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Effects of whole body vibration training on cardiorespiratory fitness and muscle strength in older individuals (a 1-year randomised controlled trial)

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Abstract

Background: whole body vibration (WBV) training appears to be an efficient alternative for conventional resistance training in older individuals. So far, no data exist about the vibratory effect on cardiorespiratory fitness.
Objectives: this randomised controlled trial assessed the effects of 1-year WBV training on cardiorespiratory fitness and muscle strength in community-dwelling adults over the age of 60.
Methods: a total of 220 adults (mean age 67.1 years) were randomly assigned to a WBV group, fitness group or control group. The WBV group exercised on a vibration platform, and the fitness group performed cardiovascular, resistance, balance and stretching exercises. The control group did not participate in any training. Heart rate was measured during a single WBV session. Peak oxygen uptake (VO_{2peak}) and time-to-peak exercise (TPE) were measured during progressive bicycle ergometry. Muscle strength was assessed by a dynamometer.
Results: heart rate increased significantly during WBV training. After 1 year, VO_{2peak}, TPE and muscle strength increased significantly in the WBV and fitness groups. Both training groups improved similarly in VO_{2peak} and muscle strength. The fitness group improved significantly more in TPE than the WBV group.
Conclusion: WBV training in community-dwelling elderly appears to be efficient to improve cardiorespiratory fitness and muscle strength.

Keywords: *vibration training, cardiorespiratory fitness, muscle strength, older adults, elderly*

Introduction

Increased age is associated with a decline in cardiorespiratory fitness as well as in muscular performance [1, 2]. The maintenance of sufficient muscle strength and cardiorespiratory fitness is, however, important to function independently and to perform activities of daily living [3, 4]. Even in old age, progressive resistance training appears to enhance muscle strength [5, 6], and aerobic training at appropriate intensity can enhance cardiorespiratory fitness [7–9]. Unfortunately, progressive resistance training alone does not consistently change VO_{2peak} [10], and aerobic training on its own does not affect muscle mass and/or strength [11], suggesting that a combination of both types of training is needed. A significant proportion of older adults are, however, unable or unwilling to comply with two training regimens.

Whole body vibration (WBV) training might be an efficient 'combination' training method for older adults. WBV

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training is performed on a platform that generates vertical sinusoidal vibrations, stimulating muscle spindles and resulting in muscle contractions, comparable to the tonic vibration reflex (TVR) [12, 13]. Previously, we have shown that 6 month WBV training resulted in increased muscle strength in older women (58–74 years) to a similar extent as regular resistance training [14], supporting WBV as an alternative for conventional resistance training. To date, it is unclear whether WBV training provides sufficient cardiorespiratory stimulation to improve cardiorespiratory fitness in older adults in the long term. In healthy young adults, Rittweger found increased oxygen uptake and heart rate when squatting on a vibration platform, as compared to squatting without vibration [15, 16]. The increases in heart rate and oxygen uptake were only mild, arguing against stimulating effects on cardiorespiratory fitness in young subjects. Da Silva, however, found that vibration training provides cardiovascular stimuli similar to those experienced during moderate walking at 4 km/h [17]. In seated WBV, older and young adults showed an increase in heart rate and in oxygen uptake by 0.35 metabolic equivalent [18]. Squat exercises on a vibration plate (3s up-3s down) lead to a similar metabolic rate as cycling at 70 W [19]. Taking into account that the relative stress induced by the WBV programme on the cardiorespiratory system might be increased in elderly compared to young subjects, the metabolic rate induced by WBV might be potentially sufficient, when repeated frequently, to induce changes in cardiorespiratory fitness in the long term.

The current randomised controlled trial studied the long-term effect of WBV on cardiorespiratory and muscular strength in healthy, community-dwelling people over 60 years of age, and this compared to a regular fitness training group and a non-exercising control group. We hypothesise that WBV training may be capable of eliciting minor cardiorespiratory responses in older individuals but this to a lower extent than fitness training, where the load on the cardiovascular system is higher.

Methods

Subjects

Community-dwelling individuals aged between 60 and 80 years were locally recruited through newspaper advertisements, fliers and regional television programmes. Exclusion criteria were medications known to affect bone metabolism or muscle strength and engagement in moderate-intensity exercise programmes for more than 2 h a week in the past 2 years. Additionally, people suffering from diabetes, neuromuscular or neurodegenerative diseases, stroke, serious heart sicknesses or had an implant, bypass or stent were also excluded. After a medical screening by a physician, 154 subjects (78 men and 76 women) were randomly assigned (in a 1.5:1 ratio) to one of two training groups: the WBV group ($n = 94$, mean age 66.8 years) or the fitness (FIT) group ($n = 60$, 66.8 years). As this was the first 1-year WBV trial in older individuals, a higher dropout rate compared to other studies was expected, and therefore more subjects were assigned to the WBV group. A control (CON) group was recruited separately for a 'check-up of fitness status' programme ($n = 66$, 67.8 years). A power calculation (0.80) on the basis of the expected increase in muscle strength was performed to determine sample size.

Some subjects dropped out/stopped training for different reasons, mostly not related to training (Figure 1). A total of 214 subjects were finally included in the intention-to-treat analysis.

The study was approved by the University's Human Ethics Committee according to the declaration of Helsinki. All subjects gave written informed consent.

Interventions

The FIT and WBV groups trained three times weekly during 1 year. All sessions were held at the Leuven University Training Center and were closely supervised by qualified health and fitness instructors. The WBV and FIT training programmes were designed to improve muscle strength and not primarily cardiorespiratory fitness.

The WBV group performed exercises for upper and lower body on a vibration platform (Powerplate®, Amsterdam, The Netherlands). Sessions were organised as group sessions with vibration platforms set up in a circle. The duration of one session was maximally 40 min, including warming up and cooling down. Training load increased gradually according to the overload principle. To keep the compliance rate as high as possible and bring some variation, once a week 15 min of the WBV programme was performed in a more dynamic way; 15 s of traditional exercises on the platform were alternated with 15 s stepping on and off the vibrating platform (see Appendix 1 in the supplementary data available at *Age and Ageing* online).

The FIT programme consisted of cardiovascular, resistance, balance and flexibility exercises and lasted between 60 min in the beginning and 90 min in the end of the study. The guidelines of the American College of Sports Medicine [20] for exercise prescription in older individuals were used to set up the intensity of the programme (see Appendix 2 in the supplementary data available at *Age and Ageing* online).

The CON group was repeatedly advised not to change their lifestyle or physical activity during the project. They participated in an 'assessment only' condition. The Flemish Physical Activity Computerized Questionnaire was used to determine lifestyle and activity patterns [21].

Outcome measurements

All subjects were tested at baseline and after 12 months.

To investigate the cardiovascular load of a single vibration session, heart rate was measured in a subset of individuals of the WBV group ($n = 10$) during a vibration training in week 32 (Polar®, Tampere, Finland).

Cardiorespiratory fitness was assessed on an electronically braked cycle ergometer (Lode-Excalibur®, Groningen, The Netherlands) using an incremental protocol to

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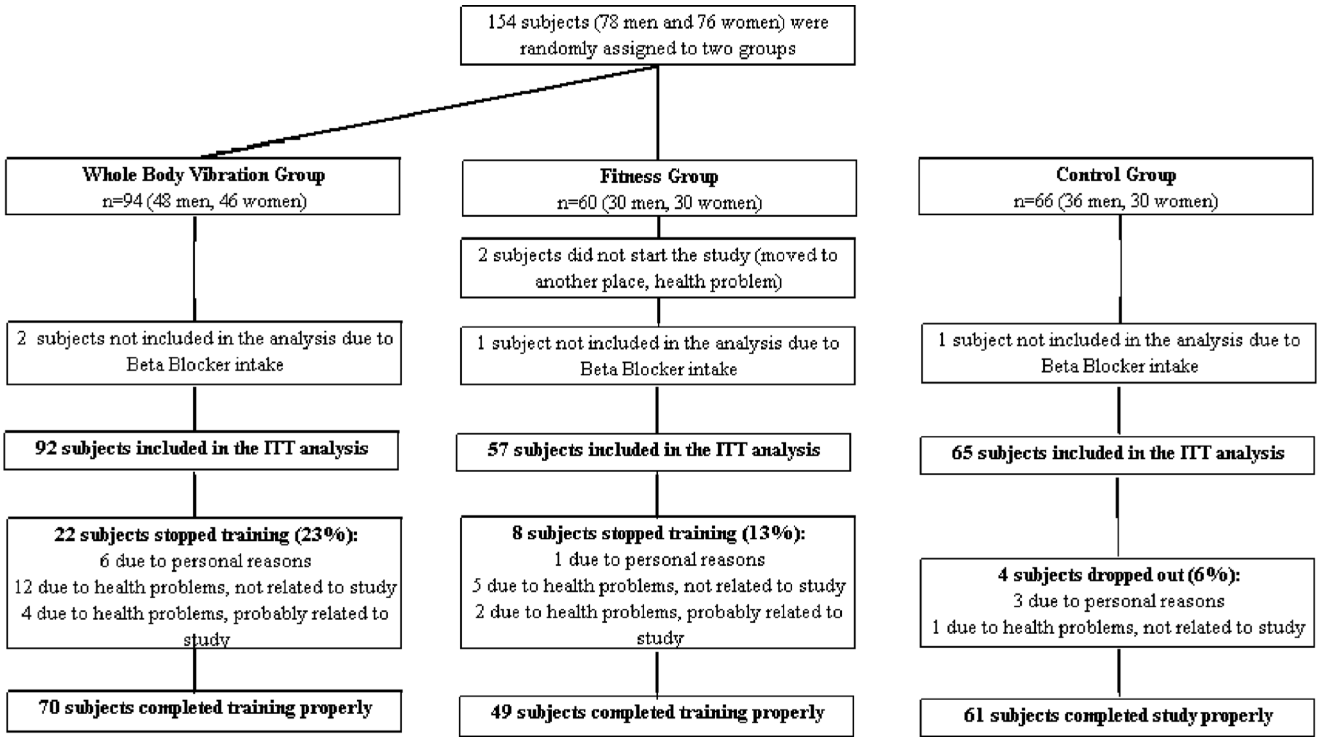

Figure 1. Flow of subjects.

voluntary exhaustion under the supervision of a physician and with continuous 10-lead ECG (Cardiolyzer Ultra®, Leipzig, Germany). The initial power output was 20 W and increased by 20 W every minute with a maintained pedalling frequency of 70 revolutions per minute. Expired gas analysis was acquired with computerised open-circuit spirometry (Cortex Biophysik Metalyzer 3B diagnostic®, Leipzig, Germany). Peak oxygen uptake (VO_{2peak}) ($ml*kg^{-1}*min^{-1}$) and time to peak exercise (TPE) (seconds) were used for analysis. VO_{2peak} was defined as the highest value of oxygen uptake during the last 30 s of the exercise testing.

Isometric knee extension strength was tested on a dynamometer (Biodex®, Shirley, NY, US). The testing protocol has been described previously in more detail [14]. The subjects performed two isometric contractions (knee joint angle of 120°) of 5 s, with a rest period of 10 s between the two trials. The highest torque (Nm) was used for analysis.

Statistical analysis

One-way analysis of variance (ANOVA) was used to test for differences between the groups at baseline. The changes in VO_{2peak}, TPE and isometric muscle strength over time for the WBV, FIT and CON groups were analysed by repeated measures ANOVA. Contrast analysis was used to assess between- and within-group differences. A Bonferroni correction adjusted the P-values according to the number of comparisons that were performed. All analyses were executed using Statistica 6.1 (Statsoft®, Tula, OK, US). The level of significance was set at $P \leq 0.05$.

Results

The compliance of the subjects to the training (5×/2 weeks) was 87.9% in the WBV group and 86.0% in the FIT group. The baseline characteristics of the 214 subjects who were included in the intention-to-treat analysis are presented in Appendix 3 in the supplementary data available at *Age and Ageing* online. No significant baseline differences were found between the groups (all $P > 0.05$).

Regarding the WBV group, no adverse side-effects were reported.

Outcome measurements

Heart rate increased significantly up to 62% of heart rate reserve (HRR) in a traditional vibration session and up to 80% of HRR in a more dynamic training session ($P < 0.05$) with an average of 41% and 59% of the HRR during 25 min in a traditional and 31 min in a more dynamic WBV session (Figure 2).

VO_{2peak} increased significantly over time [$F(1) = 296.024$, $P < 0.001$], but the increase was different between groups [$F(2) = 14.745$, $P < 0.001$] (Figure 3). Whereas VO_{2peak} increased significantly in all groups ($P < 0.001$), the increase in VO_{2peak} of the WBV (+18.2%) and FIT (+21.0%) groups was similar ($P = 0.588$) and significantly larger than that of the CON group (+8.4%) (both $P < 0.001$).

TPE also increased significantly over time [$F(1) = 109.119$, $P < 0.001$] (Figure 3). This increase was different between the three groups [$F(2) = 25.357$, $P < 0.001$]. TPE improved significantly in the WBV group (+8.6%, +40 s,

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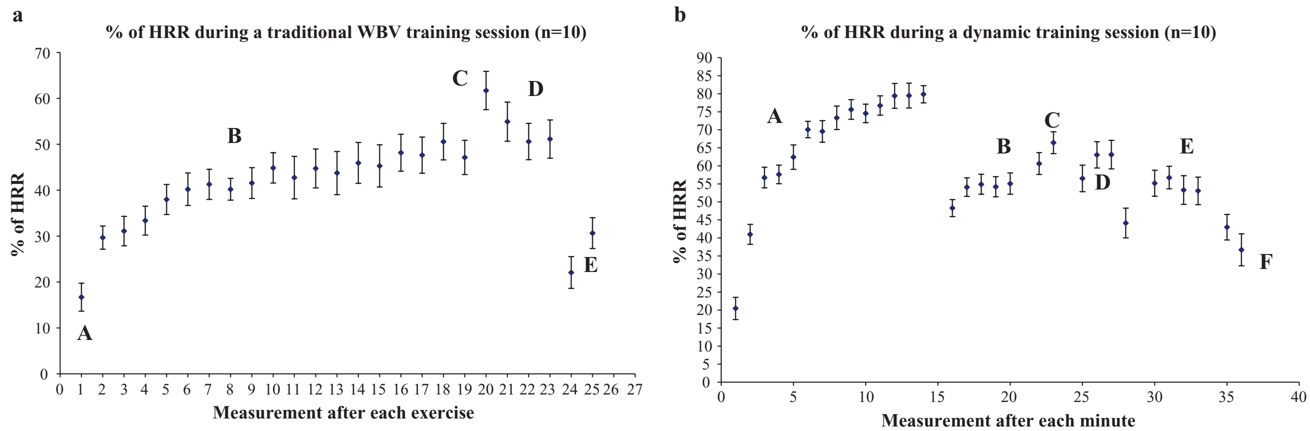

Figure 2. Heart rate, expressed as a% of the heart rate reserve (HRR, calculated with the formula of Karvonen) for a subset of the whole body vibration group. Heart rate was measured during a traditional training session (a) and during a dynamic training session (b) in week 32. (a) Heart rate was measured with a Polar Smart Heart Rate Monitor Set® after each exercise, each exercise lasted for 60 s and rest in between the exercises was 15 s. A: warming up, B: exercises for the lower limb muscles, C: exercise for the upper limb (biceps curl), D: exercise for the abdominals, E: cooling down. (b) Heart rate was measured each minute with a Polar Smart Heart Rate Monitor Set®. A: dynamic exercises, B: exercises for the lower limb muscles, C: exercise for the upper limb (biceps curl), D: exercise for the abdominals, E: exercises for the lower limbs, F: cooling down.

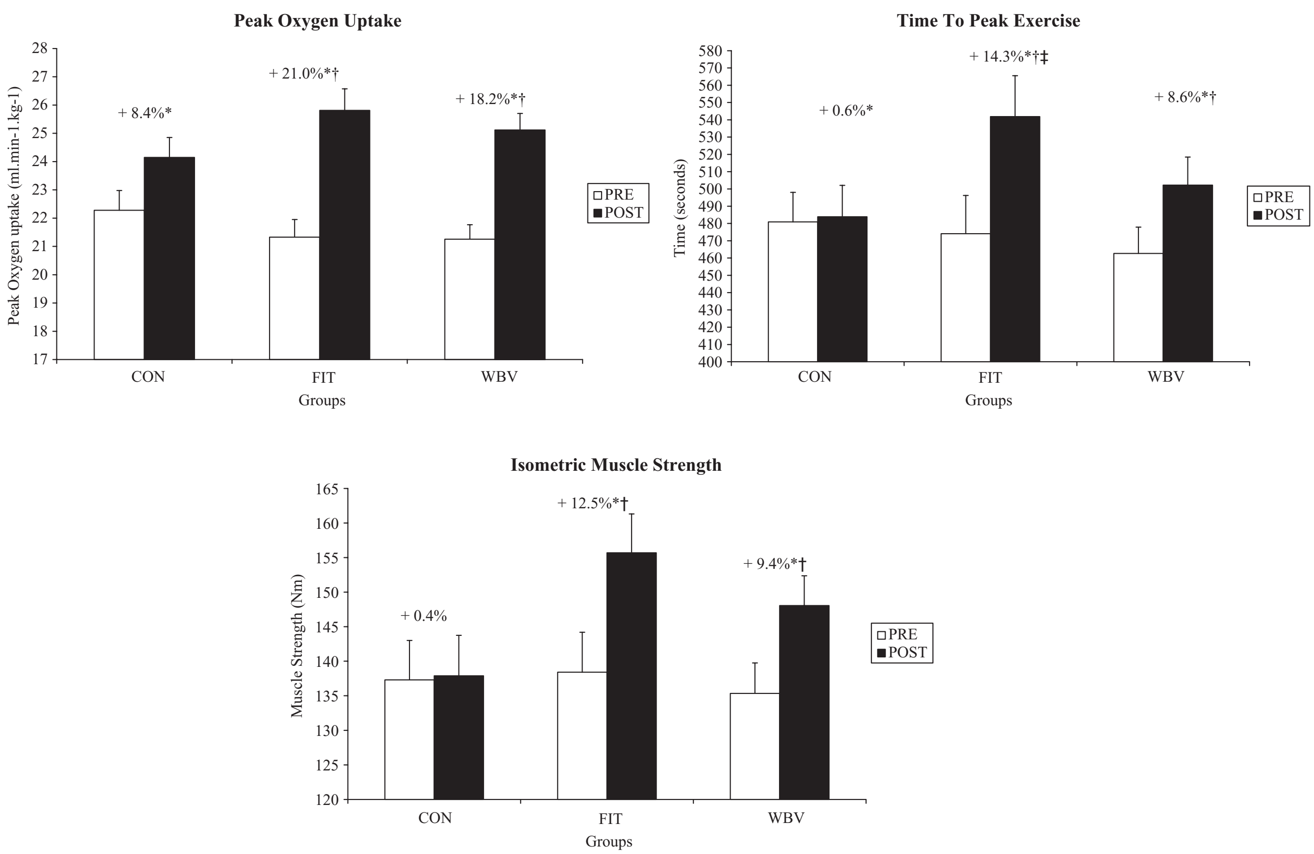

Figure 3. Peak oxygen uptake (ml*min^{-1}*kg^{-1}), time to peak exercise (seconds) and isometric knee extension muscle strength (Nm) of the Control (CON), fitness (FIT) and whole body vibration (WBV) groups at baseline (pre-test) and after 1 year (post-test). Results are expressed as means ± standard errors. Results of repeated measures ANOVA, level of significance set at $P = 0.05$. *Significant change from pre- to post-test. †Significant difference over time compared to the CON group. ‡Significant difference over time between the WBV and FIT groups.

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$P < 0.001$) and in the FIT group (+14.3%, +68 s, $P < 0.001$), but not in the CON group (+0.6%, +3 s $P = 0.625$). The increase in TPE in the WBV and FIT groups was significantly larger than in the CON group ($P < 0.001$). The TPE in the FIT group increased significantly more than in the WBV group ($P = 0.003$).

Isometric muscle strength (Figure 3) increased significantly over time [$F(1) = 54.957$, $P < 0.001$], and this increase was different between groups [$F(2) = 12.167$, $P < 0.001$]. Muscle strength improved significantly in the WBV group (+9.4%, $P < 0.001$) and in the FIT group (+12.5%, $P < 0.001$) but not in the CON group (+0.4%, $P = 0.841$). The increase in muscle strength was similar in the WBV and FIT groups ($P = 0.513$) and larger than in the CON group (both $P < 0.001$).

Discussion

To the best of our knowledge, this is the first report on the long-term effects of WBV training on the cardiovascular and muscular system in community-dwelling men and women over the age of 60. WBV training resulted in an increased VO_{2peak} (+18.2%, with a net gain of 9.8% compared to the CON group) and TPE (+8.6%) during progressive bicycle ergometry. Additionally, consistent with previous studies [14, 22], a positive effect on muscle strength was found.

To elicit significant improvements in $VO_{2peak,}$ heart rate during training should be between 40 and 50 to 85% of HRR, for a minimum of 20 min, with a training frequency of 3–5 days a week, according to the ACSM recommendations [20]. The subjects of the FIT group trained three times weekly for about 40 min at an intensity of 70–85% of the HRR, resulting in 21.0% improvement in VO_{2peak}. During WBV, heart rate increased significantly up to 62% of HRR in a traditional vibration session and up to 80% of HRR in a more dynamic training session. Taking into account the rest periods between the exercises, target training heart rates of more than 40% HRR were reached for less than 20 min per static vibration session. Nevertheless, a significant improvement in VO_{2peak}/TPE was observed in the WBV group, suggesting that the relative cardiovascular load of the WBV programme was high enough to induce changes in the long term. However, in line with our hypothesis, the training effect of the FIT group for TPE (not for VO_{2peak}) was significantly larger than that of the WBV group, as the FIT group performed a specific cardiovascular programme for 40 min.

Currently, we can only speculate about the adaptive mechanisms leading to the enhanced VO_{2peak} following WBV training. In the literature, the improvement in cardiorespiratory fitness after strength training or after local electrical stimulation is attributed to improvements in peripheral components of the cardiovascular system (e.g. enhanced vascular function and increased blood flow to the active skeletal muscle (also described for WBV [23]) and/or to improvements in skeletal muscle function and morphology (e.g. hypertrophy, increase in capillary density, capillary-to-fibre ratio and oxidative enzyme activity) [24–27]. All these adaptations, some of them already shown following WBV [22, 23], may result in enhanced capacity for transporting and utilising oxygen in the muscle and improve VO_{2peak}. For instance, vibration-induced hypertrophy [22] may account for improved VO_{2peak}, as the reduction in muscle mass associated with ageing accounts for a large proportion to the decline in VO_{2peak} [28].

Limitations

Our study has limitations, and the results must be interpreted in the context of its design. Our results may not be generalised to the overall older population, as the subjects were healthy community-dwelling elderly, with no significant health problems and thus not a representative sample of the general older population. Further research with more specific measurements (e.g. oxygen uptake during vibration training) is required to identify the cardiorespiratory effect of vibration training in young and older individuals, based on varying vibration characteristics (frequency and amplitude). Despite the fact that the CON group was asked not to change the activity level during the study (confirmed by the unaltered Flemish Physical Activity Computerized Questionnaire, $P = 0.909$), the CON group did show an improvement in VO_{2peak}, although significantly less than the training groups. Possibly, subjects may not have reached their real maximal oxygen uptake in the pretest, and the improvement in maximal oxygen uptake in all groups may partly be due to a familiarisation effect with the test set-up. However, maximal heart rate at the end of the ergometer test showed no significant change from pre- to post-test in the CON group ($P = 0.155$).

Although the total dropout rate appears to be higher in the WBV group (23%) than in the FIT and CON groups, this may not be interpreted that the WBV training programme is not feasible. The dropouts in the WBV group are mostly by coincidence and not related to the training programme.

In our eyes, it is not acceptable to recruit subjects for a 'health improving exercise intervention' and afterwards assign them to a CON group that is not allowed to start exercises. Therefore, the CON group was recruited separately. Although this could have produced a bias, the baseline characteristics of the three groups are not different suggesting comparable groups.

No placebo group performing exercises without vibration was included in the study. However, Rittweger and coworkers detected increased oxygen uptake when squatting on a vibration platform, compared to squatting without vibration, showing that the additional load of the cardiovascular system is due to the vibration stimulus [29].

Practical implications

The present study shows that WBV may provide a clinically meaningful stimulus to the cardiorespiratory and muscular systems in the older population. The results of this study, the low dropout rate related to training and the high compliance rate, underscore the feasibility of WBV training in community-dwelling individuals. Overall, subjects in the

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WBV group did not experience the training sessions as a hard strenuous work out, in contrast with the FIT group. WBV training minimises the need for conscious exertion and stress on the musculoskeletal, respiratory and cardiovascular systems, with a much shorter training programme (0.5 h) in comparison with a traditional fitness programme (±1.5 h). In this regard, the WBV training programme with its specific features used in the present study can be proposed as an efficient, non-exhausting alternative for a conventional FIT training programme to enhance muscle strength and cardiorespiratory fitness in older individuals. Whether this improvement is sufficiently large for subjects to improve their capacity to perform activities of daily living and to improve quality of life remains to be clarified.

Key points

- Heart rate is significantly increased during WBV training in men and women between 60 and 80 years of age.
- One-year WBV training in older individuals leads to significant enhancements in VO_{2peak}, TPE and isometric muscle strength.
- The increases in VO_{2peak} and isometric muscle strength due to vibration training were comparable with the increases found after following an equal number of fitness training sessions. Probably due to the specificity of their training programme, the subjects of the fitness group improved significantly more in TPE than the subjects of the WBV group.

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Conflicts of interest

None.

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Supplementary data

Supplementary data are available at *Age and Ageing* online.

References

1. Hawkins S, Wiswell R. Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. Sports Med 2003; 33: 877–88.
2. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 1998; 30: 992–1008.
3. Fleg JL, Morrell CH, Bos AG *et al.* Accelerated longitudinal decline of aerobic capacity in healthy older adults. Circulation 2005; 112: 674–82.
4. Kostka T, Rahmani A, Berthouze SE *et al.* Quadriceps muscle function in relation to habitual physical activity and VO_2max in men and women aged more than 65 years. J Gerontol A Biol Sci Med Sci 2000; 55: B481–8.
5. Morganti CM, Nelson ME, Fiatarone MA *et al.* Strength improvements with 1 yr of progressive resistance training in older women. Med Sci Sports Exerc 1995; 27: 906–12.
6. Vincent KR, Braith RW, Feldman RA *et al.* Improved cardiorespiratory endurance following 6 months of resistance exercise in elderly men and women. Arch Intern Med 2002; 162: 673–8.
7. Seals DR, Hagberg JM, Hurley BF *et al.* Endurance training in older men and women. I. Cardiovascular responses to exercise. J Appl Physiol 1984; 57: 1024–9.
8. Kohrt WM, Malley MT, Coggan AR *et al.* Effects of gender, age, and fitness level on response of VO2max to training in 60–71 yr olds. J Appl Physiol 1991; 71: 2004–11.
9. Hagberg JM, Graves JE, Limacher M *et al.* Cardiovascular responses of 70- to 79-yr-old men and women to exercise training. J Appl Physiol 1989; 66: 2589–94.
10. Alway SE, Coggan AR, Sproul MS *et al.* Muscle torque in young and older untrained and endurance-trained men. J Gerontol A Biol Sci Med Sci 1996; 51: B195–201.
11. Hurley BF, Seals DR, Ehsani AA *et al.* Effects of high-intensity strength training on cardiovascular function. Med Sci Sports Exerc 1984; 16: 483–8.
12. Burke D, Schiller HH. Discharge pattern of single motor units in the tonic vibration reflex of human triceps surae. J Neurol Neurosurg Psychiatry 1976; 39: 729–41.
13. Hagbarth KE, Eklund G. Tonic vibration reflexes (TVR) in spasticity. Brain Res 1966; 2: 201–3.
14. Roelants M, Delecluse C, Verschueren SM. Whole-body-vibration training increases knee-extension strength and speed of movement in older women. J Am Geriatr Soc 2004; 52: 901–8.
15. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000; 20: 134–42.
16. Rittweger J, Ehrig J, Just K *et al.* Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. Int J Sports Med 2002; 23: 428–32.
17. Da Silva ME, Fernandez JM, Castillo E *et al.* Influence of vibration training on energy expenditure in active men. J Strength Cond Res 2007; 21: 470–5.
18. Cochrane DJ, Sartor F, Winwood K *et al.* A comparison of the physiologic effects of acute whole-body vibration exercise in young and older people. Arch Phys Med Rehabil 2008; 89: 815–21.
19. Cochrane DJ, Stannard SR, Sargeant AJ *et al.* The rate of muscle temperature increase during acute whole-body vibration exercise. Eur J Appl Physiol 2008; 103: 441–8.

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20. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription, 7th edition. Baltimore: Lippincott Williams & Wilkins, 2005; 223–30.
21. Matton L, Wijndaele K, Duvigneaud N *et al.* Reliability and validity of the Flemish Physical Activity Computerized Questionnaire in adults. Res Q Exerc Sport 2007; 78: 293–306.
22. Bogaerts A, Delecluse C, Claessens AL *et al.* Impact of whole-body vibration training versus fitness training on muscle strength and muscle mass in older men: a 1-year randomized controlled trial. J Gerontol A Biol Sci Med Sci 2007; 62: 630–5.
23. Kerschan-Schindl K, Grampp S, Henk C *et al.* Whole-body vibration exercise leads to alterations in muscle blood volume. Clin Physiol 2001; 21: 377–82.
24. Haykowsky M, McGavock J, Vonder Muhll I *et al.* Effect of exercise training on peak aerobic power, left ventricular morphology, and muscle strength in healthy older women. J Gerontol A Biol Sci Med Sci 2005; 60: 307–11.
25. Frontera WR, Meredith CN, O'Reilly KP *et al.* Strength training and determinants of VO2max in older men. J Appl Physiol 1990; 68: 329–33.
26. Banerjee P, Caulfield B, Crowe L *et al.* Prolonged electrical muscle stimulation exercise improves strength and aerobic capacity in healthy sedentary adults. J Appl Physiol 2005; 99: 2307–11.
27. Mohr T, Andersen JL, Biering-Sorensen F *et al.* Long-term adaptation to electrically induced cycle training in severe spinal cord injured individuals. Spinal Cord 1997; 35: 1–16.
28. Fleg JL, Lakatta EG. Role of muscle loss in the age-associated reduction in VO2 max. J Appl Physiol 1988; 65: 1147–51.
29. Rittweger J, Schiessl H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. Eur J Appl Physiol 2001; 86: 169–73.

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