBV and health-related physical fitness in children and adolescents with disabilities included in this review. For a better understanding, we divided the outcomes into two sections: body composition and

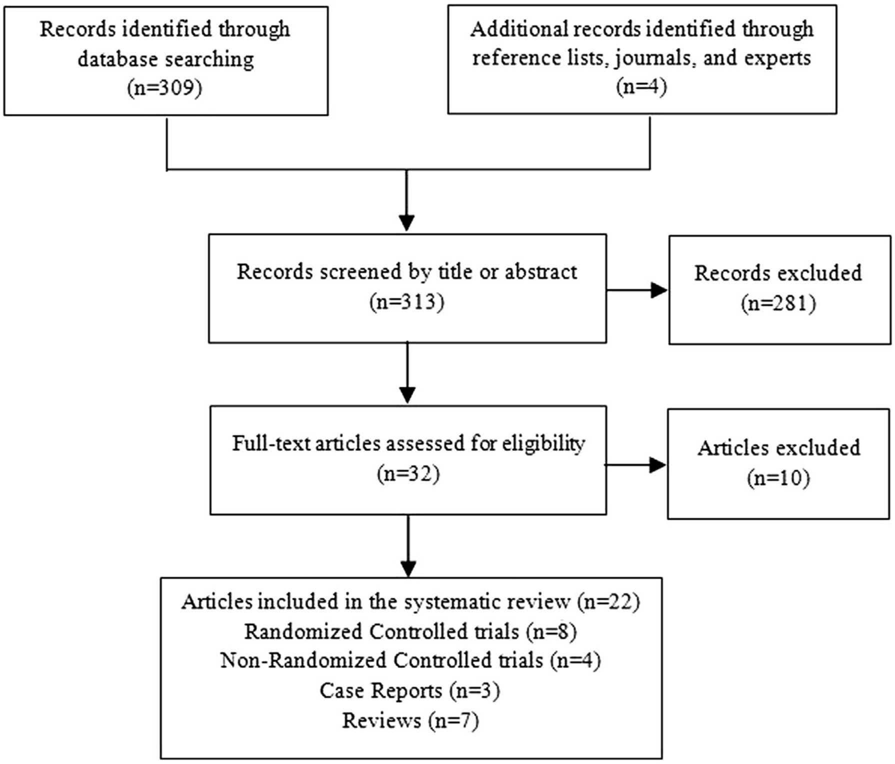

Figure 1. Flowchart diagram of studies that were selected.

Table 1
Methodological quality assessment

Study	Quality score	Quality criteria								
		a	b	c	d	e	f	g	h	i
Villaroya et al. [56]	6	Y	N	Y	N	Y	Y	Y	Y	N
O'Keefe et al. [73]	2	N	N	N	N	N	Y	Y	N	N
González-Agüero et al. [55]	6	Y	N	Y	N	Y	Y	Y	Y	N
Söderpalm et al. [58]	2	N	N	N	N	N	Y	Y	N	N
Lee and Chon [50]	8	Y	Y	Y	Y	Y	Y	Y	Y	N
Dalen et al. [63]	3	N	N	N	N	N	Y	Y	Y	N
Lam et al. [51]	6	Y	Y	UK	N	N	Y	Y	Y	Y
Ruck et al. [52]	7	Y	Y	Y	Y	UK	Y	Y	Y	N
Stark et al. [62]	1	N	N	N	N	Y	UK	UK	N	N
Wren et al. [53]	6	Y	Y	Y	Y	N	N	Y	Y	N
Semler et al. [72]	1	N	N	N	UK	UK	UK	Y	N	N
Semler et al. [71]	1	N	N	N	UK	UK	UK	Y	N	N
Gilsanz et al. [37]	4	N	N	UK	UK	Y	N	Y	Y	Y
Pitukcheewanont and Safani [57]	3	N	N	N	Y	N	Y	Y	N	N
Ward et al. [54]	6	Y	Y	N	Y	N	N	Y	Y	Y

Maximum obtainable quality score = 9 points.
a = acceptable method of randomization; b = concealed treatment allocation; c = similar group values at baseline; d = blinded assessor; e = avoider or similar co-interventions; f = acceptable compliance; g = acceptable dropout rate; h = similar timing of the outcome assessment in all groups; i = intention-to-treat analysis; N = no; UK = unknown; Y = yes.

physical fitness. Also, within each section, studies were grouped by type of outcome.

Body composition

Bone mass. The first study regarding WBV and body composition in children was developed by Ward et al. [54]. They evaluated the effects of WBV on bone mass (assessed with three-dimensional quantitative computed tomography [CT]) of children with muscular dystrophy or CP. After 26 weeks, those allocated into the WBV group had a higher increment of trabecular volumetric bone mineral density (vBMD) at the proximal tibia compared with those in the control group. Also, a tendency toward a greater increment of spinal trabecular vBMD in the WBV group was observed compared with the control group. In contrast, no changes in diaphyseal cross-sectional bone area, periosteal circumference, cortical vBMD, polar moment of inertia, or cortical thickness were found in this study. In another study of similar characteristics, Pitukcheewanont and Safani [57] showed improvements in trabecular vBMD of the lower axial spine and cortical vBMD in the femurs of eight female children with endocrine disorders. The greatest improvements were found in patients with the lowest initial trabecular vBMD. At the same time, changes in bone-specific alkaline phosphate (a good bone-remodeling marker) levels were correlated with the changes in trabecular vBMD of the spine, but no correlation was observed with cortical vBMD at the femur. This reflects a direct influence on the level of bone modeling and an increase in bone formation activity. No improvements in cortical bone area of the femur were observed. Söderpalm et al. [58] observed a trend for bone-specific alkaline phosphate to increase after 13 weeks of WBV in children with DMD. No changes were found in other biochemical markers such as sclerostin, osteocalcin, type I collagen, and insulin growth factor binding protein in that study. Also, most bone parameters assessed by dual-energy X-ray (DXA) and peripheral quantitative CT showed no significant changes. Research performed by Gilsanz et al. [37] studied young females with low areal BMD and a previous history of fracture, and found increments in trabecular vBMD at the lumbar spine and cortical bone area in the femoral midshaft after 52 weeks of WBV treatment. Some studies were performed in children with CP because of their typically defined low bone mass and their high susceptibility to fractures [59]. Initially, Wren et al. [53] reported that 26 weeks of WBV in children with CP were enough to increase cortical bone area and moments of inertia in the appendicular skeleton. However, trabecular vBMD did not change during that period, either in the appendicular or in the axial skeleton. These results can be partially explained by the fact that trabecular vBMD does not increase in typically developed children until approximately age 12 years [60], and WBV treatment had no effect on trabecular vBMD in the appendicular skeleton in adults [30] or in postmenopausal women [61]. Stark et al. [62] showed that 26 weeks of WBV accompanied by other training methods (i.e., physiotherapy, resistance, and treadmill training) improved whole-body BMD and bone mineral content (BMC) in bilateral spastic CP children. They divided the sample into > and <10 years of age. Despite improvements in BMD, the results were not affected by this classification; the group <10 years of age had higher improvement than the group >10 years of age. However, Ruck et al. [52] compared the effect of WBV and physiotherapy sessions on areal BMD at the lumbar spine and the distal femur of children with CP, and found that areal BMD increased in the physiotherapy group and decreased in the WBV group. Dalen et al. [63] studied four children with severe CP, using a novel dynamic platform with a standing shell; the study design was developed in two periods in which two children used the platform whereas the two others did not. In Period 1, the children were free to vary the frequency of vibration and were allowed a standing time of up to 20 minutes; in Period 2, the children used the platform in a more structured way. Bone mineral content increased at the lumbar spine in both periods, but the increment was more constant during Period 2. The authors pointed out that WBV treatment might be more efficient when it is used in a structured way, two or three times per week for 10 minutes each time. Finally, Lam et al. [51] showed that WBV treatment was effective in improving areal BMD at the femoral neck of the dominant side and lumbar spine BMC in adolescents with idiopathic scoliosis. Changes in the dominant leg and lumbar spine in the WBV group were comparable to those reported using a treatment of bisphosphonate [64,65]; however, these results were not comparable with the control group in bone quality parameters.

Lean and fat mass. The effects of WBV treatment on the lean mass of children and adolescents with disabilities remain controversial. Some of the studies cited above also evaluated lean mass. Gilsanz et al. [37] showed increments in the cross-sectional area of the paraspinous musculature using CT after 52 weeks of WBV treatment in females with low BMD; these improvements were not evident using DXA in total lean mass because DXA does not allow for the assessment of muscle mass independently of other lean tissues [66]. However, Stark et al. [62] found an increase in whole-body lean mass in children with bilateral CP using DXA after 26 weeks of WBV treatment accompanied by other methods such as physiotherapy, resistance, and treadmill training. After 8 weeks of WBV combined with conventional

Table 2
Effects of whole-body vibration therapy on health-related physical fitness in children and adolescents with disabilities

Author	Subject	N	Sex	Age, years (Mean ± Standard Deviation or Range)	Data source	Protocol					Type of vibration and brand	Use of shoes	Outcomes
						Duration	Frequency, Hz	Peak-to-Peak, mm	Acceleration, g	Body position and exercises			
Villaroya et al. [56]	DS and non-DS	11 WBV CON 14 CON CON 16 WBV DS 13 CON DS	M-F	11–20	Pressure distribution platform	5–10 min/day 20 wk 3 times/wk	25–30	2	1.8–2.6	Squat	V Power Plate® Pro5	Sport shoes	WBV had positive effects on balance of DS adolescents, although only under specific conditions
O'Keefe et al. [73]	CF	7 WBV	M-F	8–15	Muscle function (strength and power) and CMJ performance	10–15 min/day 4 wk 3 times/wk	20–22	1	1.6–1.9	Standing with slight flexion	O Galileo Basic Platform	N	WBV had no significant effect on muscle function (strength and power), but several indices of upper and lower body relative strength and power tended to improve, with moderate to large effect sizes in some cases
González-Agüero et al. [55]	DS	16 WBV 14 CON	M-F	12–18	DXA	5–10 min/day 20 wk 3 times/wk	25–30	2	1.8–2.6	Squat	V Power Plate® Pro5	Sport shoes	WBV showed higher reduction in body fat at upper limbs and little increase in whole-body lean body mass
Söderpalm et al. [58]	DMD	6 WBV		5.7–12.5	DXA, DXL, p-QCT, and biochemical markers of bone and mineral metabolism, and handheld myometer	6 min/day 13 wk 2–3 times/wk	16–24	4	2.1–4.6	Standing with knee flexion	O Galileo Delta		No changes in creatine kinase activity, bone mass, muscle strength, and bone markers

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Table 2
continued

Author	Subject	N	Sex	Age, years (Mean ± Standard Deviation or Range)	Data source	Protocol					Type of vibration and brand	Use of shoes	Outcomes
						Duration	Frequency, Hz	Peak-to-Peak, mm	Acceleration, g	Body position and exercises			
Lee and Chon [50]	CP	15 WBV 15 CON	M-F	10.0 ± 2.2	Three-dimensional gait analyses and ultrasonographic imaging	18 min/day 8 wk 3 times/wk	5–25	1–9	.05–11.3[a]	Squatting exercise ranging from 30° to 100° knee flexion	O Galileo System	N	WBV improved gait speed, stride length, cycle time, ankle angle, and thicknesses of tibialis anterior and soleus No differences in hip and knee angle and in thickness of gastrocnemius muscle between WBV and CON
Dalen et al. [63]	CP	4 WBV	M-F	4–6	DXA	10–20 min/day 34–39 wk 2–3 times/wk	20–64	.3	.2–2.5[a]	Standing into shell	V Novel dynamic platform with standing shell		WBV increased BMC at lumbar spine and both legs
Lam et al. [51]	Osteopenic girls with adolescent idiopathic scoliosis	61 WBV 63 CON	F	17.7 ± 1.5	DXA and high-resolution pQCT	20 min/day 52 wk 5 times/wk	32–37	.085	.3	Standing with knee flexion	V Juvent 1000 DMT platform		WBV improved areal BMD at femoral neck of dominant side and lumbar spine BMC WBV had no significant effect for bone quality parameters comparing both groups
Ruck et al. [52]	CP	10 WBV 10 CON	M-F	6.2–12.3	DXA	9 min/day 26 wk 5 times/wk	12–18	2–4	2.6	Standing with knee flexion	O Vibraflex Home Edition II® (Galileo Basic)	Y	Distal femoral diaphysis areal BMD increased in CON and decreased in WBV No differences in areal BMD at lumbar spine between WBV and CON WBV increased average walking speed No differences in GMFM

Stark et al. [62]	Bilateral spastic CP	78 WBV	M-F	9.7 ± 4.0	DXA	18 min/day 26 wk 7 times/wk	5–25	0–7.8	.05–9.8[a]	Standing or lying on tilt table with feet placed on vibrating platform	O	Galileo system with tilt table		Improvement in BMD, BMC/cm. and muscle mass/cm of whole body WBV had higher angle of verticalization, maximal force in extension, and GMFM
Wren et al. [53]	CP	16 WBV 14 CON	M-F	6–12	Quantitative CT and dynamometer	10 min/day 26 wk 7 times/wk	30	.016[a]	.3	Standing with knee flexion	V	Juvent Medical, Inc.	Y ankle-foot orthoses	WBV increased cortical bone area and moments of inertia in tibial diaphysis No changes in cancellous bone in lumbar vertebrae, calf muscle area, and calf muscle strength between WBV and CON
Semler et al. [72]	Immobilized children and adolescents	6 WBV	F	5–15	Alternations of tilt angle of table and with BAMF	18 min/day 26 wk 14 times/wk	15–22	0–6	.4–5.8[a]	Patient lies on back with feet placed on vibrating platform	O	with tilt table Galileo system		Descriptive data regarding individual improvement Children with OI improved muscle force in lower limbs General improvement in mobility
Semler et al. [71]	OI	8 WBV	M-F	5–15	Ground reaction force of tilting angle and BAMF	18 min/day 26 wk 14 times/wk	15–25	1–2	.4–2.5[a]	Patient lies on back with feet placed on vibrating platform	O	with tilt table Galileo system		WBV improved muscle force
Gilsanz et al. [37]	Young women with low BMD	24 WBV 24 CON	F	15–20	Quantitative CT and DXA	10 min/day 52 wk 7 times/wk	30	.016[a]	.3	Standing up	V			WBV increased cancellous bone in lumbar vertebrae, cortical bone in femoral midshaft and cross-sectional area of paraspinous musculature

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Table 2
continued

Author	Subject	N	Sex	Age, years (Mean ± Standard Deviation or Range)	Data source	Protocol					Type of vibration and brand	Use of shoes	Outcomes
						Duration	Frequency, Hz	Peak-to-Peak, mm	Acceleration, g	Body position and exercises			
Pitukcheewanont and Safani [57]	Children with low BMD	8 WBV	F	7.6–11.6	BALP and quantitative CT	30 min/day 8 wk 3 times/wk	30	.016[a]	.3	Standing with knee flexion	V Smith and Nephew, Ltd.		WBV improved cancellous BMD of spine, cortical BMD, muscle mass of femur, and BALP levels WBV had no changes in fat mass or cortical bone area of femur
Ward et al. [54]	Children with disabling conditions	10 WBV 10 CON	M-F	4–19	Three-dimensional quantitative CT	10 min/day 26 wk 5 times/wk	90	.018[a]	.3	Standing with knee flexion	V		WBV improved volumetric trabecular BMD at proximal tibia and lumbar spine CON decreased volumetric trabecular BMD at proximal tibia Diaphyseal bone and muscle parameters did not change in any group

BALP = bone-specific alkaline phosphatase; BAMF = brief assessment of motor function; BMC = bone mineral content; BMD = bone mineral density; CF = cystic fibrosis; CON = controls; CP = cerebral palsy; CT = computed tomography; DMD = Duchenne muscular dystrophy; DS = Down syndrome; DXA = dual-energy X-ray absorptiometry; DXL = dual-energy X-ray laser; F = female; GMFM = gross motor function measure; M = male; N = no; O = oscillating vibration; OI = osteogenesis imperfecta; pQCT = peripheral quantitative computed tomography; V = vertical vibration; WBV = whole-body vibration group; Y = yes.

[a] When g-force was not reported here, it was calculated using the formula for acceleration peak [32]: $g = (2\ \pi^2 f^2 D)/9.81$, where D = peak-to-peak vibration amplitude (m), and f = frequency (Hz).

physical therapy training, Lee and Chon [50] showed improvement in the thickness of the tibialis and soleus in children with CP. On the other hand, neither Ward et al. [54] nor Wren et al. [53] found changes in the cross-sectional muscle area in the appendicular and axial skeleton after 26 weeks' WBV treatment in their respective populations of children with disabling conditions and with CP. Similar results were described by Söderpalm et al. [58], who showed no changes in lean mass measured with DXA, but found a trend toward increasing muscle density in the calf measured with peripheral quantitative CT after 13 weeks of WBV in children with DMD. The most recent research was carried out by González-Agüero et al. [55] showing that 20-week WBV training was not enough in itself to increase lean body mass in adolescents with DS.

The heterogeneity of the studies is evident, and therefore a conclusion cannot be drawn regarding this matter because methodological standardizations are needed. Several studies evaluated how fat mass was affected by WBV treatment, and showed no changes in femoral fat mass measured with quantitative CT [57] and in fat mass measured by DXA [58]. However, the study by González-Agüero et al. [55] found that adolescents with DS who performed 20 weeks of WBV intervention had a higher reduction in body fat at the upper limbs than those who did not.

Overall, WBV has been considered a potentially useful technique to improve bone mass in general because it is based on Wolff's law, which states that bone adapts to mechanical load [67]. Certain diseases such as adolescent idiopathic scoliosis, DS, and CP are characterized by low bone mass [68]. Because peak bone mass is a main determinant for osteoporosis later in life [69], an intervention with WBV could reduce the risk of developing osteoporosis in late adulthood.

The effects of WBV treatment on body composition seem to be greatly relevant for children and adolescents with disabling conditions. Not only significant differences, but also statistically nonsignificant improvements may have important biological importance in terms of bone mass acquisition. Differences in results between studies might be explained as a result of different treatment protocols and by variables as weight, body size, and the placement of the weight, which can influence the effect of the vibrations on bone mass [70]. Moreover, the wide variety in treatment protocols (the duration ranged from 8 to 52 weeks, from three to seven times per week, from 30 seconds to 30 minutes, with frequencies from 5 to 90 Hz and amplitudes from .3 to 4 mm) make comparisons difficult between studies. However, overall, it has been observed that 10–20 minutes, at least 3 times per week, for a minimum of 26 weeks with high frequency (between 25 and 35 Hz) and a peak-to-peak displacement (no more than 4 mm) might be an appropriate protocol to achieve improvement in the body composition of children and adolescents with disabilities [37,53–55,57,62,63]. Because of the relatively few studies to date, no significant differences can be attributed to the type of vibration; some studies used vertical vibration [37,53–55,57] and others oscillating vibration [52,62]. Despite this, Marin and Rhea [43] showed that vertical platforms had a significantly larger treatment effect for chronic adaptations compared with oscillating platforms.

Generally, most studies concerning body composition and WBV included in this review were characterized by the treatment being applied to children and adolescents with different disabilities. In summary, results from the few available studies seem to point out that improvement in terms of bone health might be achieved with this type of training mainly from adolescence, although new research should also focus on the most efficient training protocol. Data on the effects on lean and fat mass remain unclear. They may be clarified using the results of the proposed research.

Physical fitness

Muscle strength. The effect of WBV on different aspects of muscular strength has been studied in children and adolescents with disabilities [53,58,62,71–73]. In a study on immobilized children and adolescents between 5 and 15 years of age with osteogenesis imperfecta, Semler et al. [71] reported improvement in the force developed and the muscle force of their lower limbs after 26 weeks of WBV [72]. The study by Stark et al. [62] found that WBV was effective in improving maximal force in the extension of lower limbs in children with CP, whereas no changes in concentric or eccentric calf muscle strength after 26 weeks were found [53], or in knee extensor muscle strength or foot plantar- and dorsi-flexor muscle strength in children with DMD after 13 weeks of WBV therapy [58]. O'Keefe et al. [73] showed that muscle function changes after 4 weeks of WBV therapy were not statistically significant in children with cystic fibrosis. However, moderate to large relative effect sizes after WBV therapy were reported for leg strength and explosive power in those children. The authors suggested that the improvements resulted from changes in neuromuscular function rather than an increase in muscle mass.

Studies concerning WBV and muscular strength focused on the rehabilitation of children and adolescents with several diseases or conditions showed a tendency toward improvements in strength variables. Gains in muscular strength could appear with 26 weeks of training, at least seven times per week for 10–20 minutes, working with a frequency between 15 and30 Hz and a peak-to-peak displacement between 1 and 4 mm. We might conclude that WBV is an effective method to augment muscular strength in children and adolescents with special needs, but efforts should be made to clarify an appropriate and perhaps more efficient protocol.

Benefits of whole-body vibration training in overall aspects of children and adolescents with disabilities

According to the American College of Sports Medicine, skill-related physical fitness includes agility, balance, coordination, speed, and reaction time [74]. Although this review focused on describing the effects of WBV training on health-related physical fitness and body composition, various studies also provided some data regarding skill-related physical fitness and/or general health aspects of children and adolescents with and without disabilities; therefore, we also included those data within this section.

Semler et al. [71] showed that children with CP reduced spasticity and improved in the functional motor pattern of walking, and that adolescents with meningomyelocele had decreased joint-associated contractions after performing WBV training. They also found improvements in mobility in children and adolescents with osteogenesis imperfecta, with this type of training [72]. The same improvement in mobility was described by Lee and Chon [50], who used three-dimensional gait analyses. They showed that the children with CP who performed WBV for 8 weeks improved in gait speed, stride length, cycle time, and ankle angle. In populations with CP, other studies have also found increments in walking speed [52] or improvements in different dimensions of gross motor functions, such as sitting, crawling and kneeling, standing, and walking, running and jumping [62] after WBV training. Recently, Villarroya et al. [56] showed that 20-week WBV therapy had positive effects on the balance of DS adolescents, although only under specific conditions, with vision and somatosensory input altered.

Compliance with training and its relationship to outcomes

The relationship between compliance with training and the achievement of expected results has not been yet ascertained. A study showed that the gains in different variables were strongly correlated with a threshold of compliance [37], whereas others showed that those benefits were not related to training compliance [53,54]. Therefore, this variable may be important to understand the real effect of interventions; consequently, more information is needed in this regard.

Adverse effects of whole-body vibration training

No severe negative side effects were found in most studies [54,55,57,58,63,72,73]. The most important example of WBV therapy as a safe and well-tolerated treatment was carried out by Söderpalm et al. [58] with the assessment of creatine kinase activity (muscle damage biomarker), which remained stable after the WBV period. Unexpected events were found in three studies [51,52,71], but all of them recommended WBV as a safe method of training. As mentioned by Lam et al. [51], all patients tolerated WBV training well except for one subject who had transient heel discomfort, but it resolved spontaneously in a few weeks. Fewer than 1% of WBV sessions were interrupted because of pain but, as mentioned by Ruck et al. [52], it was not clear whether those episodes of pain were caused by the training itself. The worst adverse effect was described by Semler et al. [71]: Some participants suffered dislocation of the telescopic rod during the training. However, this type of dislocation is frequent in individuals affected with osteogenesis imperfecta [75]. Nevertheless, a negative effect of WBV on the stability of implanted material cannot be excluded.

Limitations

Some limitations of this review should be recognized. The relatively few studies that conducted WBV in children and adolescents, and the disparity in the studied variables, participants' condition, and training protocols, resulted in a series of heterogeneous results. Therefore, no strong conclusions can be made yet. However, because interest in WBV is increasing, it seems convenient to show the state of the art of this hot topic, to help the design of future research.

Although most studies included in this review were randomized, controlled trials, three nonrandomized, controlled trials and two case reports were included. The latter may influence the results as consequence of participants' possible self-selection of group assignment, because individuals may be predisposed to participate in the exercises. A common limitation of these types of studies is the absence of a control group performing the same exercises (commonly a squat) on a vibration platform at 0 Hz. However, the squat is an isometric exercise that can generate physiological benefits. Another limitation is that often, studies that do not achieve expected results are not published; therefore, we are not able to discern which were ineffective trainings.

From the available literature, it is not clear what role WBV treatment has on body composition and muscle strength, although positive results predominate versus neutral ones in this review. In relation to body composition, overall, 10–20 minutes, at least three times per week, for a minimum of 26 weeks with high frequency (between 25 and 35 Hz) and a peak-to-peak displacement no more than 4 mm might be appropriate guidelines to achieve improvement in bone mass in children and adolescents with disabilities. In muscle strength, gains could appear with 26 weeks of training, at least seven times per week for 10–20 minutes, working with a frequency between 15 and 30 Hz and a peak-to-peak displacement between 1 and 4 mm. Whole-body vibration is effective in augmenting muscular strength in children and adolescents with special needs; however, efforts are needed to determine the most effective intervention protocol. Because no serious adverse events related to this therapy were observed, WBV might be defined as a safe treatment to be applied in children and adolescents with disabling conditions.

Perspective

Because this type of treatment seems to improve bone health, further research should be conducted to explore the minimum dose of exposure to WBV required to elicit an optimal response in different populations characterized by low bone mass levels, such as young persons with DS, CP, DMD, and osteogenesis imperfecta [10–14]; elderly people [6]; or young athletes practicing nonosteogenic sports [76,77].

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