

Effects of whole body vibration training on postural control in older individuals: A 1 year randomized controlled trial

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Abstract

This randomized controlled trial investigated the effects of a 12 month whole body vibration training program on postural control in healthy older adults. Two hundred and twenty people were randomly assigned to a whole body vibration group ($n = 94$), a fitness group ($n = 60$) or a control group ($n = 66$). The whole body vibration and fitness groups trained three times a week for 1 year. The vibration group performed exercises on a vibration platform and the fitness group performed cardiovascular, strength, balance and stretching exercises. Balance was measured using dynamic computerized posturography at baseline and after 6 and 12 months. Whole body vibration training was associated with reduced falls frequency on a moving platform when vision was disturbed and improvements in the response to toes down rotations at the ankle induced by the moving platform. The fitness group showed reduced falls frequency on the moving surface when vision was disturbed. Thus, whole body vibration training may improve some aspects of postural control in community dwelling older individuals.

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1. Introduction

Falls are a major problem in older individuals and around 30% of the community dwelling population over 65 falls each year [1]. This can result in functional impairment, serious injuries, fractures or even death. Poor balance is one of the few risk factors for falls that can improve with intervention. Advancing age is associated with impaired postural stability due to deficits in sensory function, central processing, neural pathways for motor control and musculoskeletal integrity [2].

Several studies have shown that training can improve balance in older persons. Most of these have included multidimensional exercise interventions directed towards strength, flexibility and aerobic capacity [3,4]. Visual feedback training [5], aerobic dancing [6] and exercise balls [7] can also enhance postural control. Some studies focusing on strength training alone did not show any positive effect on balance [8,9] and one trial [10] reported deterioration after 12 weeks of low volume strength training. In contrast, another provided evidence for improved postural sway in elderly after 18 months of strength training [11].

Whole body vibration (WBV) training might potentially be useful to enhance balance. The subject performs exercises on a platform that generates vertical sinusoidal vibrations.

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The mechanical stimuli are transmitted to the body where they stimulate the primary endings of the muscle spindles which in turn activate alpha-motor neurons resulting in muscle contractions [12,13]. Previous studies have shown that WBV is associated with increases in lower limb muscle strength [14–19] which is essential for postural stability. Because WBV provides a strong sensory stimulus that activates the muscle spindles [12,13], it might also enhance proprioception.

Torvinen et al. [17] showed improvements in postural sway on a sway platform after 4 min of WBV training in young adults yet no effects after 4 months of training [18]. Our earlier study reported reduced postural sway after a fast brief abduction of the arms in older women following 6 months of WBV [19]. Bruyere et al. reported an improvement in body balance score in the Tinetti Test after 6 weeks WBV training combined with physical therapy in institutionalized elderly people [20].

The current study is the first to evaluate the effects of a 12 month WBV program on balance, measured by dynamic computerized posturography. The results for a group that received WBV training were compared with a fitness group and a control group. Assuming that WBV training would enhance postural control via the tonic vibration reflex and sensory stimulation, we hypothesized that 1 year WBV training would improve balance in men and women over 60 to a greater extent than fitness training or no training.

2. Methods

2.1. Subjects

Subjects were locally recruited through newspaper advertisements, fliers, regional television programs and meeting groups and had to be between 60 and 80 years and

non-institutionalized. Exclusion criteria were diseases or medications known to affect bone metabolism or muscle strength and engagement in moderate intensity exercise programs for more than 2 h a week. People suffering from diabetes, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses or had an implant, bypass or stent were also excluded from the study. After an extensive medical screening where a physician checked the in- and exclusion criteria and where subjects performed a graded maximal ergometer test, 220 men and women were randomly assigned to one of three groups: two training groups, the WBV group ($n = 94$; 46 women, 48 men; 66.8 ± 0.5 years) or the fitness (FIT) group ($n = 60$; 30 women, 30 men; 66.8 ± 0.6 years), respectively, or a control (CON) group ($n = 66$; 30 women, 36 men; 67.8 ± 0.6 years). The study was approved by the University's Human Ethics Committee according to the declaration of Helsinki. All participants gave written informed consent.

3. Training programs

3.1. Whole body vibration group

The WBV group exercised on a vibration platform (Powerplate[®], Badhoevedorp, The Netherlands): squat, deep squat, wide stance squat, toes-stand, toes-stand deep, one-legged squat and lunge. Training load increased gradually according to the overload principle (as previously described [16]). Training characteristics are presented in Table 1. Initially, balance was trained indirectly by exercising on one leg, after 3 months by exercising as often as possible without using the handrail and after 6 months additionally the eyes were closed. The duration of one training session was maximum 40 min, including warming up and cooling down.

Table 1
Characteristics of the whole body vibration training program

Period (week)	Volume		Intensity		Modality	Number of series per exercise ^a								
	Duration of exercise (s)	Frequency (Hz)	Amplitude (high 5 mm/low 2.5 mm)	Rest (s)		a	b	c	d	e	f	g	h	
1 → 4	30	35	Low	60	Static	3	1							
5 → 9	45	40	High	60	Dynamic + static	3	1	1			1	1		
10 → 14	60	40	High	45	Dynamic	3	3	3	1		1	1		
15 → 19	60	40	High	45	8-seconds principle ^b	3	3	3	1		1	1		
20 → 24	60	30	High	30	8-seconds principle ^b	3	3	3	1		1	1		
Mid-tests (25 → 26)	30	30–35	Low	30	Dynamic + static	3	3	3	1		1	1		
25 → 29	30–45	35	High	30	Dynamic	3	3	3	1		1	1		
30 → 34	45–60	35	High	15	Dynamic	3	3	3	2		1	1	1	
35 → 39	60	35	High	15	8-seconds principle ^b	3	3	3	2	1	1	1	1	
40 → 44	60	35	High	15	8-seconds ^b + dynamic	3	3	3	2	1	1	1	1	1
Post-tests (45 → 47)	60	35–40	High	15	8-seconds ^b + dynamic	2	2	2	1	1	1	1	1	1

^a Exercises: (a) squat (knee angle 90°), (b) deep squat (knee angle 120–130°), (c) wide stance squat, (d) one-legged squat, (e) lunge, (f) toes-stand, (g) toes-stand deep, (h) moving heels.

^b 8-seconds principle: four repetitions going slowly up (2 s) and down (2 s), 8 s static performance, four repetitions going up and down, static performance until the end of the exercise.

3.2. Fitness group

The program consisted of cardiovascular, resistance, balance and flexibility exercises and lasted for approximately 1.5 h [16]. The guidelines of the American College of Sports Medicine (ACSM) for exercise prescription in older individuals were used to set up the intensity of the program [21]. The cardiovascular program (70–85% of the heart rate reserve) consisted of walking, running, cycling or stepping. The resistance program (1–2 sets with a load between 8 and 15 RM) consisted of exercises for the whole body, including leg press and leg extension (Technogym Systems[®], Gambotella, Italy). Balance was trained by exercises standing on one or two legs performed with the eyes open or closed on a firm or unstable surface. At the end of each session, the subjects performed some stretch exercises.

The WBV and FIT groups trained three times weekly during 1 year with at least one day of rest between the sessions. All sessions were held at the University training center and were closely supervised by qualified health- and fitness-instructors.

3.3. Control group

The subjects of the CON group were requested not to change their lifestyle during the study or to engage in any new type of physical activity.

4. Outcome measurements

Postural control was evaluated after 6 and 12 months using the Sensory Organization Test, Motor Control Test and Adaptation Test by using a computerized dynamic posturography platform (Equitest, Neurocom International Inc.[®]), which has been shown to be a reliable and valid tool to investigate different aspects of balance [22].

4.1. Sensory Organization Test (SOT)

The SOT Test measures the ability to make effective use of (or suppress inappropriate) visual, vestibular and proprioceptive information to maintain balance [23]. The support surface, visual surround, or both could be stable or sway-referenced, meaning that the support surface and/or visual surround moved in phase with the subject's sway resulting in inaccurate information delivered to eyes, feet and joints. The test consisted of six conditions: (C1) normal vision and support surface, (C2) eyes closed and normal support surface, (C3) sway-referenced vision and normal support surface, (C4) normal vision and sway-referenced support surface, (C5) eyes closed and sway-referenced support surface and (C6) sway-referenced vision and support surface. The SOT Test provides an equilibrium score (ES) (%) reflecting the amount of sway in anterior-posterior direction. The higher the score, the less the subject swayed [24]. Falls frequency was recorded in the

most challenging condition (C6) where subjects tended to fall or thus fail the trial frequently. The SOT Test has been shown to be reliable [24] and valid [25].

4.2. Motor Control Test (MCT)

The MCT Test measures the ability to coordinate automatic movement responses after unexpected forward and backward platform translations [23]. The subject was exposed to translations of two sizes adjusted to the subject's height to produce disturbances of equal size. A random delay between the trials prevented predicting the initiation of the platform movement. Latency (ms) and response strength ($^{\circ} \text{s}^{-1}$) of the active response were calculated. Latency is defined as the time between the onset of the translation and the onset of the subject's active responses to the platform movement. Response strength measures the amount of angular momentum imparted by the active force response to stop the induced sway and to move back to equilibrium and is based on the rate at which the position of the vertical force center changes immediately after the onset of an active force response. A lower response strength represented more adequate amplitude scaling.

4.3. Adaptation Test (ADT)

The ADT Test analyzes the adaptation of the motor system to platform rotations causing the subject's toes to go up or down [23]. In contrast with the perturbations in the MCT Test, the rotations at the ankle in the ADT Test do not cause a displacement of the center of mass of the subject. The subject was exposed to a series of five consecutive rotations for each type of rotation. The analysis delivered a non-dimensional sway energy score (SES) which quantified how well the subject minimized anterior-posterior sway after platform rotations and was based on the velocity and acceleration of the center of pressure [23]. A smaller SES represented the ability to react more efficiently.

5. Statistical analysis

One-way analysis of variance (ANOVA) was used to test for differences between the groups at baseline. The changes in the different balance parameters for all groups were analyzed by repeated measures ANOVA. Contrast analysis was used to assess between- and within-group differences. A Bonferroni correction adjusted the p -value in relation to the number of contrasts that were performed. A Chi-square Test was used to test for differences in falls frequency between the groups at baseline in C6 of the SOT Test. The McNemar Test analyzed the changes in falls frequency after 6 and 12 months. All analyses were executed using Statistica 6.1 (Statsoft Inc., Tulsa, OK, USA). The level of significance was set at $p \leq 0.05$.

6. Results

Two subjects assigned to the FIT group never started the training sessions (one person moved to another location and the other had an acute health problem). Eleven subjects (WBV = 6, FIT = 1, CON = 4) withdrew from the study for personal reasons unrelated to the trial. Another 16 subjects (WBV = 11, FIT = 4, CON = 1) dropped out because of health problems that, according to the physician, were unrelated to the training program. Seven subjects (WBV = 5, FIT = 2) discontinued because of knee pain.

The average overall adherence (number of exercise classes attended as a percentage of the total number of classes) to the training program was 87.9% in the WBV group and 86.5% in the FIT group. Only the results of subjects with a minimal compliance rate of 80% (at mid- and post-test) are reported. Therefore, data of 23 subjects (WBV = 11, FIT = 12) were not included in the analysis. No significant differences at baseline were found between the groups in age, body mass, body mass index, VO_{2max} (determined by a graded maximal ergometer test) and isometric knee extension strength (measured with isokinetic dynamometry) (Table 2).

As the effect of time was similar for both genders in all tests (no significant time by gender effect, $p < 0.05$), the result section focuses on the pooled data of men and women. At baseline, no significant differences were found between the groups for any of the measurements.

6.1. Sensory Organization Test (Table 3)

Subjects swayed more with increasing difficulty of the test condition (declining equilibrium scores (ES) from C1 to C6 when data from all groups were combined, $p < 0.001$). The overall analysis also showed that the ES changed over time (when all groups and all conditions were combined) ($p < 0.001$). ES increased significantly (i.e. sway decreased) across all groups between the pre-test and mid-test ($p < 0.001$), pre-test and post-test ($p < 0.001$) and mid-test and post-test ($p = 0.037$). No changes over time were observed in the conditions with stable platform (C1, C2 and C3). When the support surface was moving (C4, C5 and C6), the ES improved significantly from pre-test to mid-test and from pre-test to post-test. In C6 (Fig. 1), the number of failed trials decreased significantly in the WBV and FIT

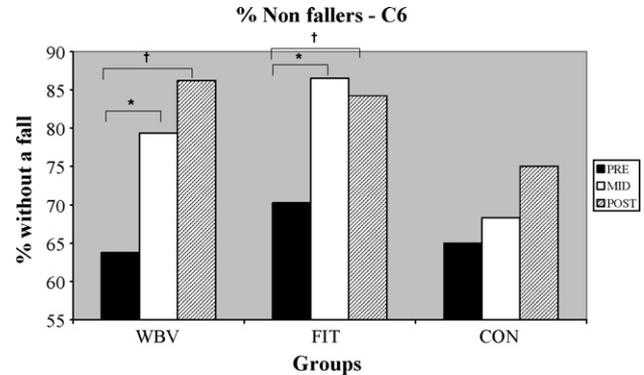


Fig. 1. Percentage of subjects without a fall in condition 6 of the SOT Test for the whole body vibration (WBV), fitness (FIT) and control (CON) groups at pre-, mid- and post-test. The McNemar Test for significance of change is used to analyse the change in fall frequency. Pre, baseline measures; mid, after 6 months; post, after 12 months. * $p < 0.05$ between pre- and mid-test, † $p < 0.05$ between pre- and post-test.

groups from pre-test to mid-test and pre- to post-test ($p < 0.05$). No significant changes were detected in the CON group (Table 3).

6.2. Motor Control Test (Table 4)

Latency did not change over time in three of the four translation conditions. Only in the forward translations of medium amplitude, latency increased significantly between pre-test and post-test ($p = 0.036$) and mid-test and post-test ($p = 0.016$) but this increase was observed in all groups. Training had no effect on latency for any condition. The response strength did not change significantly over time in any group for any condition (Table 4).

6.3. Adaptation Test (Table 5)

The response to rotations improved from trial 1 to trial 5 in the toes up ($p < 0.001$) and toes down conditions ($p < 0.001$). In the toes up condition, improvement in the sway energy score (SES) was seen over time from the pre-test to the mid-test ($p = 0.009$) and from the pre-test to the post-test ($p < 0.001$). In the toes down condition, SES improved significantly between pre-test and mid-test ($p = 0.036$), pre-test and post-test ($p < 0.001$) and mid-test and post-test ($p = 0.015$). In the toes up condition, the changes over time in SES were not different between the

Table 2

Subject characteristics of the whole body vibration (WBV), fitness (FIT) and control (CON) groups (mean \pm S.E.)

Characteristics	Mean \pm S.E.			p -Value ^a
	WBV ($n = 61; 29\text{♀}, 32\text{♂}$)	FIT ($n = 39; 17\text{♀}, 22\text{♂}$)	CON ($n = 61; 29\text{♀}, 32\text{♂}$)	
Age (years)	66.75 \pm 0.55	66.58 \pm 0.66	67.85 \pm 0.68	0.24
Body mass (kg)	75.94 \pm 1.60	75.15 \pm 2.12	75.32 \pm 1.39	0.94
Body mass index (kg m^{-2})	27.43 \pm 0.49	26.70 \pm 0.54	26.82 \pm 0.43	0.52
VO_{2max} ($\text{ml min}^{-1} \text{kg}$)	21.53 \pm 0.69	21.85 \pm 0.66	22.13 \pm 0.70	0.81
Isometric knee extension strength (Nm)	130.11 \pm 5.14	132.67 \pm 6.00	129.35 \pm 5.24	0.92

^a Results of one-way analysis of variance between pre-test-means of the WBV, FIT and CON groups.

Table 3

Equilibrium scores (%) of the SOT Test for the whole body vibration (WBV), fitness (FIT) and control (CON) groups at pre-, mid- and post-test (Mean ± S.E.)

	WBV		FIT		CON		p-Values	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Time	Time by group
C1: Normal vision and support surface							0.519	0.962
Pre	94.3	0.3	94	0.3	94.1	0.3		
Mid	94.2	0.3	93.9	0.3	94.1	0.3		
Post	94.2	0.3	94.1	0.4	94.2	0.3		
C2: Eyes closed and normal support surface							0.719	0.091
Pre	92.1	0.3	91.9	0.4	92.3	0.3		
Mid	92.2	0.3	92.5	0.4	92	0.4		
Post	92.4	0.3	92.6	0.3	91.8	0.4		
C3: Sway-referenced vision and normal support surface							0.61	0.545
Pre	91.7	0.5	91.9	0.5	91.4	0.4		
Mid	92	0.4	91.4	0.5	91.9	0.4		
Post	91.4	0.5	92.1	0.5	91.8	0.4		
C4: Normal vision and sway-referenced support surface							<0.001	0.297
Pre	78.6	1.2	79.5	1.3	80.3	1	<0.001 ^a	
Mid	83.3	1	82.3	1.1	83	0.8	<0.001 ^b	
Post	83.3	1.1	84	0.8	83.1	0.8	0.163 ^c	
C5: Eyes closed and sway-referenced support surface							<0.001	0.33
Pre	60.1	1.4	59.9	1.6	58.8	1.3	<0.001 ^a	
Mid	62.2	1.4	66.2	1.7	62.4	1.1	<0.001 ^b	
Post	64.1	1.6	66.9	1.8	63.5	1.2	0.105 ^c	
C6: Sway referenced vision and support surface							<0.001	0.955
Pre	58.7	1.7	61.2	1.8	60.1	1.6	<0.001 ^a	
Mid	62.4	1.5	63.8	1.7	62.3	1.4	<0.001 ^b	
Post	63.4	1.5	64.5	1.7	63.3	1.3	0.3 ^c	

Pre, baseline measures; mid, after 6 months; post, after 12 months.

^a Between pre- and mid-test.

^b Between pre- and post-test.

^c Between mid- and post-test when all groups and all conditions combined.

three groups although they were different in the toes down condition ($p = 0.040$) (Fig. 2), with a significant improvement in the WBV group between pre-test and mid-test ($p < 0.001$) and pre-test and post-test ($p < 0.001$). The SES of the FIT and CON group showed no significant changes over time. Compared to the CON group, the WBV group

showed significantly more improvement in SES between pre-test and mid-test ($p = 0.032$) (Table 5).

7. Discussion

This is the first randomized controlled study investigating the effect of a 1 year WBV training program on postural control as measured by dynamic computerized posturography. The results suggest that WBV training may contribute to improvements in some aspects of postural control in community dwelling individuals over 60 years of age. In line with previous data [26], sway increased when visual information was absent or disturbed and even more so when the support surface was disturbed. When the platform remained stable, the sway scores did not change significantly, possibly because these tests posed no challenge to postural control and may therefore not be sensitive to intervention. When the platform surface was disturbed, the sway score improved significantly and similarly for all groups. In the WBV and FIT groups, falls frequency was significantly reduced when the platform moved and vision was disturbed.

We did not find significant effects of WBV or exercise training on the performance of the SOT Test. It is possible that this test was not challenging enough for healthy older

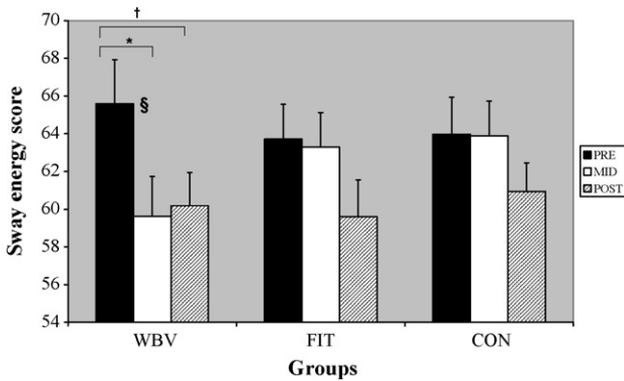


Fig. 2. Sway energy score for the toes down rotations for the whole body vibration (WBV), fitness (FIT) and control (CON) groups at pre-, mid- and post-test. Pre, baseline measures; mid, after 6 months; post, after 12 months. * $p < 0.05$ between pre- and mid-test, [†] $p < 0.05$ between pre- and post-test, [§] $p < 0.05$ when comparing the WBV group with the CON group between pre- and mid-test.

Table 4

Latency (ms) and response strength ($^{\circ} \text{s}^{-1}$) of the MCT Test for the whole body vibration (WBV), fitness (FIT) and control (CON) groups at pre-, mid- and post-test (Mean \pm S.E.)

	WBV		FIT		CON		<i>p</i> -Values	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Time	Time by group
Latency (ms)/response strength ($^{\circ} \text{s}^{-1}$)								
Medium backward								
Pre	137.3/96.2	1.8/2.4	140.4/95.3	2.6/3.5	138.3/93.6	2.1/2.9	0.882/0.500	0.848/0.224
Mid	138.4/98.7	2.1/2.5	136.9/101.9	2.7/2.2	139.8/90.9	2.1/2.9		
Post	139.4/95.8	2.1/2.6	137.2/98.6	2/3.2	139.3/97.8	1.6/2.8		
Medium forward								
Pre ^a	141.6/102.0	1.4/1.7	141.8/100.9	2.3/2.5	137.4/96.0	1.6/1.7	0.027/0.979	0.365/0.285
Mid ^b	136.9/101.3	1.8/2.0	141/102.4	2.3/1.7	138.7/96.6	1.5/2.4		
Post	143.8/103.0	2.0/1.9	144.1/100.6	2.4/1.7	143.4/96.7	1.6/1.6		
Large backward								
Pre	136.3/94.1	1.6/2.0	140/94.1	2.6/3.0	136.8/96.1	1.9/1.8	0.140/0.079	0.611/0.940
Mid	138.2/96.3	1.7/1.9	134.7/97.4	2/3.0	136.9/89.8	1.9/2.9		
Post	133.8/97.9	1.7/2.4	136/100.5	2/2.6	134.4/97.6	1.9/2.2		
Large forward								
Pre	140.0/101.5	1.8/1.9	137.9/99.6	2.6/2.8	136.8/95.3	2.1/1.8	0.742/0.581	0.622/0.985
Mid	137.8/99.8	2.1/1.6	141.3/99.2	2.7/2.3	139.1/94.0	2.1/2.4		
Post	140.4/100.6	2.1/1.5	139.6/97.7	2/1.5	138.3/94.2	1.6/1.4		

Pre, baseline measures; mid, after 6 months; post, after 12 months.

^a $p < 0.05$ between pre- and post-test.

^b $p < 0.05$ between mid- and post-test when all groups and all conditions combined (latency score).

persons to detect effects of training on postural sway. Gustafson et al. [27] suggested that the SOT Test does not detect subtle changes. Participants in the present study were healthy volunteers without any balance problems. Their baseline equilibrium scores were higher than age related American norms [23] (but lower than the scores of adults between 30 and 40 years, unpublished data). The SOT Test may potentially be more adequate to test and retest people

with sensory problems. However, the WBV group was more successful in performing the most challenging condition. This is consistent with the notion that WBV might potentially reduce falls frequency.

Falling has been associated with an age related decline of physiological factors such as muscle strength, proprioception and stability [28]. The improvement in muscular strength [14–19] after WBV training and the extensive

Table 5

Sway energy score of the ADT Test for the whole body vibration (WBV), fitness (FIT) and control (CON) groups at pre-, mid- and post-test (Mean \pm S.E.)

		WBV		FIT		CON	
		Mean	S.E.	Mean	S.E.	Mean	S.E.
Sway energy score							
Toes up							
All trials	Pre ^{a,b}	80.7	2.5	83.1	2.6	80.2	2.5
	Mid	74.4	2.4	80.5	2.8	79.2	2.6
	Post	73.6	2.2	79.4	3.0	76.9	2.5
Toes down							
All trials	Pre ^{a,b}	65.58	2.3	63.7	2.1	64	1.7
	Mid ^c	59.64	1.8	63.3	1.8	63.9	1.9
	Post	60.2	2.0	59.6	2.0	60.9	1.5
<i>p</i> -Values ^c							
Toes down	Pre-mid	<0.001 ^d		2.513		2.847	
	Pre-post	<0.001		0.087		0.109	
	Mid-post	1.982		0.082		0.069	

Pre, baseline measures; mid, after 6 months; post, after 12 months.

^a $p < 0.05$ between pre- and mid-test.

^b $p < 0.05$ between pre- and post-test.

^c $p < 0.05$ between mid- and post-test when all groups and all conditions combined.

^d $p < 0.05$ when comparing the WBV group with the CON group between pre- and mid-test.

^e *p*-Values, Bonferroni-corrected, regarding the changes over time in each group.

stimulation of the proprioceptive pathways might be partly responsible for the decrease in falls frequency found in the present study. Because the FIT group also showed a decreased number of failed trials, it might be that the exercise component (resulting in improved muscle strength) has most impact in both groups. Recently, the SOT Test was shown to be highly predictive of the falls risk in an older population [25]. Therefore, it would be important to confirm our findings in frail elderly, with an increased risk of falls.

All participants performed a series of anterior-posterior platform translations to investigate their ability to scale motor responses to the size of different perturbations. No meaningful changes over time in latency of their response were found. Perturbations caused by platform translations stimulate sensory receptors in joints, muscles and ligaments which, in turn, can activate reflex pathways. The receptors send afferent impulses to the dorsal part of the spinal cord where the direction and amplitude of the perturbation is encoded and the appropriate response is selected, initiated and sent directly to the appropriate muscles [29]. The results of the present study suggest that training has no effect on the velocity of this process. This is in line with Ledin et al. [30], who found no effect of 9 weeks balance training exercises on the latency of the response of the MCT Test. These authors suggested that latencies are merely monitors of stretch reflexes, nerve impulse transmissions and the time required to activate muscles around the ankles and therefore unlikely to be improved by training. In the present study there were no changes in response strength in any condition, suggesting that training has no effect on central processing, including encoding direction and amplitude of the translation and initiating the appropriate response.

Finally, we measured the response and adaptation of the motor system to recurrent platform rotations. This showed reduced responses to rotations during consecutive trials in all groups, indicating an ability of the automatic motor system to adapt to repeated platform rotations, possibly by reducing the resistance of the ankle joints. Vibration training improved the response to rotations in the toes down condition, with no significant changes in the FIT and CON groups. The improved performance in the WBV group is likely to be caused by the extensive sensory stimulation and a more efficient use of the proprioceptive feedback loop due to vibration training. Whether this improved reaction to rotations is also clinically significant cannot be answered.

Our study failed to show a significant benefit of any of the two training programs on most aspects of postural control. It has been recommended that training should target the visual, vestibular, somatosensory, motor and musculoskeletal systems involved in postural control, to enhance the functioning of the balance control system [7]. Although the training program of the WBV and FIT groups met these criteria, the improvements in balance were generally small. The present study did not analyze medio-lateral sway, which

might have shown different results. Moreover postural control improved in the control group, even though controls were asked not to change their activity levels. Our focus on healthy volunteers is likely to have attracted individuals with an active and healthy way of living.

The acceptance of the program by virtually all participants was encouraging. Overall, the sessions were experienced as pleasant and both socially and physically rewarding. All sessions were organised as group sessions and the vibration platforms were set up in a circle to increase the interaction between the participants. After the trial had been discontinued, most people expressed their willingness to continue to participate in this type of training, suggesting that vibration training is feasible, even over longer time periods, in healthy older individuals. In the current study, the rate of dropout (due to injuries and/or complaints possibly related to the training program) was slightly higher in the vibration training group (5%) than in the fitness group (3%). Because of the continuous load of the lower extremities in vibration training, it is not possible to skip some exercises of the program when suffering pain at the lower extremities. Thus, vibration training is not always appropriate for individuals with knee pain.

To conclude, whole body vibration training was associated with reduced falls frequency on a moving platform in the most challenging condition of the SOT Test. It was also associated with improved responses to support surface rotations. The positive effects of vibration training on muscle strength seen in previous studies [14–19], its short training time and the encouraging trends seen in the present study, support the need for future research of WBV in frail elderly individuals.

Conflict of interest

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Author Contributions: S. Verschueren had primary responsibility for the study concept and design. A. Bogaerts was in charge of the training sessions. A. Bogaerts and S. Verschueren were responsible for data collection and the preparation of the manuscript. C. Delecluse and S. Verschueren/A. Bogaerts were responsible for subject recruitment and for the design and supervision of the fitness training program and of the WBV training program, respectively. All authors contributed to the study concept and were involved in the interpretation of the results and

drafting of the report. They all have seen and approved the final version.

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