

# Is whole-body vibration beneficial for seniors?

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**Abstract** Normal aging processes result in losses of functional flexibility and muscular strength, which increase seniors' fall risk and dependence on others. A relatively new intervention to reduce and/or reverse the adverse effects of aging is whole-body vibration (WBV) exercise. The purpose of this article is to review the established effects of WBV exercise exclusively with the aging population. A systematic search utilizing PubMed and Sport Discus databases uncovered journal articles specific to seniors and whole-body vibration. An extensive hand search supplemented the database results to find other relevant articles. Twenty-seven articles were obtained; all articles have been published in the past 8 years, reflecting the recent and growing interest in this area. Researchers have determined that WBV training can reduce fall risk and improve postural control in seniors. It has also been determined that WBV training can be as effective as conventional resistance training to improve seniors' lower body strength. However, little is known about the effect of WBV exercise on flexibility and upper body strength in the aging population. More research is required to establish how effective WBV training is on these specific components and how it may affect seniors' quality of life.

**Keywords** Whole-body vibration · Aging · Vibration exercise · Muscle strength · Postural control · Flexibility

## Introduction

Over the last century, life expectancy has increased dramatically to the point that individuals in developed nations can expect to

live beyond 80 years of age [16, 17, 22, 32]. With continuing advancement in medical technology and baby boomers approaching mid-to-late adulthood, the aging population is steadily increasing. Seniors aged 65 and older will soon comprise a massive proportion of the global population, growing to an estimated 690 million in developed countries by 2030 from 249 million in 2000 [46]. Governments and private funding agencies have recognized that seniors will be a large portion of the general population and have increased age-related funding initiatives [21]. The goal of these initiatives is to further understand the mechanisms of aging so effective strategies can be developed for treating age-related ailments, maintaining seniors' independence, reducing risk factors, and improving activities of daily living [21].

## Slips and falls

Slips and falls are a common occurrence in the aging population [26]. Approximately 30% of the community-dwelling population over 65 years of age falls at least once a year [26, 50]. Of those who fall, 50% will never regain functional walking [31]. This high prevalence of seniors falling puts a substantial financial burden on national governments. For example, the Canadian government spends 2.4 billion dollars per year (one billion in direct costs) because of the injuries and rehabilitation that are associated with seniors' falls [50].

Musculoskeletal integrity is a major reason why seniors are more susceptible to falling [3, 15]. Recently, researchers have examined skeletal muscle to better understand how it deteriorates with age in order to determine methods of reversing its adverse effects and reducing seniors' risk of falling [16, 17, 21, 30].

Sarcopenia has been identified as the normal age-related loss of muscle mass and strength [22]. Typical sarcopenic

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characteristics include reduced muscle mass, a shift in fiber-type distribution, a loss of force-generating capacity, and reduced ability to effectively perform activities of daily living [22]. Cross-sectional research has demonstrated that skeletal muscle mass noticeably decreases by 45 years of age, and declines by 0.5–1% per year thereafter [21]. Lexell [25] found that limb muscles of older men and women are 25–35% smaller than younger individuals. When biopsies were compared between the young and old participants, type II (fast twitch) fibers and to a lesser extent type I (slow twitch) fibers were smaller in the older participants, reducing the ability to produce strong muscular contractions [25]. Lexell [25] concluded that with advancing age, there is a gradual decrease in muscle fiber size and volume, which is accompanied by a replacement with fat and connective tissue. Most of these changes are a primary consequence of aging which can be delayed in the elderly with increases in physical activity.

### Resistance training

A loss in muscle mass and strength influences the prevalence of falls, thereby reducing the quality of life and perhaps decreasing longevity in seniors [22]. Leigh [24] emphasized the need for nonpharmacological intervention to help reduce fall risk factors. Since aging does not alter the skeletal muscle response to strength training, resistance training (e.g., free weights, exercise machines, rubber bands) is currently the most effective known strategy to combat sarcopenia and increase strength [22]. However, resistance exercise programs may not be feasible with seniors who have mobility and/or neurological impairments [45].

### Whole-body vibration

Whole-body vibration (WBV) has shown potential as an alternative form of strength training. WBV has benefits over conventional resistance exercise as it generally requires less time and effort [43], yet evidence suggests it is as effective as conventional training [41]. WBV training normally consists of performing static and/or dynamic exercises on a vibrating platform [27]. There are two common forms of vibration platforms: synchronous vibration or side altering vibration [34]. Synchronous platforms have a vertical or up and down vibration stimulus [10, 27, 34] and side altering vibration platforms deliver an asynchronous vibration (teeter totter) stimulus as the platform balances around a central fulcrum [27, 34, 39]. WBV apparatuses vary in terms of frequency (in hertz) they can produce and the magnitude of vibration. While researchers have used both “amplitude” and “peak-to-peak displacement” to describe the magnitude of vibration, the

latter (peak to peak) is the recommended term, which is the total vibration excursion of a point (in millimeters) between its positive and negative extremes [27, 34].

Typically the vibrations are transmitted through the legs to the body, stimulating the neuromuscular system [41]. With each vibration the platform shifts slightly downward (vertical displacement ~1–10 mm), lengthening the tendon resulting in an involuntary contraction [3, 10]. The platform then shifts back to its initial position and repeats (normal frequency range is 15–60 Hz) [10]. By the WBV platform providing both physical and neural overloads, it causes the body’s skeletal and neural tissues to adapt [43]. Pairing WBV with a common task, such as a squat, has been reported to increase electromyographical activity, strength, power, balance and postural control in the muscles being trained [43]. Although there are several proposed theories that attempt to explain how WBV enhances muscle function (e.g., neural potentiation of the stretch reflex [40] and muscle tuning hypothesis [10]), the biological mechanisms elicited due to WBV remain equivocal and require further investigation.

### Whole-body vibration studies among the aging population: *targeting specific needs*

Initially, WBV training studies examined primarily young and athletic participants. More recently WBV research has been applied to a wide variety of populations, including the young and old, fit and unfit, and healthy and pathological participants (e.g., [6, 24, 29, 45]). A search was conducted using electronic databases PubMed and Sport Discus using the following combination of search words: (whole-body vibration OR vibration training OR vibration exercise) AND (elder\* OR ag\* OR senior). There was no time restriction on the literature search, performed in April 2011, which resulted in a total of 139 journal articles. Articles were checked for relevant content and were included if they were published in English and used participants aged 55 and older. Review articles, duplicates, and studies that used locally applied vibration and/or used animals as test participants were excluded. An extensive hand search supplemented the database results to find other journal articles specific to seniors and WBV. Potential articles were retrieved and read to attain three additional WBV aging studies. While other review articles have included WBV and aging as part of a larger context, this paper focuses solely and exclusively on WBV as it applies to the older population. Thus, the search uncovered 27 journal articles, which are compiled and summarized in Table 1. This table draws upon and builds on Rehn et al. [38] and Totosty de Zepetnek et al. [44], but is specific to WBV within an older population. Table 1 identifies each study’s specific objectives, design (i.e., randomized controlled study), and whether the participants were institutionalized or noninstitutionalized. In addition, Table 1 identifies the WBV

plate and parameters,<sup>1</sup> exercises performed, along with measurements and results specific to each study. All 27 studies have been published in the last 8 years, reflecting the recent and growing interest in this area. This is an opportune time to provide an overview of the research and provide direction for future areas of investigation.

### Balance and fall prevention

Thirteen published articles discussed the effects of WBV on seniors' postural control and balance. Twelve of the articles showed significant benefits of using WBV to improve balance and/or postural control, while one showed no significant improvement [11]. A potential limitation of the Carlucci et al. [11] study was that their intervention consisted of one session of WBV. The articles that show significant results suggest WBV can improve elements of fall risk and improve postural control [1, 8, 13, 23, 37].

In an attempt to decrease fall risk and improve health-related quality of life in nursing home residents, Bruyere and colleagues [8] investigated the effects of WBV on 42 seniors who resided in a nursing home. Participants were randomized to receive physical therapy alone or physical therapy plus a WBV intervention. Physical therapy consisted of a standard exercise program with components of balance and gait training along with strengthening exercises. The experimental group participated in three sessions of WBV training per week for 6 weeks. A typical session involved the participant standing on the vibration platform for 1 min of vibration stimulus four times, with 90 s of rest between sets.

The Tinetti Test consists of 16 test variables used to assess balance and gait, as it grades gait speed, stride, symmetry, and balance. Each component of the test was graded from 0 to 1 or 0 to 2 (the lower score indicates poorer physical ability), with the highest possible overall score on the test being 28. The test was performed on each participant at baseline and after 6 weeks of training. The overall score of the Tinetti Test increased by  $5.6 \pm 3.7$  points in the WBV experimental group vs. the physical therapy only group, which actually decreased  $0.1 \pm 1.3$  points after 6 weeks. This suggests that combining WBV exercise with physical therapy is more effective at improving gait and balance as measured by the Tinetti Test than physical therapy alone and, therefore, may reduce nursing home residents' risk of falling [8].

<sup>1</sup> The reader should be cautioned that there has been inconsistent use of the words amplitude and peak-to-peak displacement in the literature [27]. Although peak-to-peak displacement is the recommended term, both are still used in research articles. Therefore, the values in the chart may be either of the two terms peak-to-peak displacement or amplitude. Caution is warranted here, particularly as researchers themselves have occasionally confused the two terms [27].

In a separate study, Kawanabe and colleagues [23] found that after 2 months of training, WBV in addition to routine exercise (walking, balance training, and muscle strengthening) significantly improved maximum standing time on one leg. The group that only performed routine exercises did not show any significant improvement with maximum standing time, suggesting adding WBV exercise to an exercise regimen can improve selected balance tasks [23].

Rees et al. [37] conducted a 2-month trial in an attempt to delineate the direct effects of WBV by randomly assigning 43 participants (66–85 years) into three groups: a WBV group, an exercise without WBV group, and a control group. The study was designed to determine the effectiveness of WBV exercise on postural steadiness by evaluating 8 weeks of standard WBV exercise with respect to the same program performed without vibration [37]. Both exercise groups performed static squats for the first 4 weeks and dynamic squats and dynamic calf raises for the last 4 weeks of training, the key difference being that the WBV group performed all of the exercises on a vibration platform.

To determine the effectiveness of WBV on postural steadiness, all participants were assessed by analyzing patterns of ground reaction force variability via a one-legged postural steadiness (OLPS) test. The OLPS starting position had the participant stand with feet shoulder width apart, with their eyes looking forward. The investigator then instructed the participant to stand freely on one leg for a maximum of 15 s. Three consecutive trials of OLPS were performed on both legs of all participants; however, only the results for the right leg were reported. Results indicated WBV improved OLPS between 24.9% and 27.5%, on average following 8 weeks of WBV exercise. There were no significant differences found pre- to posttest for the exercise without WBV group or the control group. Of interest was the fact that individuals with the largest improvements were those with the worst baseline scores; thus, the authors postulated that those with very poor balance are the ones most likely to derive the largest benefits from a WBV intervention [37].

### Lower extremity power and strength

Fourteen studies examined muscular power and/or strength while using WBV. A pilot study examining polio patients was the only study that did not show increased strength benefits with WBV training [7]. For the remaining 13 articles specific to lower body strength, two main themes exist; WBV improves muscular strength in seniors (e.g., [2, 28, 49]), and WBV is as effective as conventional resistance training (e.g., [35, 41]).

To determine if WBV improved seniors' muscular power, Russo and colleagues [42] recruited 29 postmenopausal women who were randomly assigned to a WBV group or

**Table 1** Overview of whole-body vibration studies that examine the aging population

Reference	Purpose	Type of study	Participants	WBV exercises performed	Study results	Plate/parameters	Frequency and duration	Measurements
Baumanns et al. [1]	To investigate the feasibility of WBV in institutionalized elderly, and its impact on functional capacity and muscle performance	Randomized controlled trial: 1. WBV group 2. Exercise group (static)	N=24 F: 15, M: 9 Mean age, 77.5±11.0 Type: institutionalized	Lunge, squat, deep squat, wide stance squat, calf, calves deep (all static)	WBV performed significantly better on timed up-and-go test and Tinetti Test	Power Plate® (vertical vibration) 30–40 Hz 2 or 5 mm	3 times/week for 6 weeks, 1–3×30–60 s/session	Maximum grip strength Chair stand test Timed up-and-go test Tinetti balance scale test Back scratch test Chair sit-and-reach test Leg extension
Bissonnette et al. [3]	To evaluate the effects of 8 weeks of WBV training on functional movements	1. WBV group	N=19 F: 14, M: 5 Age range, 60–85 Mean age, 71.4±7.2 Type: noninstitutionalized	Calf raises, squats, bicep curls, triceps ext (all static)	WBV significantly improved balance, flexibility, strength, and functional determinants (walk longer distances and were able to get in and out of car more easily)	WAVE Pro® (vertical vibration) 35–40 Hz (upper body) 40–45 Hz (lower body) 2 or 4 mm	3 times/week for 8 weeks, 2×30 s/session approx. 15 min/session	Chair stand test Arm curl test Chair sit-and-reach test Back scratch test 8-ft up-and-go test
Bogaerts et al. [6]	Evaluate the effects of 12-month WBV program on balance (measured by computerized posturography)	Randomized controlled trial: 1. WBV group 2. Exercise group (cardiovascular and resistance training) 3. Control group	N=220 F: 106, M: 114 Age range, 60–80 Type: noninstitutionalized Mean age, 67.1±0.6	Squat, deep squat, wide stance squat, one-legged squat, lunge, toes stand, toes stand deep, moving heels (static and dynamic)	No significant differences between groups regarding most aspects of postural control. WBV may improve aspects of seniors' postural control	Power Plate® (vertical vibration) 30–40 Hz (overload principle) 2.5 or 5.0 mm	3 times/week for 1 year, 4–15×30–60 s/session Max. 40 min/session (progressive increase)	Sensory organization test Motor control test Adaptation test
Bogaerts et al. [5]	The effects of 1-year WBV training on cardiorespiratory fitness and muscle strength in community-dwelling adults	Randomized controlled trial: 1. WBV group 2. Exercise group (cardiovascular, resistance balance, and flexibility training) 3. Control group	N=220 F: 106, M: 114 Age range, 60–80 Mean age, 67.1±0.6 Type: noninstitutionalized	Squat, deep squat, wide stance squat, one-legged squat, lunge, toes stand, toes stand deep, moving heels (static and dynamic)	WBV and exercise group increased significantly on time-to-peak exercise peak VO2 and muscle strength. WBV group increased significantly on heart rate. Exercise group improved significantly more in time-to-peak exercise.	Power Plate® (vertical vibration) 30–40 Hz (overload principle) 2.5 or 5.0 mm	3 times/week for 1 year, 4–15×30–60 s/session Max. 40 min/session (progressive increase)	Heart rate Cycle ergometer Isometric knee extension strength (dynamometer)
Bogaerts et al. [4]	Investigated the effect of 6 months of WBV training, in combination with daily supplements of calcium and high dose vitamin D, on balance, functional performance and fall risk in institutionalized women	Randomized controlled trial: 1. WBV group 2. Control group 3. Control group	N=113 F: 113, M: 0 Age range, over 70 Mean age, 79.6 Type: institutionalized	Squat, deep squat, wide stance squat, toes stand and one-legged squat	Significant improvements in endurance capacity, walking at preferred speed, and TUG vs. supplementation alone. Sway velocity and maximal isometric knees strength improved only in WBV group. No additional benefit of WBV training detected on fall risk and postural control	Power Plate® (vertical vibration) 30–40 Hz (overload principle) 1.6 or 2.2 mm	3 times/week for 6 months Max. 15 min/session (progressive increase)	Sway velocity Sensory organization test Timed up-and-go test 10 m walk test Shuttle walk Physiological profile Assessment
Brogardh et al. [7]	To evaluate the feasibility and possible effects of WBV training on muscle strength and gait	Case-controlled pilot study 1. WBV group	N=5 F: 2, M: 3	Static squat position (knees flexed 40° to 55°)	No statistically significant difference in isokinetic or isometric knee muscle strength or in gait performance	Xrsize (vertical vibration)	2 times/week for 5 weeks	Isokinetic and isometric knee muscle strength

**Table 1** (continued)

Reference	Purpose	Type of study	Participants	WBV exercises performed	Study results	Plate/parameters	Frequency and duration	Measurements
Bruyere et al. [8]	performance in people with late effects of polio To investigate the effects of WBV in elderly	Randomized controlled trial: 1. WBV group (plus physiotherapy) 2. Exercise group (physiotherapy only)	Age range, 55–71 Mean age, 64±6.7 Type: recruited from hospital rehabilitation  N=42 F, 31; M, 11 Age range, 63–98 Mean age, 81.9±6.9 Type: institutionalized	Just stood on platform (static)	WBV group improved on gait score vs. no change in control group. WBV group improved on body balance score and timed test vs. no change in control group. WBV group had significantly greater improvements from baseline on 8 of 9 items on the 36-Item Short-Form Health Survey compared to control	25 Hz 3.75 mm	4–10×40–60 s/session Max. 30 min/session (progressive increase)	Timed up-and-go test Comfortable and fast gait Speed test 6-min walk test Tinetti balance scale test
Cardinale et al. [9]	To analyze the acute effects of a single session of WBV exercise on anabolic hormones in aged individuals	Randomized controlled crossover trial: 1. WBV group 2. Exercise group (same exercises, no WBV)	N=20 F, 11; M, 9 Age range, 66–85 Median age, 70 Type: institutionalized	Static squat position	WBV produced an acute increase in circulating levels IGF-1a and cortisol greater than that observed following the same exercise protocol conducted without vibration	Galileo 900 10–26 Hz 3 or 7 mm	3 times/week for 6 weeks, 4×1 m/session	Anthropometric measures Plasma cortisol Plasma testosterone Plasma growth hormone Plasma IGF-1
Carlucci et al. [11]	To investigate acute residual effects of a single vibration session on balance control in a group of elderly women	1. WBV group 2. Control group	N=36 F, 36; M, 0 Mean age, 71.8±4.7 Type: noninstitutionalized	Static high squat, dynamic squat, static deep squat, static wide stance squat, static right lunge, static left lunge	No significant variations in postural parameters. A single bout of WBV does not induce dangerous acute effects on elderly women balance control ability.	Well-net Vibe (vertical vibration) 35 Hz	1 session, 1–2× 30–60 s  Max. 9.5 min	Various body sway parameters (force plate)
Cheung et al. [13]	To investigate the efficacy of high-frequency WBV on balance ability in elderly women	Randomized controlled trial: 1. WBV group 2. Control group	N=69 F, 69; M, 0 Age range, over 60 Mean age, 72.36±4.93 Type: noninstitutionalized	Just stood on platform (static)	WBV showed significant improvement in movement velocity, maximum point excursion, and directional control. Reaction time and endpoint excursion failed to show significant changes. No significant changes in functional reach test between groups.	Galileo 900	3 times/week for 3 months, 1×3 min/session	Limits of stability (Basic Balance Master System) Functional reach test Directional control Movement velocity
Cochrane et al. [14]	Examine the acute physiological effects of acute WBV exercise in healthy young and older people	Comparative control trial: 1. Young group 2. Old group	12 healthy young (mean age, 21.5±2.8) 12 healthy old (mean age, 69.2±7.2) Type: noninstitutionalized F, 12; M, 12	9 conditions, static squat  1. No load (0% body mass) 2. 20% body mass  3. 40% body mass	Load and vibration associated with increase VO <sub>2</sub> , heart rate, rating of perceived exertion and blood pressure. No significant differences between groups. Jendrassik maneuver increased VO <sub>2</sub> but no significant differences between groups	Galileo 900 20 Hz 0 or 5.3 mm (medial to distal) Prototype: seated WBV leg press machine 30 Hz  1 mm	1 session, 9×4 min	Anthropometric measures Countermovement jump  Isometric maximal voluntary contraction Oxygen uptake Blood pressure Rating of perceived exertion Heart rate Physical activity

Table 1 (continued)

Reference	Purpose	Type of study	Participants	WBV exercises performed	Study results	Plate/parameters	Frequency and duration	Measurements
Ebersbach et al. [18]	To compare the effects of WBV and conventional physiotherapy on levodopa resistant disturbances of balance and gait in idiopathic Parkinson's disease	Randomized controlled rater-blinded trial: 1. WBV group 2. Exercise group (physiotherapy)	N=21 (27 I.T.T) F, 7; M, 14 Age range, 62–84 Mean age, 73.8±6.42 Type: institutionalized	Static squat position (slightly bent knees and hip)	No conclusive evidence for superior efficacy of WBV compared with conventional balance training. Both groups improved on Tinetti Balance Scale, gait velocity, stand-walk-sit test and Unified Parkinson's Disease Rating Scale. Posturography improved in patients with WBV.	Galileo 900, 25 Hz 7 or 14 mm	5 times/week for 4 weeks Max. 15 min/session	Questionnaire Tinetti balance scale test Time to walk 10 m test Stand-walk-sit test Unified Parkinson's disease Rating scale (section III) Posturography Pull test
Gusi et al. [19]	To compare the effects of WBV using a reciprocating platform at frequencies lower than 20 Hz and a walking-based exercise program on bone mineral density and balance in postmenopausal women	Randomized controlled trial: 1. WBV group 2. Exercise group (walking)	N=28 (36 I.T.T) F, 28; M, 0 Mean age, 66.0±5 Type: noninstitutionalized	Static squat position (knees flexed 60°)	WBV is more effective than walking to improve 2 major determinants of bone fractures: hip bone mineral density (4.3%) and balance (29%). Bone mineral density at lumbar spine was unaltered in both groups.	Galileo 2000 12.66 Hz 3 cm	3 times/week for 8 months, 6×1 min/session	Hip and lumbar bone mineral density (using dual-energy X-ray absorptiometry) Blind flamingo test
Haas et al. [20]	To analyze the effects of WBV on motor control in Parkinson's disease patients	Randomized controlled crossover trial: 1. WBV group 2. Control group	N=68 F, 15; M, 53 Mean age, 65.0±7.8 Type: not disclosed	Static squat position	Significant improvement (16.8%) on the Unified Parkinson's Disease Rating motor score vs. marginal changes in control. Tremor and rigidity scores were improved by 25% and 24%, respectively.	Zaptor® med System 6 Hz 3 mm	1 session 5×1 min	Unified Parkinson's Disease Rating Scale
Kawanabe et al. [23]	Determine the beneficial effect of WBV in addition to muscle strengthening, balance and walking exercises on walking ability in the elderly	1. WBV group (plus exercise) 2. Exercise group (exercises not defined)	N=67 F, 63; M, 4 Age range, 59–86 Mean age, 72.0 Type: noninstitutionalized	Static squat position	Walking speed, step length, max standing time on one leg significantly improved in WBV group; no significant changes in exercise group.	Galileo 12–20 Hz	1 time/week for 2 months, 1×4 min/session	Walking speed Step length Max standing time on one leg (bilateral)
Machado et al. [28]	Determine whether 10 weeks of WBV training has a significant effect of strength, muscle mass, muscle power, and mobility in older women	Randomized controlled trial: 1. WBV group 2. Control group	N=26 F, 26; M, 0 Age range, 65–90 Mean age, 77.5 Type: noninstitutionalized	Half squat, deep squat, wide stance squat, calves (static and dynamic)	WBV training significantly increases muscle strength induced by thigh muscle hypertrophy with no change in muscle power. Timed up-and-go test improved significantly after training (9%) in WBV group only.	Fivibe 20–40 Hz 2 or 4 mm	3–5 times/week for 10 weeks Max. 22 min/session (progressive increase)	Muscle cross-sectional area Timed up-and-go test Leg-press MVIC test Surface electromyographic activity
Raimundo et al. [33]	To compare the efficacy of 8 months of low frequency vibration and a walk-based program in health-related fitness	Randomized trial: 1. WBV group 2. Exercise group (walking)	N=27 F, 27; M, 0 Mean age, 66.0±5 Type: noninstitutionalized	Static squat position (knees flexed 120°)	Exercise group improved the time spent to walk 4 m (20%) and to perform the chair rise test (12%) compared to WBV group. WBV group showed improved (7%) vertical jump. No changes in isokinetic measurements in both groups	Galileo 2000 12.6 Hz 3 mm	3 times/week for 8 months 6×1 min/session	Anthropometric variables Vertical jump test Chair rise test Maximal walking speed (4 m)
Rees et al. [35]	Investigate the effects of vibration on muscle	Randomized controlled trial:	N=43 F, 20; M, 23	1. Standing with bent knees (week 1–4)	WBV increases lower limb strength. No effect on functional performance	Galileo	3 times/week for 2 months	Sit-to-stand test

**Table 1** (continued)

Reference	Purpose	Type of study	Participants	WBV exercises performed	Study results	Plate/parameters	Frequency and duration	Measurements
	performance and mobility in healthy untrained population	1. WBV group 2. Exercise group (same exercises, no WBV) 3. Control group Randomized trial:	Age range, 66–85 Mean age, 73.5±4.59 Type: not disclosed	2. Dynamic lower limb exercises (week 5–8)	tasks (compared with exercise group). Both WBV and exercise groups improved on sit-to-stand test, fast walk test, and knee extension strength compared with control group.	26 Hz 5–8 mm	Max. 8 min/ session	Timed up-and-go test Fast walk Start mobility test Isokinetic strength
Rees et al. [36]	Investigated the effects of vibration on strength (force-producing capacity) and power in older adults who are healthy	1. WBV group 2. Exercise group (same exercises, no WBV) 3. Control group Randomized trial:	N=30 F, 14; M, 16 Age range, 66–85 Mean age, 73.7±4.6 Type: not disclosed	1. Standing with bent knees (week 1–4) 2. Dynamic lower limb exercises (week 5–8)	WBV group significantly improved ankle plantar flexor strength and power compared with the exercise group. No significant differences between both for knee flexor or extensor strength.	Galileo 26 Hz 5–8 mm	3 times/week for 8 weeks, 6×45–80 s/ session (overload principle)	Maximum isokinetic strength and power (examined hips, knees, and ankles)
Rees et al. [37]	Investigate the effects of vibration exercise on postural steadiness performance in a healthy, older population	Randomized controlled trial: 1. WBV group 2. Exercise group (same exercises, no WBV) 3. Control group	N=43 F, 20; M, 23 Age range, 66–85 Mean age, 73.5±4.59 Type: not disclosed	1. Standing with bent knees (week 1–4) 2. Dynamic lower limb exercises (week 5–8)	Vibration exercise can improve balance in an older population. Increases in one-legged postural steadiness (in WBV compared to control and exercise groups)	Galileo 26 Hz 5–8 mm	3 times/week for 8 weeks, 6×45–80 s/ session	One-legged postural steadiness test
Roelants et al. [41]	Investigate the effects of 24 weeks of WBV training on knee extension strength and speed of movement and on countermovement jump performance in older women	Randomized controlled trial: 1. WBV group 2. Exercise group (resistance training) 3. Control group	N=89 F, 89; M, 0 Age range, 58–74 Mean age, 64.25±0.69 Type: not disclosed	High squat, deep squat, wide stance squat, lunge (static and dynamic)	WBV as effective as exercise group to improve knee extension strength, speed of movement and countermovement jump. Training effects not significantly different between exercise and WBV groups.	Power Plate® (vertical vibration) 35–40 Hz, 2.5 or 5 mm	3 times/week for 24 weeks Max. 30 min/ session	Isometric and dynamic strength of knee extensors (dynamometer) Countermovement jump performance Speed of movement of knee extension Muscle power Cortical bone density Biomarkers of bone turnover
Russo et al. [42]	To test whether training on a high-frequency vibrating platform improves muscular power and bone characteristics in postmenopausal women	Randomized controlled trial: 1. WBV group 2. Control group	N=29 F, 29; M, 0 Mean age, 61.04±6.68 Type: noninstitutionalized	Static squat position	Muscle power improved 5% in WBV group women, whereas control declined slightly. WBV may be useful to improve muscular power in postmenopausal women. No changes in bone mineral density	Galileo 2000 12–28 Hz	2 times/week for 6 months Max. 6 min/ session	Postural stability (narrow and tandem standing) Biomarkers of bone turnover
Turbanski et al. [45]	To determine the effects of WBV on postural control in Parkinson's disease subjects (PD)	Controlled trial: 1. WBV group 2. Control group	N=52 F, 14; M, 38 Mean age, 69.1±8.9 Type: not disclosed	Not disclosed; the assumption is standing	WBV can improve postural stability in PD spontaneously WBV group improved significantly better on both the narrow standing and tandem standing test conditions compared to the control	Zeptor® med System 6 Hz 3 mm	1 session, 5× 1 min	Postural stability (narrow and tandem standing)
van Nees et al. [47]	To determine short-term effects of WBV as a novel method of somatosensory stimulation on 23 chronic stroke patients	1. Stroke group 2. Control group (nonstroke)	N=46 F, 10; M, 13 (reported stroke group only) Mean age, 61±10.35 Type: noninstitutionalized	Static squat position (slight flexion)	WBV may improve proprioceptive control of posture in stroke patients.	Galileo 900/ Galileo 2000 30 Hz 3 mm	1 session, 4× 45 s	Center of pressure Movement (force plate) Motoricity index Berg Balance Scale Functional ambulation categories
van Nees et al. [48]	To determine long-term effects of 6 weeks of	Randomized trial: 1. WBV group	N=53 F, 0; M, 53	Static squat position	Daily sessions of WBV are as effective in terms of recovery, balance, and	Galileo 900/	5 times/week for 6 weeks,	Berg Balance Scale

Table 1 (continued)

Reference	Purpose	Type of study	Participants	WBV exercises performed	Study results	Plate/parameters	Frequency and duration	Measurements
	WBV on postural control and activities of daily living compared to exercise therapy with music	2. Exercise group (same exercises, no WBV)	Mean age, 61.12±9.99 Type: institutionalized		activities of daily living when comparing to exercise therapy with music in the postacute phase of stroke	Galileo 2000 30 Hz 3 mm	4×45 s/ session	Barthel index Trunk control test Rivermead Mobility Index Functional ambulation categories Motricity index Somatosensory threshold
Verschueren et al. [49]	Assess the musculoskeletal effects of high-frequency WBV in postmenopausal women	Randomized controlled trial: 1. WBV group 2. Exercise group (resistance training) 3. Control group	N=70 F, 70; M, 0 Age range, 58–74 Mean age, 64.24±3.39 Type: not disclosed	Squat, deep squat, wide stance squat, lunge and one-legged squat (static and dynamic)	WBV improved isometric (+15%) and dynamic (+16%) muscle strength and also significantly increased bone strength and increased bone mineral density of the hip. No changes in hip bone mineral density in exercise or control groups	Power Plate® (vertical vibration) 35–40 Hz 1.7 or 2.5 mm	3 times/week for 24 weeks Max. 30 min/session (progressive overload)	Bone mineral density Bone turnover Bone strength Postural control
von Stengel et al. [51]	To examine whether the effect of multipurpose exercise can be enhanced by WBV	Randomized controlled trial: 1. WBV group (plus exercise) 2. Exercise group (same exercises, no WBV) 3. Control group	N=151 F, 151; M, 0 Age range, over 65 Mean age, 68.5±3.1 Type: noninstitutionalized	Heel rise, one-legged squat, leg abduction, one-legged deep squats with heel raises (dynamic)	WBV embedded in a multipurpose exercise program showed minor additive effects on body composition and neuromuscular performance. Only WBV training resulted in significant increases of leg and trunk flexion strength compared to control group	Vibrafit 25–35 Hz 1.7 or 2 mm	2 times/week for 18 months 2×1 min/session 60 min exercise/ 15 min WBV/ session	Anthropometric variables Maximal isometric leg strength Maximal grip strength



a control group. The WBV group stood on the WBV platform with their knees slightly bent for three 2-min sessions twice a week, for 6 months. The control group did not receive any training. Muscular power was quantified by measuring participants' ground reaction forces from jumps on a force plate. After 6 months, muscle power improved 5% in women who received WBV training, whereas the control group declined slightly. This suggests that WBV may be useful for improving muscular power in postmenopausal women [42].

Verschueren et al. [49] investigated postmenopausal women to determine if WBV training would improve muscular strength. Seventy women (58–74 years) were randomly divided into three groups: WBV training group (WBV), exercise without vibration group, and a control group. Baseline measures were taken for all participants to determine initial isometric and dynamic strength. The WBV and exercise group trained three times per week for 24 weeks; the WBV group performed various static and dynamic lower body exercises on the vibration platform, while the exercise group trained their lower body by leg extension exercises and dynamic leg presses. After training, isometric strength of the knee extensors increased in both WBV and exercise groups, by 15% and 16%, respectively. Dynamic strength increased by 16.5% in the WBV group and 10.6% in the exercise group. The controls showed no significant change in isometric and dynamic strength from pre- to posttest [49]. These results are consistent with Roelants et al. [41], who had parallel results with 89 postmenopausal women. Both studies suggest WBV can significantly improve dynamic and isometric strength in postmenopausal women. Roelants and colleagues [41] also proposed WBV was as effective as conventional resistance training when testing knee extension strength, speed of movement of knee extension (the highest possible speed the participant could extend their knee from 90° to 160°), and countermovement jump performance (flight time of a concentric muscle contraction following an eccentric muscle contraction) in older women [41].

To determine if WBV training has a significant effect on both muscular strength and power, Machado et al. [28] randomly assigned 26 senior women (65–90 years) to either a WBV training group or a control group. The WBV group trained for 10 weeks on the WBV platform performing calf raises and various squatting exercises, after which participants were compared to their baseline measurements. The WBV group had increases in maximum voluntary isometric contraction (MVIC—38.8%) as well as increases in the cross-sectional area of both the vastus femoris (8.7%) and biceps femoris muscles (15.5%). No changes were detected in the control group. Muscle power with an external resistance of 20%, 40%, and 60% MVIC decreased from pre- to posttest only in the control group; the authors concluded that WBV training prevented the decrease in muscular power in the WBV group. These results further suggest that WBV can

improve muscular strength in older women, which Machado et al. [28] attributed to thigh muscle hypertrophy.

## Flexibility

Bautmans and colleagues [1] were the first researchers to test an element of flexibility training with WBV in seniors. Twenty-four nursing home residents (9 male and 15 female) were randomly selected to either a WBV group or a control group. Participants from both groups were examined on flexibility pre- and posttest utilizing the chair sit-and-reach test (lower body flexibility) and the back scratch test (upper body flexibility). The WBV group performed lunges along with various types of squats and calf raises on a vibration platform, which target all the lower limb muscles. After 6 weeks, lower body flexibility improved significantly in the WBV group, indicating that general exercises may benefit flexibility. No significant differences were found in upper body flexibility pre- to posttest in either group, which may be attributed to participants not performing any exercises that targeted the upper body specifically [1].

Similarly, Bissonnette et al. [3] examined upper and lower extremity flexibility using the same protocol. Nineteen participants (60–85 years) performed the chair sit-and-reach test and back scratch test pre- and post-WBV training. After completing the initial assessment, participants performed squats, calf raises, tricep extensions, and bicep curls on the WBV platform three times per week for 8 weeks. At week 4, lunges were added to the participants' exercise regimen. Both upper and lower body flexibility increased significantly from 0 to 8 weeks. Although the two aforementioned articles studied flexibility somewhat indirectly, results suggest WBV can be a very promising intervention to maintain or regain flexibility. This is noteworthy considering that flexibility can decline by up to 50% in certain joints by age 70 [12]. Based upon the search of the literature, these are the only two studies that tested a component of flexibility, indicating a vast potential to examine the effects of targeted flexibility exercises using WBV.

## Upper body studies

Along with flexibility, upper body studies are one of the least established areas of WBV research with older adults. Bissonnette and colleagues [3] are the sole investigators of the 27 articles to examine upper body strength. Nineteen participants (60–85 years) were tested on upper body strength at baseline and after 4 and 8 weeks of training by performing a standardized arm curl test. Following their initial assessment, participants performed static WBV tricep extensions and bicep curls three times per week for 8 weeks.

Following training participants could lift 49% more weight compared to baseline performance, on average. This implies meaningful improvement in upper body strength can be attained from WBV exercises targeting those specific muscles [3].

### Randomized controlled trials

Of the 27 WBV studies examining older adults, 19 were randomized controlled trials (RCTs). Components most frequently examined were muscular strength (nine studies) and balance (seven studies). Other variables measured included muscular power (five studies), mobility (four studies), and bone mineral density (BMD—three studies). To a lesser extent, RCTs have examined functional capacity, cardiorespiratory fitness, anabolic hormones, electromyographic activity, torque, motor control, and muscle mass.

The nine studies that examined strength all found statistically significant improvements in muscular strength [1, 5, 28, 33, 35, 36, 41, 49, 51], and three studies suggested WBV is as effective as conventional resistance training [5, 41, 49]. Of the seven studies that examined balance, each one found statistically significant improvements in the components measured. WBV exercise increased balance/postural control [4, 7, 13, 37], WBV exercise was more effective than walking to improve balance [19], and WBV exercise was as effective [18] or possibly superior [37, 48] to their comparative traditional exercise programs.

Two studies examining BMD revealed increases in the hip [49] and femoral neck [19]. In addition, Russo et al. [42] found the decline of cortical BMD tended to be less in the WBV group than the control group. Of the three studies that examined BMD, there were no reported adverse effects due to treatment, with the exception of one participant who complained of knee pain [42]. Therefore, WBV may be a viable alternative for individuals who have low BMD, although Totosty de Zepetnek and colleagues [44] have advised caution for individuals suffering from severe osteoporosis. With just three studies specific to adults over 55, this work is clearly in its early stages, and more research is needed prior to providing definitive recommendations for those in this age category who have low BMD or osteoporosis. In the absence of a substantive body of research, caution is warranted.

It is important to note that there were considerable differences in methodologies among the RCTs. Studies ranged from one session to 1 year, participants exercised between two and five times per week and the WBV platform's frequency ranged from 6 to 40 Hz. In addition, there was an underrepresentation of men in the 19 RCT studies. Of the 1,315 individuals who participated in the RCTs, 316 (24.0%) were men. Therefore, the literature would benefit from replication and/or greater consistency in the methodologies employed,

particularly with respect to study duration, the number of weekly exercise sessions, and the hertz utilized.

### Limitations and future research

Although WBV research specific to an older population is relatively new, the evidence suggests that WBV training is a viable option for increasing muscular strength, improving flexibility, improving balance, and reducing the risk of seniors falling. Many of the published studies show that WBV is as effective as resistance training. Readers should be cautioned that this may be due, at least in part, to publication bias; studies with significant findings are more likely find their way into the academic literature. Additionally, the majority of the studies that we reviewed did not mention whether or not the experimenters were blinded when taking measurements. The potential for investigator bias should be controlled for in future studies.

While there are potential limitations, the scientific literature indicates that there is substantial evidence supporting WBV as an effective intervention for older adults, which is important information for seniors who are unable to perform conventional exercise. Additionally, WBV may be appropriate for those with time constraints, as a typical WBV training session takes approximately 15 min, considerably less time than a traditional 45–60 min resistance training regimen. In the studies reviewed, six minutes per body part was the maximum time allotted for WBV training.

Specific vibration platform settings varied significantly from study to study. This can be partially attributed to the different types of WBV platforms used. In addition, researchers have increased the frequency and peak-to-peak displacement of the WBV platform after a few weeks of training to counteract any potential plateau effect [3, 6, 26]. Determining optimal frequency and peak-to-peak displacement settings to maximize results is an important area of future research.

From a practical standpoint, WBV training can be an expensive intervention for the senior population. A vibration platform for home use can cost up to 2,000 euros [52]. Seniors may find it more cost-effective to go to a facility that has an industrial size vibration platform and pay a monthly membership fee. Although, as WBV training for the general public is relatively new, fitness clubs are only beginning to incorporate these devices.

Of the 27 studies that are specific to WBV and the senior population, the primary focus has been on strength or balance components of the lower body. While the results suggest that WBV is effective for lower body muscular strength and postural control, more conclusive evidence is needed to determine if WBV can improve overall flexibility and upper body strength with the aging population, as this area of research is still in its infancy. Ideally, future flexibility and upper body

strength WBV research would incorporate a randomized controlled study utilizing a WBV group, an exercise without vibration group, and a control group.

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