Clinical Interventions in Aging

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REVIEW

The Focal Mechanical Vibration for Balance Improvement in Elderly – A Systematic Review

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Background: Aging has been associated with the progressive depletion of lean mass, reductions in muscle strength and the coordination of the lower extremities, accompanied by decreased gait assurance and balance control. Also, less balance control favors falling which is the leading cause of injury among the elderly. The aim of this systematic review is to identify and evaluate existing evidence regarding the use of focused vibration (FV) to improve balance and reduce the risk of falling during the rehabilitation of elderly populations.

Methods: The PICO question is what are the effects of focal/segmental/local vibration training on the assessment of balance and the risk of falls among the elderly population? A thorough literature review was conducted between May 1, 2009, and June 30, 2019, for studies in English, randomized clinical trials, including crossover and prospective design studies with assessing balance and the risk of falls in elderly populations (age > 60 years).

Results: Eight articles (N = 8) satisfied the inclusion criteria and were considered, of which 6 are RTC, one cross-sectional study and one clinical study, for a total of 635 participants. A total of 6 different vibration devices were used, each of which was associated with different FV frequency and amplitude characteristics and different treatment protocols.

Conclusion: In conclusion, FV can be effective in decreasing the risk of falls and improving the assessment of balance, but more evidence is necessary considering the limits of the studies; however, it does look an important promise during rehabilitative treatment.

Keywords: rehabilitation, risk of falls, exercise, vibration, equilibrium

Introduction

The progressive aging of the population is a phenomenon that can no longer be ignored. According to the World Health Organization (WHO), the proportion of people aged older than 60 years is increasing faster than other age groups, in all countries; for instance, in 2016, 19% of the European population was aged 65 years or older, and this group is expected to encompass 30% of the population by 2060.[1]

Aging has been associated with the progressive depletion of lean mass, especially muscle mass, a phenomenon known as "sarcopenia" resulting in the loss of muscle strength, loss of mobility, neuromuscular impairments, and homeostatic balance failure syndrome, accompanied by gait and balance disorders.[2] Sarcopenia is a multifactorial process, associated with intrinsic causes [decreased levels of growth hormone (GH) and sex hormones and decreased numbers of motor neurons] and extrinsic or environmental causes (nutrition, partial or total immobility, and a lack of exercise).[3,4] With advancing age, motor units, "i.e." an α motor neuron and the muscle fibers it innervates, become reduced, in total number and size, causing changes in the abilities of muscle tissue to generate strength.[5]

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Received: 13 July 2021
Accepted: 9 October 2021
Published: 2 December 2021

Muscle strength begins to decrease rapidly after the age 65 years, with the lower limb muscles, particularly the quadriceps femoris muscle being affected more than other muscle groups.[6] These changes have negative effects on balance maintenance and posture among the elderly, which have been associated with reductions in autonomy and the establishment of a "fear of falling" as a serious consequence since it leads to a mobility reduction, social isolation, and diminished quality of life.[6,7]

In the present study, we have defined a fall to be an event that "results in a person coming to rest inadvertently on the ground or other lower level and other than as a consequence of a violent blow, loss of consciousness, or sudden onset of paralysis".[8] Falls are the leading cause of injury among the elderly and have been associated with increased morbidity, functional decline, reductions in social activity, and poor quality of life. Further, many indicators of frailty, such as poor vision, low handgrip strength, decline in walking speed, the use of walking aids, drug use, and depression, have been recognized as risk factors for falls.[9] To reduce the risk of falls, evidence in the literature supports a crucial role for exercise, especially exercises that are designed to improve balance and gait and increase lower limb strength.[10]

Rehabilitation plays a similarly important role as exercise, with the aim of addressing the disabilities that are characteristic among the elderly population. The primary aim of rehabilitation among the elderly is the recovery and maintenance of the bodily functions that are necessary to perform independent activities of daily life (ADLs).[10]

Among the elderly, the importance of physical exercise for maintaining muscle strength, optimizing reaction times, and improving balance and coordination has been demonstrated.[11] Moreover, several studies have reported specific benefits in response to whole-body vibration training in the older population, including improvements in balance and gait speed.[12] In fact, Sarabon et al, in a recent meta-analysis, showed that whole-body vibration training in the older population seems to be comparably effective for improving muscle strength, but not muscle cross-sectional area.[13] However, limitations exist for the administration of whole-body vibration training, especially among the elderly population, who have numerous comorbidities, such as cardiac and vascular diseases.[14] Several adverse effects following whole-body vibration exposure have been reported, including low back pain; circulatory disorders, such as Raynaud syndrome, nervous system alterations; perception disorders, and dizziness. However, most of these adverse effects have been reported following prolonged exposure to vibrations for occupational purposes.[15] Therefore, during rehabilitation procedures, focused vibration (FV) is generally preferred, which allows the stimulation of individual muscle groups and selectively activates type Ia and IIb fibers and the Golgi tendon organs, depending on the stimulus.[16]

In a recent review, Aboutorabi et al[17] investigated the existing reports of the effects of FV interventions on postural control and gait among the elderly, particularly the use of vibratory insoles and the application of localized vibrations to the ankle and foot. Vibrating footwear appeared to improve balance [based on reductions in center of pressure (CoP) velocity and displacement] in healthy elderly individuals and increased the walking speed, cadence, step time, and step length among stroke patients. If the exteroceptive afferents found on the sole of the foot play important roles during balance maintenance, then multiple pieces of sensory information must be evaluated by the central nervous system and integrated with other stimuli, to maintain an erect posture.[18] Postural control strategies can include "reaction" (feed-back), "anticipation" (feed-forward), or a combination of both. Postural control is a complex motor skill that relies on interactions between multiple sensorimotor processes; thus, even the slightest age-related changes in the peripheral and central components of the visual, somatosensory, and vestibular systems can affect balance and mobility.[19] With decreased cognitive functions, these impairments lead to an increased risk of falling among the elderly.[11–20] Therefore, the aim of this systematic review was to identify and evaluate existing evidence regarding the use of FV to improve balance and reduce the risk of falling during the rehabilitation of elderly populations.

Materials and Methods

Search Strategy

The method for conducting this systematic review is based on the guidelines that have been established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[21]

A systematic review of the literature was performed, using the following search engines: PubMed, PEDro, Scopus, and Cochrane Library. To perform the search, the following algorithm was developed, based on the PICO acronym,[22] to evaluate a Population (elderly), Intervention (focal/segmental/local vibration training), Comparator (no treatment, placebo, or other exercises), and Outcomes (postural control, risk of falls, and functional balance). The research question was as follows: What are the effects of focal/segmental/local vibration training on the assessment of balance and the risk of falls among the elderly population?

The primary outcome of interest was the assessment of balance, whereas the secondary outcome of interest was the quantification of fall risk. Two independent reviewers (RL and LP) screened all titles, abstracts and full texts for eligibility, and the authors evaluated the studies identified by the searches based on the inclusion and exclusion criteria established.

This review included articles that utilized the following MeSH terms "elderly" AND "vibration" AND "balance". The reference lists for most of the relevant studies were scanned for additional citations. Country, author, affiliated institution, and enrollment period data were extracted and reviewed to identify and exclude duplicate publications using the same cohort. Any disagreement regarding accepting full-text articles was resolved by discussion until consensus was reached.

Study Criteria and Selection

The inclusion criteria were as follows: (1) published between May 1, 2009 and June 30, 2019; (2) assessed balance or the risk of falls in elderly populations; (3) randomized clinical trials, including crossover and prospective design studies using focused vibration; (4) availability of a full English text; and (5) population age > 60 years.

The exclusion criteria were as follows: (i) neurological diseases; (ii) treatment with whole-body vibration; (iii) vibratory insoles or footwear; (iv) animal or in vitro studies; and (v) lack of English abstract or English full text.

Data Extraction

The investigators retrieved all the information from each study. After the application of the eligibility criteria, the included studies were analyzed based on sample demographics, study aims, conflict of interest statements, study durations and follow-up (time and percentage), vibration devices that were used, evaluation times, intervention protocols, and the outcome parameters assessed (clinical and functional).

Methodology Quality Assessment

The assessment of the quality and risk of bias was done independently by two authors (RL and LP). The quality of each study was assessed using the PEDro scale,[23] which consists of 11 items that are related to scientific rigor. Items 2 through 11 on the scale contribute to internal validity, and each study is awarded 1 point for each criterion that is not met by the study. The first item relates to external validity and is not included in the final score. To describe the potential for bias for each individual study, the level of evidence presented by each study was assessed according to the Oxford Centre for Evidence-Based Medicine system, which uses 5 levels of evidence, with Level 1 being the highest (eg, systematic reviews and meta-analyses) and Level 5 being the lowest (eg, expert opinion).[24] These criteria, suggested by Law and MacDermid, have been recommended as being adequate for the evaluation of rehabilitation literature.[25]

Results

Figure 1 shows the PRISMA flow diagram for a selection of studies. A total of 8 articles (N = 8) satisfied the inclusion criteria and were considered in the review, and detailed information for each study can be found in Tables 1 and 2. Furthermore, in Table 3 the results of the single studies are summarized as mean and SD, only the data concerning balance and/or risk of falling. The PEDro score values and levels of evidence for each of the included studies can be found in Table 4. The studies comprised a total of 635 participants, including 551 females and 84 males. Different protocols applied during each study can be observed in Table 2.

Most of the included studies[26–31] featured a control group of similar age, except for Yu et al[32] and Ehsani et al,[33] in which the elderly treatment group was compared with healthy young people. These 2 studies sought to explain how and why vibration conditions could affect balance control in the elderly population compared with young adults. Yu et al[32] attempted to determine age-related changes under various vibration conditions, especially when vibrations were applied to the tibialis anterior tendon (TAT) and the Achilles tendon (AT), individually or in combination, during 1- and 2-legged stances, and Ehsani et al[33] examined the effects of low-frequency, low-amplitude vibratory stimulation of both Gastrocnemius muscles by including a third group of

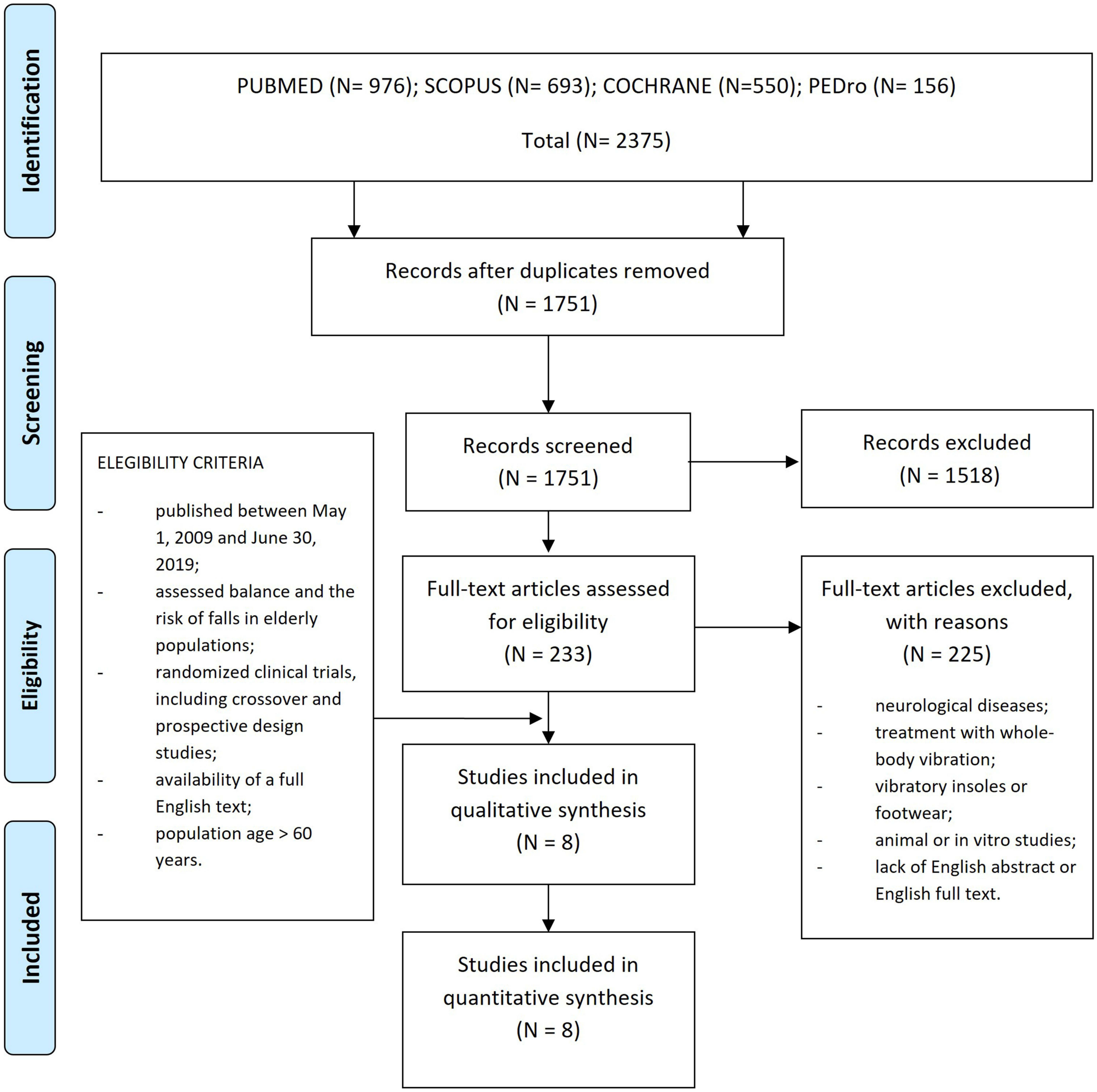

Figure 1 PRISMA flow-diagram indicating the selection of studies included in the review.
Notes: PRISMA figure adapted from Moher D, Liberati A, Altman D, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Journal of Clinical Epidemiology. 2009;62(10). Creative Commons[21].

elderly people with high fall risk. Ehsani et al[33] only used evaluation scales to stratify the sample, based upon the Center for Disease Control and Prevention's STEADI Risk for Falling Assessment questionnaire,[34] and administered a visual analog pain scale for the lower extremities (VAS-10),[35] during a 2-week period prior to the visit and at the time of the visit, and administered the short Falls Efficacy Scale-International (Short FES-I) to assess the fear of falling.[36]

When assessing balance as the primary outcome, 4 studies Bellomo et al, Filippi et al, Wanderley et al, and Yu et al[26–32] used balance platforms to evaluate postural stability by calculating body sway relative to CoP displacement. In contrast, Ehsani et al[33] used a wearable motion sensor (a tri-axial gyroscope designed to estimate 3-dimensional ankle and hip angles) to calculate the center of gravity (CoG). Moreover, Wanderley et al,[21] in addition to assessing balance, assessed performance on the one-leg

Table 1 Summary of the Studies Included in the Review

Authors & Year	Diagnosis	n° (M/F); (Mean Age ± SD)	n° TG n° CG	Treatment	Outcome Parameters	Evaluation Time	Conclusions
Bellomo et al[26]	Sarcopenic elderly	40 (M); (70.9 ±5.2)	TG1: 10 TG2: 10 TG3: 10 CG: 10	TG1: Global Sensorimotor Training TG2: Resistance Training for lower limbs TG3: Vibratory mechanical-acoustic focal therapy CG: usual activity	Maximal force contraction: Maximal isometric test; Balance assessment: sway area of CoP (mm^2)	T0: baseline T1: after 12 weeks	Maximal force contraction: TG2>TG3>TG1>CG Balance assessment: TG1>TG3>TG2=CG
Celletti et al[27]	Elderly women	350 (F); (73.4 ±3.11)	TG: 175 CG: 175	TG: vibratory stimulation CG: Sham vibratory stimulation	Risk of falling assessment: POMA	T0: baseline T1: after 30 days T2: after 180 days	Risk of falling assessment: TG>CG
Ehsani et al[33]	Healthy young adults Healthy older adults High fall risk older adults	30 (12M/18F); (23.30±2.26) (72.90±2.81) (83.60±9.46)	TG1: 10 TG2: 10 TG3: 10	TG1, TG2, TG3: vibratory stimulation	Balance assessment: CoG	T0: baseline T1: after treatment	Balance assessment: TG1>TG2>TG3
Filippi et al[28]	Sedentary life-style women	60 (F); (65.3 ±4.2)	TG1: 20 TG2: 20 CG: 20	TG1: vibratory stimulation contracted muscles TG2: vibratory stimulation relaxed muscles CG: Sham vibratory stimulation contracted muscles	Balance assessment: sway area of CoP (mm^2) and velocity Leg muscle performance: Vertical jumping test	T0: baseline T1: after 1 day T2: after 30 days T3: after 90 days	Balance assessment: TG1>TG2&CG Leg muscle performance: TG1>TG2&CG

(*Continued*)

Table 1 (Continued).

Authors & Year	Diagnosis	n° (M/F); (Mean Age ± SD)	n° TG n° CG	Treatment	Outcome Parameters	Evaluation Time	Conclusions
Rabini et al[29]	Men and women >60yrs, with OA	50 (11M/39F); (73.72±5.24) (75.08±5.74)	TG: 25 CG: 25	TG: vibratory stimulation CG: Sham vibratory stimulation	Pain, stiffness, functional limitation assessment: WOMAC Physical performance assessment: SPPB Risk of falling assessment: POMA	T0: baseline T1: after 3 day T2: after 3 months T3: after 6 months	Pain, stiffness, functional limitation assessment: TG>CG Physical performance and Risk of falling assessment: TG>CG
Tankisheva et al[30]	Post-menopausal women	35 (F); (75.7) (77.6)	TG: 17 CG: 18	TG: Bilateral m. quadriceps, m. gluteus maximus and m. gluteus medius CG: usual activity	Muscle strength: isokinetic dynamometry Muscle mass: CT BMD: DXA Physical Performance assessment: SWT, mPPT	T0: baseline T1: after 6 months	Muscle strength: TG>CG Muscle mass: TG=CG BMD: TG=CG Physical Performance assessment: TG=CG
Wanderley et al[31]	Women >60yrs, with balance deficit but independent gait	30 (F); (68.6±5.7) (68.1±4.9)	TG: 15 CG: 15	TG: vibratory stimulation CG: usual activity	Balance assessment: OLS test EO/EC; TUG test; FR test; sway area of CoP (cm^2)	T0: baseline T1: after 1st intervention period T2: after 2nd intervention period	Balance assessment: TG>CG
Yu et al[32]	Healthy elderly Young adults	40 (21M/19F); (72±3.2) (22±2.5)	TG1: 20 TG2: 20	TG1, TG2: vibratory stimulation	Balance assessment: sway area of CoP (cm^2)	During treatment (NVO, CVO, TATVO, ATVO; NVT, CVT, TATVT, ATVT)	Balance assessment: in TG1 the ability to balance improves during CVO; in both groups using Combined Vibration decrease CoP sway area.

Abbreviations: TG, treatment group; CG, control group; OA, Knee Osteoarthritis; CoP, Center of Pressure; OLS test EO/EC, One-leg stance test Eyes open/Eyes closed; TUG test, Time Up-and-Go test; FR test, Functional reach test; POMA, performance-oriented mobility assessment; WOMAC, Western Ontario and McMaster University Osteoarthritis Index; SPPB, Short Physical Performance Battery; CT, Computed Tomography; BMD, Bone Mass Density; DXA, dual-energy X-ray absorptiometry; SWT, Shuttle walk test; mPPT, modified physical performance test; VAS, visual analogic scale; FES-I, short falls efficacy scale-international; STEADI, Stopping Elderly Accidents, Death and Injuries; CoG, center of gravity; NVO, no vibration during one-legged stance; CVO, combined vibration to the Tibialis anterior tendon and Achilles tendon during one-legged stance; TATVO, Tibialis anterior tendon vibration during one-legged stance; ATVO, achilles tendon vibration during one-legged stance; NVT, no vibration during two-legged stance; CVT, combined vibration to the Tibialis anterior tendon and Achilles tendon during two-legged stance; TATVT, Tibialis anterior tendon vibration during two-legged stance; ATVT, achilles tendon vibration during two-legged stance.

Table 2 Characteristics of Vibration and Parameters Used in the Included Studies

Authors & Year	Treated Muscles/ Muscles Condition	Duration of One Session	Number of Sessions	Total Number of Sessions	Frequency/ Amplitude	System
Bellomo et al[26]	Bilateral vastus medialis, vastus lateralis and rectus femoris muscles/Relaxed	15 minutes	1 session per week for 8 weeks,	20	300 Hz	VISS
			3 sessions per week for the last 4 weeks			
Celletti et al[27]	Bilateral quadriceps/Contracted	30 minutes (for every 10 min of vibrations, there was a 1-min interval)	1 session/day, 3 consecutive days	3	100 Hz/ 0.2–0.5 mm	Cro® System
Ehsani et al[33]	Bilateral m. gastrocnemius/Contracted	1-min warm-up; 30 sec vibratory test; 2-min rest	One day	8	30–40 Hz/ 1 ±0.002 mm	Focal vibrator attached with Velcro straps to muscle' belly
Filippi et al[28]	TG1: Bilateral quadriceps/Contracted TG2: Bilateral quadriceps/Relaxed	30 minutes (for every 10 min of vibrations, there was a 1-min interval)	1 session/day, 3 consecutive days	3	100 Hz/ 0.2–0.5 mm	Cro® System
Rabini et al[29]	Bilateral quadriceps/ Contracted	30 minutes (for every 10 min of vibrations, there was a 1-min interval)	1 session/day, 3 consecutive days	3	100 Hz/ 0.2–0.5 mm	Cro® System
Tankisheva et al[30]	Bilateral m. quadriceps, m. gluteus maximus and m. gluteus medius/ Relaxed	30 minutes	5 day per week, consecutive per 6 months	120	25–45 Hz	Powerbox (custom-made vibration design)
Wanderley et al[31]	Bilateral Plantar region/ Relaxed	10 minutes	12 sessions over 5 weeks, rest period and further 12 sessions over 5 weeks	24	100 Hz/ 2 mm	Novafon SK2[c]
Yu et al[32]	Muscle belly of the Tibialis anterior tendon and/or the Achilles tendon/ Contracted	5 sec vibratory test, on one or two legs with eyes closed with and without vibration	One day	8	90 Hz/ 0.33mm	JA1

Table 3 The Results Effect of Focused Vibration on Balance and/or Risk of Fall Assessment: Between-Group Differences

Authors & Year	Outcome Parameters	Results							
Bellomo et al[26]	CoP sway area (mm^2)	T0 Eyes-open TG1: 7287.8±2402.4 TG2: 6962.4±1558.05 TG3: 7100.2±2920.5 CG: 6874.6±2351.3	T0 Eyes-closed TG1: 7287.8±2402.4 TG2: 6962.4±1558.05 TG3: 7100.2±2920.5 CG: 6874.6±2351.3	T1 Eyes-open TG1: 4436±1884.9 TG2: 6761.2±2301.1 TG3: 5927.4±2882.4 CG: 6941.5±1899.5	T1 Eyes-closed TG1: 4436±1884.9 TG2: 6761.2±2301.1 TG3: 5927.4±2882.4 CG: 6941.5±1899.5				
Celletti et al[27]	POMA (point)	T0 TGa:16.1±1.98 TGb:21.4±0.83 TGc:24.9±0.87 CGa:16.5±1.71 CGb:21.1±0.83 CGc:24.6±1.34	T1 TGa: 22.6±3.44 TGb: 26.74 ±1.34 TGc: 26.07±1.28 CGa: ° CGb: ° CGc: °	T2 TGa: 24.4 ±3.21 TGb: 27.16±1.84 TGc: 27.27±1.43 CGa: ° CGb: ° CGc: °					
Ehsani et al[33]	CoG sway area (cm^2)	T0 Eyes-open TG1: 0.40±0.27 TG2: 0.40±0.23 TG3: 0.58±0.43	T0 Eyes-closed TG1: 0.65±0.33 TG2: 0.54±0.33 TG3: 1.04±0.59	T1 Eyes-open 30Hz TG1:1.35± 0.99 TG2:0.74±0.27 TG3:1.15±1.08	T1 Eyes-open 40Hz TG1:1.29±0.71 TG2:0.92±0.40 TG3:0.85±0.60	T1 Eyes-closed 30Hz TG1:1.41±0.97 TG2:0.93±0.64 TG3:1.24±0.60	T1 Eyes-open 40Hz TG1:1.62±1.18 TG2:1.10±0.52 TG3:1.52±1.07		
Filippi et al[28]	CoP sway area (mm^2)	T0 TG1: 339±55 TG2: 325±59 CG: 329±56	T1 TG1: ° TG2: ° CG: °	T2 TG1: ° TG2: ° CG: °	T3 TG1: ° TG2: ° CG: °				
Rabini et al[29]	POMA (point)	T0 TG:18.60±4.90 CG:19.28±4.85	T1 TG:22.56±4.07 CG:19.08±3.75	T2 TG:24.36±2.96 CG:18.00±4.07					
Tankisheva et al[30]	mPPT (points), SWT (m)	T0 TG: 33.5 (28–36)†, 317.1 (180–469)† CG: 32.5 (25–36)†, 307.8 (188–447)†	T1 TG: 40.5±2.12, 313.3±39.4 CG: 32.6±2.87, 322.3±55.0						
Wanderley et al[31]	CoP sway area (cm^2)	T0 Eyes-open TG: 2.95±1.66 CG: 3.05±2.16	T0 Eyes-closed TG: 3.40±1.89 CG:3.44±2.22	T1 Eyes-open TG:2.26±1.21 CG:2.77±2.07	T1 Eyes-closed TG: 2.49±1.61 CG:3.32±2.16	T2 Eyes-open TG: 2.23±1.30 CG:2.95±1.74	T2 Eyes-closed TG:2.28±1.34 CG:3.55±1.56		
Yu et al[32]	CoP sway path (mm)	NVO TG1: 255.51 ±59.80 TG2: 220.49 ±39.75	CVO TG1: 191.90±40.67 TG2: 185.65±29.38	TATVO TG1: ° TG2: °	ATVO TG1: ° TG2: °	NVT TG1: 180.51±47.53 TG2: 150.33±30.57	CVT TG1: 124.42±36.78 TG2: 120.53±22.35	TATVT TG1: ° TG2: °	ATVT TG1: ° TG2: °

Notes: Values are expressed as mean ± SD or ranges in parentheses. °Indicated value not detectable, because just graphical. †Indicate range value (minimum and maximum).
Abbreviations: TG, treatment group; CG, control group; a, patient with high risk of falling; b, patient with moderate risk of falling; c, patient with low risk of falling; CoP, Centre of pressure; CoG, Center of gravity; POMA, performance-oriented mobility assessment; SWT, Shuttle walk test; mPPT, modified physical performance test; NVO, No vibration during one-legged stance; CVO, combined vibration to the Tibialis anterior tendon and Achilles tendon during one-legged stance; TATVO, Tibialis anterior tendon vibration during one-legged stance; ATVO, achilles tendon vibration during one-legged stance; NVT, no vibration during two-legged stance; CVT, combined vibration to the Tibialis anterior tendon and Achilles tendon during two-legged stance; TATVT, Tibialis anterior tendon vibration during two-legged stance; ATVT, achilles tendon vibration during two-legged stance.

stance test (OLS test), with open and closed eyes (EO/EC),[37] during which the subject was asked to remain in a unipodal position as long as possible, for both legs, up to a maximum of 30". Performance on the Functional Reach test was also assessed,[38] during which the subject stood with feet shoulder-width apart and arms extended in front of the body parallel to the floor. From this position, the subject displaced his or her body in a forward motion, with the hands open and arms extended as much as possible, without receiving additional support. In addition, Wanderley et al[31] used the Timed Up & Go test[39] to assess dynamic postural balance, during which the subject was instructed to rise from a chair (with a back but no arms), walk a distance of 3 m, turn 180°, and sit down on the

Table 4 Level and Methodological Quality of the Evidence of the Included Studies

Authors & Year	Level of Evidence	Study	Eligibility Criteria*	Random Allocation	Concealed Allocation	Baseline Comparability	Blind Subjects	Blind Therapists	Blind Assessors	More Than 85% Follow-Up	Intention to-Treat Analysis	Between Group Comparisons	Point Estimates and Variability	Total Score
Bellomo et al[26]	III	RTC	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	4/10
Celletti et al[27]	II	RTC	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7/10
Ehsani et al[33]	III	CS	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	4/10
Filippi et al[28]	II	RTC	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6/10
Rabini et al[29]	II	RTC	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	9/10
Tankisheva et al[30]	II	RTC	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes	6/10
Wanderley et al[31]	II	RTC	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	7/10
Yu et al[32]	III	CSS	Yes	No	No	Yes	No	No	No	Yes	No	Yes	Yes	4/10

Note: *This criteria item does not contribute to total score.
Abbreviations: RTC, randomized trial clinical; CSS, cross-sectional study; CS, clinical study.

chair again (a time longer than 13.5 seconds indicates an increased risk of falling among elderly subjects). Bellomo et al and Tankisheva et al[26–30] measured dynamic postural balance, respectively, using gait analysis (on a podobarographic platform, 4 meters long) and the shuttle walk test (SWT),[40] which is a standardized, incremental, submaximal field-walking test.

To assess balance, gait and the risk of falling, the included studies[27–29] used rating scales, such as the Performance-Oriented Mobility Assessment (POMA) scale.[41] Rabini et al[29] also evaluated physical performance using the short physical performance battery (SPPB)[42] and Western Ontario and McMaster Universities Arthritis Index (WOMAC) scores,[43] to quantify pain and functional limitations of the knee.

To evaluate leg muscle performance, Filippi et al[28] used the vertical jumping test,[44] quantified using a device that allows the direct measurement of jump time and vertical body displacement during the jump, whereas leg power was indirectly computed, considering body weight and wire displacement. Bellomo et al[26] evaluated the maximum isometric strength of each subject using a leg extension machine. After adjusting the position of each subject, to achieve a 90° knee angle and a 90° hip flexion angle, the subject was asked to perform a maximum contraction for 5 seconds. The measurement was repeated 3 times, with a 2-minute rest period between each test. The best result among the 3 tests was the maximal isometric force (ISOmax).

A total of 6 different vibration devices were used among the 8 included studies, each of which was associated with different FV frequency and amplitude characteristics and different treatment protocols. Celletti et al, Filippi et al and Rabini et al[27–29] all used the CroSystem device, consisting of an electromechanical transducer, mechanical support that was rigidly attached to the floor, and an electronic control device. A mechanical arm allowed the transducer to be placed on a muscle belly, using a specific "repeated Muscle Vibration" (rMV) protocol that generated a sinusoidal displacement at 100 Hz, 0.2–0.5 mm peak to peak. In contrast, Bellomo et al[26] used a Vibration Sound System® (Vissman s.r.l., Rome, Italy) device that administered focused mechano-acoustic vibrations using a turbine, with a flow rate of 35 m^3/hour, which was able to generate airwaves with a pressure of up to 250 mbar, and of a flow modulator, capable of vibrating air with a pressure of up to 630 mbar and a frequency of up to 980 Hz (a frequency within 300 Hz is recommended), producing mechano-acoustic waves.

Discussion

The purpose of this review was to assess the effects of FV on postural control and reductions in the risk of falling among the elderly population. This review, despite the few studies included, can demonstrate the positive effects of FV stimulus on balance, despite 1 study[30] that found that FV stimulation had no effects on the physical performance of postmenopausal women.

However, discrepancies in the vibratory parameters used were identified among the included studies. According to the experience reported by Filippi et al,[28] short applications and low frequencies are less effective than other protocols. Based on the studies that showed improvements in motor performance and balance, the FV stimulus must selectively stimulate the type Ia futsal afferents, using frequencies at 100 Hz and amplitudes from 0.2 to 0.5 mm.[45] These parameters were used by 5 of the included studies,[27–32] whereas type Ib and II afferent fibers can be recruited when larger amplitudes are used.[46] Several receptor structures have been reported to be sensitive to vibratory stimuli. Cutaneous receptors, such as Pacini, Merkel, Meissner, and Ruffini receptors, can be activated by FV at various frequencies, and the Golgi tendon organs are sensitive to the vibration of Ib afferents.[15]

However, various studies have shown that the most sensitive receptor structures are the neuromuscular spindles, which consist of primary (Ia), which are the most sensitive, and secondary (II) fiber afferents. The type Ia afferents are activated during small FV amplitudes, from 0.2 to 0.5 mm, and type I afferents respond to frequencies up to 120 Hz, proportionally, one by one, whereas the type Ib and II afferents respond to greater amplitudes, and the type II afferents are recruited from 20 to 60 Hz.[47] The responses of type Ia afferents are dependent on whether the muscle is stretched, relaxed, or contracted,[48] and type Ia afferents are more responsive to FV when the muscle is stretched and during voluntary isometric contractions.[27–29] Moreover, muscle spindle shots induced by FV excite not only motor neurons but also interneurons in the spinal cord, which reciprocally inhibit the motor neurons innervating antagonistic muscles.[49]

According to recent literature, the vibration-induced activation of spindles can induce the long-term reorganization of the central nervous system, if the primary spinal afferent activity is strong and prolonged.[47] Long-term effects were observed only when using high-intensity vibrations (100 Hz).[28] Long-term effects were not assessable for all included studies, as only 3 studies reported long-term follow-up (3 months).[27–29] Among these studies, the 100-Hz vibratory stimulus-induced stability improvements, which generally persisted after 3 months. In contrast, Bellomo et al[26] used 300-Hz stimulations with high-intensity frequencies and observed improvements; however, this study did not include long-term follow-up. Unusual parameters were reported for the studies performed by Tankisheva et al and Ehsani et al[30–33] who applied a frequency of 30–45 Hz. Tankisheva et al did not report any improvements in muscle strength or physical performance assessment,[30] whereas Ehsani et al detected improvements in balance after 1 month of follow-up.[33] Given the discordant results between the only 2 studies that used low-frequency FV parameters (from 25 to 45 Hz) Tankisheva et al and Ehsani et al,[30–33] we cannot conclude that low-frequency FV has positive effects. However, the limitations and poor quality of some of the included studies must be considered: in fact, this review included 3 articles with a PEDro score of 4 (fair quality), including 2 non-randomized articles (cross-sectional and clinical study)[32,33] and 1 randomized, clinical trial.[26] In general, FV appears to have positive effects on the postural stability of the elderly.

Postural control represents a complex motor skill, derived from the interactions among multiple sensorimotor processes, including primary contributions from the auditory, visual, and vestibular systems.[50] In general, healthy adults rely on somatosensory (70%), visual (10%), and vestibular (20%) information; however, when they stand on an unstable surface, they increase sensory weighting to prioritize vestibular and visual information and decrease their dependence on surface somatosensory inputs, for improved postural orientation.[51] Among the elderly population, these multiple sensory inputs may be insufficient or difficult to integrate; thus, poor vision, low handgrip strength, walking speed declines, the use of walking aids, drug use, and depression are recognized to be risk factors for falls among the elderly population.[9]

A person who is standing in an upright position can maintain balance thanks to small but continuous oscillations that are intended to counterbalance gravitational forces. The CoG represents the vertical projection onto the ground and the center of mass (CoM) of the body; CoP and CoG only coincide perfectly under static conditions when the moment of the muscular ankle articulation force equals the gravitational force.[52] Balance is only achieved when these 2 vectors are aligned along the vertical axis of the subject.

Therefore, 2 mechanical models can be used to describe postural dynamics: hip strategy, which depends on the mobilization of the CoG, and ankle strategy, which depends on the mobilization of the CoP. The ankle strategy, during which the body moves by using the ankle as a flexible, inverted pendulum, is appropriate for maintaining balance in response to small amounts of sway when standing on a firm surface. The hip strategy, during which the body exerts torque at the hips to quickly move the CoM, is used when persons stand on narrow or compliant surfaces that do not allow adequate ankle torque or when CoM must be moved quickly.[53] The purposes of these strategies are to obtain optimal vertical alignment, allowing the subject to maintain CoG within a support polygon. Accelerometers are used to evaluate CoM dynamic performance thank you to the sensitivity of these devices to small changes in postural control systems, and it allows us to identify early changes in spatiotemporal gait parameters.[54,55] Furthermore, Leirós-Rodríguez et al. They have shown that the accelerometric gait assessment can detect alterations in the balance during aging, by detecting differences in women between 51 and 80 years. Their results indicate that during the aging process the velocity and acceleration are reduced and thus the reduction in speed makes the subject more susceptible to falls.[56] This review included 3 studies[31–33] that focused on FV stimulation of the ankle and plantar muscles, whereas 5 studies[26–30] utilized the stimulation of the quadriceps muscles, to improve balance in an elderly population. The quadriceps muscles are extremely important for ADL, including standing up, sitting down, stair-climbing, and gait. Furthermore, several studies have investigated the effects of FV applications on quadriceps muscle strength, and the prolonged vibratory stimulation of the quadriceps femoris, both at 80 and 300 Hz, resulted in increased muscle strength, which persisted at follow-up, suggesting an underlying plastic process.[57,58]

Conclusion

This review suggests that FV can be an effective training method that can decrease the risk of falls, which is a major cause of dependency among older populations. The use of FV reduces the speed and displacement of CoP and improves the results on various tests of physical performance, which increases balance. FV may be used as an alternative to classical methods used for strength and proprioceptive training, such as whole-body vibration training. Moreover, FV does not require an active contribution from the subject and can directly target a specific muscle group, making it easier to implement for improved balance and reduced fall risk among the elderly population.

However, future studies should use strong methodological quality control, including the use of a control group with similar initial characteristics, provide for long-term follow-up, and be able to identify a single adequate and reproducible protocol, detailing all necessary parameters and times.

Disclosure

The authors report no conflicts of interest in this work.

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