J Rehabil Med 2010; 42: 866–872

ORIGINAL REPORT

EXPLORING THE EFFECTS OF A 20-WEEK WHOLE-BODY VIBRATION TRAINING PROGRAMME ON LEG MUSCLE PERFORMANCE AND FUNCTION IN PERSONS WITH MULTIPLE SCLEROSIS

Tom Broekmans, MSc[1,2], Machteld Roelants, PhD[1], Geert Alders, MSc[1], Peter Feys, PhD[1,2], Herbert Thijs, PhD[1,3] and Bert O. Eijnde, PhD[1,2]

From the [1]REVAL Rehabilitation & Healthcare Research Center, Department Healthcare, PHL-University College, [2]Biomedical Research Institute, Hasselt University and [3]Interuniversity Institute for Biostatistics and Statistical Bioinformatics, Hasselt University, Diepenbeek and Katholieke Universiteit Leuven, Leuven, Belgium

Objective: **To investigate the acute effects of long-term whole-body vibration on leg muscle performance and functional capacity in persons with multiple sclerosis.**
Design: **A randomized controlled trial.**
Subjects: **Twenty-five patients with multiple sclerosis (mean age 47.9±1.9 years; Expanded Disability Status Scale 4.3±0.2) were assigned randomly to whole-body vibration training (*n*=11) or to a control group (*n*=14).**
Methods: **The whole-body vibration group performed static and dynamic leg squats and lunges on a vibration platform (25–45 Hz, 2.5 mm amplitude) during a 20-week training period (5 training sessions per 2-week cycle), and the control group maintained their usual lifestyle. PRE-, MID- (10 weeks) and POST- (20 weeks) knee-muscle maximal isometric and dynamic strength, strength endurance and speed of movement were measured using isokinetic dynamometry. Function was determined through the Berg Balance Scale, Timed Up and Go, Two-minute Walk Test and the Timed 25-Foot Walk Test.**
Results: **Leg muscle performance and functional capacity were not altered following 10 or 20 weeks of whole-body vibration.**
Conclusion: **Under the conditions of the present study, the applied 20-week whole-body vibration exercise protocol did not improve leg muscle performance or functional capacity in mild- to moderately impaired persons with multiple sclerosis during and immediately after the training programme.**

Key words: whole-body vibration; exercise; training; multiple sclerosis.

J Rehabil Med 2010; 42: 866–872

Correspondence address: Tom Broekmans, REVAL Rehabilitation & Healthcare Research Center, Dpt. Healthcare, PHL University College, Agoralaan Building A, BE-3590 Diepenbeek, Belgium. E-mail: tom.broekmans@uhasselt.be

Submitted December 14, 2009; accepted July 8, 2010

INTRODUCTION

Multiple sclerosis (MS) is a progressive inflammatory and degenerative disease of the central nervous system (1). The most prevalent symptoms are sensory changes, fatigue, balance disorders, spasticity, motor weakness and impaired muscular performance (2, 3). As a result, many persons with MS exhibit poor functional capacity and reduced quality of life (4). A considerable part of these symptoms may also result from a disease-related inactive lifestyle, which, at least in part, is reversible through physical exercise (5, 6). Contrary to earlier beliefs, aerobic exercise and resistance training to date have been shown to be well tolerated and able to induce beneficial effects in patients with MS (3, 6). Depending on the degree of disability, however, patients with MS may experience difficulties in performing conventional aerobic exercises and resistance training.

Because positive training results in various sports, fitness and geriatric rehabilitation have been demonstrated (7) and because the unloaded static and/or dynamic exercises performed usually require a limited active range of motion, whole-body vibration (WBV) exercise may be an interesting alternative exercise mode for upper motor neurone disorders. During WBV the vertical platform vibrations induce involuntary muscle contractions that are initiated by sensory receptors and reduce the recruitment threshold of motor units (8). This probably results in a more rapid activation of high-threshold fast-twitch muscle fibres (9, 10). In keeping with the WBV working mechanism suggested above, it has already been tested in stroke (11) and cerebral palsy (12). Because MS is, amongst others, associated with an impaired ability fully to activate motor units during voluntary contractions, decreased maximal motor unit firing rates and reduced average muscle fibre cross-sectional area (13–15), WBV exercise may be a promising strength-training method specifically for people with MS. Hence, to date, vibration platforms are increasingly used in MS rehabilitation centres and clinical practices, although supporting evidence is lacking. Minor acute effects on postural control and functional mobility and a trend towards a higher leg muscle peak torque after a single WBV session in patients with MS have been reported (16,17), but effects after longer-term training remain largely unexplored. To our knowledge, so far the latter has only been investigated by Schyns et al. (18), who performed a longer-term 4-week randomized cross-over pilot study in 16 people with MS. They reported that additional WBV training had no additional benefits on muscle strength

 doi: 10.2340/16501977-0609
Journal Compilation © 2010 Foundation of Rehabilitation Information. ISSN 1650-1977

and functional performance compared with exercise alone; however, patients reported fewer spasms (18). Four weeks of WBV exercise may have been too short to, on the one hand, induce neural muscle adaptations leading to increased muscle performance and functionality, and on the other hand, progressively increase training volume and training intensity to create an adequate training overload during the intervention period. Furthermore, Schyns et al. (18) investigated the additional effects of WBV compared with the performance of exercises alone, which may obscure minimal effects induced by the vibration to some extent. The effect of WBV compared with no intervention remains unknown.

For the above-mentioned reasons and because long-term WBV in sedentary healthy people exerted marked improvements in a wide variety of muscle strength and functional parameters (19–21), the present study investigated the effects of a 20-week WBV training programme on leg performance and overall functional capacity in mild- to moderately impaired MS patients.

METHODS

Subjects

After being informed of all the experimental procedures to be undertaken, 29 ambulatory community-based patients with MS residing in the Hasselt region volunteered (written informed consent) to participate in this study (see Fig. 1). Exclusion criteria on admission were: (*i*) > 3 relapses in the preceding 1 year or > 1.0 Expanded Disability Status Scale (EDSS) increase in the preceding 1 year; (*ii*) corticosteroid treatments 28 days before the study start; (*iii*) pregnancy; (*iv*) severe psychiatric disorders; (*v*) internal fracture materials and/or (total) joint replacements; and (*vi*) any contra-indication for light to moderately intense physical exercise. After the first screening 25 patients (mean ± standard error (SE) age 47.9 ± 1.9 years) with a mean ± SE EDSS score (4.3 ± 0.2, 22) ranging from 1.5 to 6.5 were included in the study and they were asked to maintain their normal living habits and not to participate in any other study. See Table I for a detailed description of the subjects. This study was approved by the Hasselt University ethics committee according to the Declaration of Helsinki.

Study design

A randomized controlled trial was performed over a 20-week period. Following study inclusion the baseline (PRE) measurements were performed on 3 separate days, interspersed by at least 48-h recovery/rest intervals. Measurements involved unilateral skeletal muscle performance testing on an isokinetic dynamometer (day 1, Biodex Medical Systems®, System 3, Inc., Shirley, New York, USA), evaluation of functional capacity (day 2) and routine neurological consultations and registration of perceived fatigue (day 3). At baseline (day 3) only, *m. quadriceps* spasticity was assessed by the Modified Ashworth Scale (MAS, 23) and cognitive functioning was determined by the Paced Auditory Serial Addition Task (PASAT, 24) test. Following baseline measurements and to ascertain equality between groups, subjects were coupled into pairs that, in a decreasing order of importance, matched for EDSS, age and gender by an independent investigator. Hence, 14 subjects were assigned to the control group (CON: mean ± SE EDSS: 4.1 ± 0.3, mean ± SE age: 49.7 ± 3.3 years, ♀: *n* = 11, ♂: *n* = 3, Table I) and were instructed to maintain their normal living habits. The remaining 11 subjects (EDSS: mean ± SE 4.5 ± 0.4, mean ± SE age: 46 ± 2.1 years, ♀: *n* = 7, ♂: *n* = 4, Table I) underwent a WBV exercise programme. Between-group baseline characteristics (Table I) were not statistically different. Following 10 (MID) and 20 (POST) weeks and at least 72 h after the last training session, baseline measurements were repeated by the same investigator on the same time of the day in both groups. As such, at MID a 12-day training break interspersed the first and last 10 weeks. With the exception of the neurologist who determined the EDSS scores, the investigators were not blinded. The

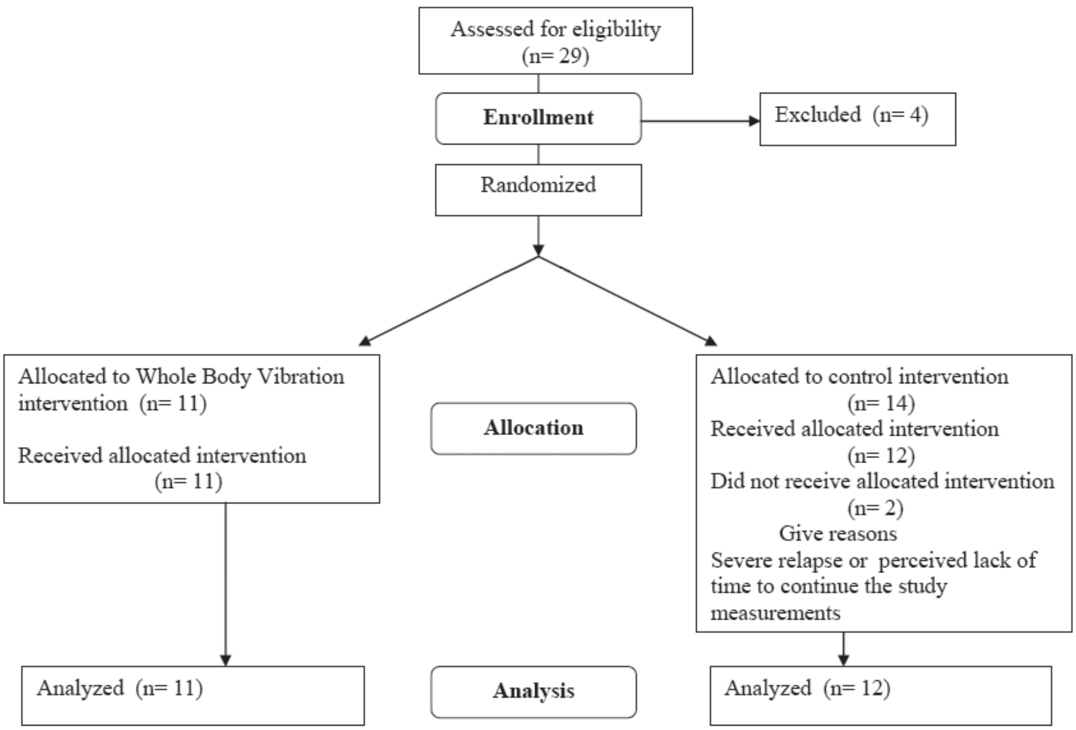

Fig. 1. Study flow diagram.

Table I. *Baseline subject characteristics of the control (CON) and the whole-body vibration (WBV) training group*

	WBV Mean ± SE	CON Mean ± SE	*p*
n	11	14	0.83
♀/♂	7/4	11/3	0.29
MS type: RR/SP/PP	6/4/1	8/4/2	0.61
EDSS, arbitrary units	4.5±0.4	4.1±0.3	0.44
Age, years	46.1±2.1	49.7±3.3	0.36
PASAT, arbitrary units	44.5±4.5	38.8±2.6	0.29
MAS, arbitrary units	0.5±0.39	0.5±0.26	0.91

See Methods for further details.
SE: standard error; MS: multiple sclerosis; RR: relapsing-remitting; SP: secondary-progressive; PP: primary-progressive; EDSS: Expanded Disability Status Scale; PASAT: Paced Auditory Serial Addition Task; MAS: Modified Ashworth Scale of the quadriceps muscle.
p-values represent baseline differences.

results were not disclosed to the subjects and investigators until study termination.

Whole-body vibration

The WBV group performed a leg muscle training programme consisting of exercises that were executed statically (weeks 1–20) or dynamically (weeks 11–20) on a vibration platform (Alpha Vibe® Nijverdal, The Netherlands). This platform was equipped with a supportive horizontal bar/handle offering bilateral standing assistance to MS patients with a high EDSS score. The acceleration of the mainly vertical vibration platform, recorded by means of an accelerometer (ADXL202-SER, Analog Devices, Norwood, USA), was 2.32 g and 2.71 g at 20 Hz and 40 Hz, respectively. The training programme included high (knee angle between 120° and 130°) and deep squats (knee angle 90°), wide stance squats, lunges and heel rises. These exercises were executed in an "unloaded" (i.e. without the use of external weights) standing posture. According to the overload principle training volume and intensity was increased systematically over the 20-week training period by increasing the duration and the number of exercise series or the number of different exercises by shortening the rest periods, varying the applied vibration frequency (25–40 Hz) and changing the execution form of the exercises from predominantly 2-legged to 1-legged exercises (see Table II for a detailed description). Between exercises, subjects were allowed to recover (chair sit). The WBV exercise protocol described above was identical to the training protocol for healthy adults previously used by Roelants et al. (19) and Delecluse et al. (20). Each WBV exercise session lasted for a maximum of 50 min including warming-up performed on a cycle ergometer (Kettler®, 5 min, 30 watt, 50–70 rpm, Ense-Parsit, Germany) and cooling-down that involved stretching of the major lower limb muscle groups. Perceived overall and leg fatigue was assessed using a visual analogue scale (VAS; range 0–10 cm; 0 cm = extremely exhausted; 10 cm = no fatigue) before and after each training session (25). Furthermore subjects completed the Borg scale (range 6–20) after each session in their training diary (26). The qualified trainer to subject ratio was 1:2.

Table II. *Training volume and intensity of the whole-body vibration programme*

	Start	Week 10	Week 20
Volume			
Total duration of vibration in 1 session, min	2.5	8.0	16.5
Series of 1 exercise, *n*	1	3	3
Different knee-extensor exercises, *n*	2	4	5
Longest duration of vibration loading without rest, s	30	45	60
Intensity			
Rest period between exercises, s	120	120	30
Vibration amplitude, mm	2.5	2.5	2.5
Vibration frequency, Hz	20	35	45

Muscle performance

Dynamometry. Maximal voluntary unilateral knee-extensor and knee flexor strength of the right leg was evaluated on an isokinetic dynamometer (Biodex Medical Systems®, system 3, Inc, Shirley, New York, USA). After a 5-min standardized warm-up on a quadriceps bench, right-side unilateral strength tests were performed in a seated position on a backward inclined (5°) chair. The rotational axis of the dynamometer was aligned with the transverse knee-joint axis and connected to the distal end of the tibia by means of a length-adjustable lever arm. The upper leg, hips and shoulders were stabilized with safety belts. The 3-dimensional positions of the rotation axis, position of the chair and length of the lever arm were identical in PRE-, MID- and POST-tests (27–29).

Maximal isometric torque. Following one submaximal trial contraction, two maximal isometric knee-extensions and flexions (3 s) were performed at knee angles of 45° and 90°. Maximal contractions were interspersed by 90-s rest intervals. The highest isometric extension and flexion torques (Nm) of the manually smoothed curves at each knee angle were selected as maximal isometric torque.

Maximal dynamic torque. Subjects performed 4 maximal consecutive isokinetic knee-extensions at a velocity of 60°/s after 3 submaximal trial contractions. Knee-extensions were initiated at a joint angle of 90° to an angle of 160°. Following each extension the leg was returned passively to the starting position from which the next contraction was immediately initiated. The highest of 4 isokinetic extension torques (Nm) was then selected as maximal dynamic torque.

Maximal strength endurance. Following 3 submaximal trial contractions, subjects performed 20 maximal dynamic knee-extensions at a velocity of 180°/s to assess strength endurance. Knee-extensions were initiated at a joint angle of 90° to an angle of 160°. Following each extension the leg was returned passively to the starting position from which the next contraction was immediately initiated. To determine muscle strength endurance, the average work (J) of the first 6 contractions was compared with the last 6 contractions and expressed as a percentage decrease.

Maximal speed of movement of knee-extension. The subjects performed 4 tests. Subjects were asked to extend their lower leg 4 times at the highest speed possible from a knee joint angle of 90° to an angle of 160°. The individual degree of resistance on the lever arm was then determined at 1%, 20%, 40% and 60% of the maximal isometric peak torque of the knee-extensors at a knee angle of 90°. At each test the maximal velocity of the lever arm (°/s) was recorded to determine the speed of movement.

Functional capacity

Functional capacity was measured using a variety of different tests.

- *Berg Balance Scale (BBS).* This performance-based measure of balance comprises 14 observable tasks involving functional balance control, transfers, turning and stepping. Scoring is based on the patients' ability to perform the tasks independently within certain time and disturbance requirements (30).
- *Timed Get Up and Go (TUG).* Here, the time (s) needed to get up off a chair without armrest, walk 3 m, turn back to the chair and sit down again, was recorded (31).
- *Two-Minute Walk Test (2MWT).* Subjects were asked to walk as far (m) as possible within 2 min, back and forth along a 30-m long stretch. Subjects were allowed to rest during the 2-minute time period and use assistive devices. Standardized verbal encouragements were given every 30 s (32).
- *The 25-Foot Walk test (T25FW).* Subjects were asked to walk on a demarked 25-foot course (7.62 m) as quickly but safely as possible. Assistive devices were permitted if necessary (33).

Statistical analysis

All analyses were carried out using SAS 9.2 for windows (SAS Institute Inc., Cary, USA). First normal data distribution was checked using the Shapiro-Wilk test and then baseline differences of all dependent variables between groups were assessed using one-way analysis of variance (ANOVA) or Kruskal-Wallis test. Changes in muscle performance, speed of movement, and functional capacity (dependent variables) in WBV and CON (independent variables) were analysed after 10 and 20 weeks. Statistical analysis were performed with an ANOVA (General Linear Model, GLM) for repeated measures: (2 [group] × 3 [time]) for isometric strength, dynamic strength, strength endurance and functional capacity; (2 [group] × 3 [time] × 4 [resistance]) for speed of movement. The Friedman test was used to analyse changes in the modified Ashworth scale. VAS and BORG data of each training session of the WBV group were summarized for 5 training periods (period 1: weeks 1–4, period 2: weeks 5–8, period 3: weeks 9–12, period 4: weeks 13–16 and period 5: weeks 17–20) and an ANOVA (GLM) for repeated measures was used to evaluate training exertion and when appropriate Tukey-Kramer *post-hoc* analyses were performed. All values are reported as means ± SE. Significance level was set at $p<0.05$.

RESULTS

Training compliance and side-effects

Training compliance (Fig. 1). In total, 23 of the 25 subjects completed the study. Two CON patients retreated before study termination due to a severe relapse or perceived lack of time to continue the study measurements. In total, 537 of the 550 planned WBV exercise sessions were performed.

Perceived training exertion. The average VAS measures before and after each training session for the overall and specific lower limb fatigue remained stable throughout the study course. BORG scores increased significantly ($p=0.02$) over the intervention period and *post-hoc* Tukey-Kramer analyses indicate a significant increase in period 4 (mean ± SE 12.6 ± 0.28, $p=0.01$) and period 5 (mean ± SE 12.8 ± 0.34, $p=0.02$), both compared with period 1 (mean ± SE 10.9 ± 0.25).

Muscle performance

Muscle strength (Table III). At baseline muscle performance did not statistically differ between groups. Compared with baseline, maximal isometric knee-flexor torque (45° and 90°) at study termination was lower (time effect, $p<0.05$) in CON. Compared with CON, 20 weeks of WBV did not increase maximal isometric knee-extensor and knee-flexor torque in both knee angles (group × time effect, knee-extensors: 45°, $p=0.07$; 90°, $p=0.23$; knee-flexors: 45°, $p=0.64$; 90°, $p=0.57$). Maximal dynamic torque and maximal strength endurance of the knee-extensors did not change following 20 weeks of WBV in any group (no statistically significant group × time effect).

Speed of movement of knee-extension. No differences were found in the group × time × resistance analyses ($p=0.99$). Furthermore, there were no significant ($p<0.05$) interaction effects (group × time) for the 4 resistance levels ($p=0.57$ (1%); 0.98 (20%); 0.06 (40%) and 0.40 (60%)).

Table III. *Maximal isometric, dynamic and endurance muscle strength*

		p	WBV (*n*=11) Mean ± SE	CON (*n*=12 Mean ± SE)
Isometric (Nm)				
Extensor				
45°	PRE	0.07	95.5±9.4	93.6±9.0
	MID		108.8±10.9	92.5±9.5
	POST		99.6±11.4	92.0±8.9
90°	PRE	0.23	101.8±11.6	94.4±8.9
	MID		103.8±12.5	90.3±9.9
	POST		100.1±13.2	86.3±9.1
Flexor				
45°	PRE	0.64	44.1±5.5	53.8±5.9
	MID		42.3±5.0	49.6±6.2
	POST		40.9±5.5	48.0±5.3*
90°	PRE	0.57	37.3±5.7	44.3±4.6
	MID		36.7±6.4	41.0±4.7
	POST		34.4±6.0	39.1±3.8*
Dynamic (Nm)				
60°/s				
	PRE	0.50	92.1±10.4	89.0±11.8
	MID		95.6±11.1	87.6±13.3
	POST		98.4±12.6	88.8±11.2
Endurance (J)				
180°/s				
	PRE	0.10	27.1±5.1	25.9±3.8
	MID		23.9±5.0	31.5±2.9
	POST		24.7±4.1	35.4±2.6

Values represent maximal isometric knee-extensor and flexor (knee angles of 45° and 90°), maximal dynamic knee-extension and maximal knee-extension strength endurance torques before (PRE) and after 10 (MID) and 20 (POST) weeks of whole-body vibration (WBV) training or control (CON) treatment. *p*-values represent interaction effects and *significant time effect ($p<0.05$) compared with baseline. SE: standard error.

Functional capacity

At baseline, there were no statistically differences between groups for the EDSS, BBS, TUG, 2MWT and T25FW values. Following the study period, no group × time interaction effects were detected for any functional capacity test (Table IV).

Table IV. *Functional capacity before (PRE) and after 10 (MID) and 20 (POST) weeks of whole-body vibration (WBV) training or control (CON) treatment.*

		p	WBV (*n*=11) Mean ± SE	CON (*n*=12) Mean ± SE
BBS	PRE	0.15	44.9±4.1	49.6±4.2
	MID		43.6±5.2	51.3±3.3
	POST		41.9±5.9	51.2±3.8
TUG	PRE	0.26	13.7±2.6	9.3±1.7
	MID		14.0±2.8	9.6±1.6
	POST		13.1±2.4	10.3±2.2
2MWT	PRE	0.25	130.5±15.6	154.8±12.6
	MID		137.3±16.0	153.9±12.8
	POST		139.4±15.6	167.5±6.8
T25FW	PRE	0.64	8.7±1.8	6.7±0.9
	MID		8.7±1.8	6.8±1.0
	POST		8.4±1.4	7.2±1.5

p-values represent interaction effects.
SE: Standard error; BBS: Berg Balance Scale; TUG: Timed Get Up and Go; 2MWT: Two-Minute Walk Test; T25FW: Timed 25-Foot Walk Test.

DISCUSSION

This study investigated the effects of 20-week WBV training on muscle performance and functional capacity in mild- to moderately impaired MS patients. The results of this study suggest that 20 weeks of WBV exercise probably does not improve leg muscle isometric and dynamic strength nor strength endurance and speed of movement. Furthermore, under the conditions of the present study WBV appears to have no effects on functional capacity in persons with MS.

To our knowledge this is the first study to investigate the impact of long-term static and dynamic WBV exercise on muscle performance, measured by isometric and isokinetic dynamometry, in persons with MS compared with no intervention at all. Here, WBV exercise did not have any significant effect on knee muscle isometric strength, dynamic strength and strength endurance, or maximal speed of movement. These are rather surprising results, because, on the one hand, the applied WBV exercise programme was very similar to previous long-term programmes in younger and older healthy people exerting significant strength gains of 7–15% (19, 20, 34–37), and, on the other hand, based on the "initial training status" principle it could be expected that MS patients could realize even greater improvements as they have a significantly lower muscle strength at baseline compared with untrained healthy subjects (38, 39). Thus, it is difficult to explain the absence of any training effect. One could argue that, despite the fact that the training volume and intensity was progressively increased according to the overload principle, the WBV training programme used in this study may have been too intense for MS patients, inducing overtraining. However, the reported overall (mean ± SE 5.6 ± 0.1) and leg muscle fatigue (mean ± SE 5.8 ± 0.2) VAS and Borg perceived exertion (mean ± SE 12.0 ± 0.1) scores during and after training correspond to moderate-intensity training (39), and subjects described the provided WBV training as non-exhausting. Because in MS muscle weakness is probably caused by both the disease process *per se* and by inactivity, the important question then arises as to what extent training stimuli exert similar physiological muscular training responses compared with healthy individuals. So far, a variety of studies have addressed this issue. To date, it is clear that strength and cardiovascular training, either combined or not, improve muscle strength and overall physical fitness in MS (6). Very often, this is associated with improved quality of life (6, 40, 41) and some improved functional mobility measures, such as walking speed and walking distance, especially when performed in supervised exercise facilities (41–44). Compared with the improvements usually acquired in cardiovascular and/or strength training studies with healthy individuals (20–30%, 45, 46), strength increases obtained in MS are markedly smaller (7–16%, 29, 44). Possible WBV effects in MS, therefore, may also be limited compared with healthy individuals. In fact, because reported strength increases resulting from WBV in healthy individuals are usually small (7), non-significant increases in persons with MS could be expected. Finally, it is important to note that the majority of the participating subjects were persons still living in the community. The persons in the intervention group made their own travel arrangment to travel to the training facility for 6 months. As such, it may hypothesized that subjects were (physically) more active than the average person with MS and therefore showed no or limited (muscular) deconditioning (13, 47), and that this would therefore limit the potential for improvement.

Similar to healthy individuals (48), a positive relationship between muscular strength and functional capacity during daily living in persons with MS has been demonstrated (4). Functional capacity can be assessed using a variety of different measures, such as gait speed, walking distance and balance (18, 29, 42, 44, 49). We applied the BBS, TUG, 2MWT and T25FW. In accordance with the muscle strength data, and despite the fact that we applied both static and dynamic WBV exercises (18), functional capacity did not improve following 20 weeks of WBV training in the MS patients in this study. This confirms results of Schyns et al. (18), who reported statistically unchanged 10 m-walking time and TUG performance following additional WBV training performance compared with exercise alone.

Due to its explorative nature the present study contains limitations. The small sample sizes used probably decreased statistical power. This could have clouded a possible statistical significance during isometric knee-extension ($p = 0.07$, interaction effect at 45° knee angle). Also, training programmes were not individualized. This may have decreased the rate of training progression. No "placebo" group was included and thus it is uncertain that a sufficient vibration stimulus was ever provided. We applied lower limb open chain strength measures. Thus, closed chain training effects, such as in WBV, may be underestimated with our test battery and lower limb training effects remain unexplored. Finally, this study investigated only the acute upper leg strength and function effects following long-term WBV training. Long-term effects and effects on quality of life that may be present remain unknown. Given its weaknesses, and considering the high variability (EDSS scores, leg muscle strength asymmetry, functional capacity) occurring in MS compared with healthy subjects, the following recommendations should be considered. First, larger scale training studies that include a "placebo" group, quality of life assessment and follow-up measurements are necessary. Secondly, a more individualized training progression approach using optimal individual vibration parameters through for example electromyography or calf muscle strength measurements may stimulate the adaptive responses of MS patients. Finally, the use of closed chain strength measurements following WBV is probably more appropriate.

In conclusion, the applied WBV protocol seems safe for MS patients, but under the conditions of the present study long-term WBV probably does not improve upper leg muscle strength and functional capacity in mild- to moderately impaired community-based MS patients during and immediately after the training programme.

ACKNOWLEDGEMENTS

The authors thank Anne Bogaers for providing skilled technical assistance. Furthermore, the cooperation of the subjects is greatly appreciated. This study was funded by IWT Tetra grant 050078.

REFERENCES

1. Noseworthy JH, Lucchinetti C, Rodriguez M, Weinshenker BG. Multiple sclerosis. N Engl J Med 2000; 343: 938–952.
2. Compston A, Coles A. Multiple sclerosis. Lancet 2002; 359: 1221–1231.
3. Rietberg MB, Brooks D, Uitdehaag BM, Kwakkel G. Exercise therapy for multiple sclerosis. Cochrane Database Syst Rev 2005: CD003980.
4. Ng AV, Miller RG, Gelinas D, Kent-Braun JA. Functional relationships of central and peripheral muscle alterations in multiple sclerosis. Muscle Nerve 2004; 29: 843–852.
5. Ng AV, Kent-Braun JA. Quantitation of lower physical activity in persons with multiple sclerosis. Med Sci Sports Exerc 1997; 29: 517–523.
6. Dalgas U, Stenager E, Ingemann-Hansen T. Multiple sclerosis and physical exercise: recommendations for the application of resistance-, endurance- and combined training. Mult Scler 2008; 14: 35–53.
7. Nordlund MM, Thorstensson A. Strength training effects of whole-body vibration? Scand J Med Sci Sports 2007; 17: 12–17.
8. Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev 2003; 31: 3–7.
9. Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. Clin Physiol 2000; 20: 134–142.
10. Rittweger J, Mutschelknauss M, Felsenberg D. Acute changes in neuromuscular excitability after exhaustive whole body vibration exercise as compared to exhaustion by squatting exercise. Clin Physiol Funct Imaging 2003; 23: 81–86.
11. Tihanyi TK, Horvath M, Fazekas G, Hortobagyi T, Tihanyi J. One session of whole body vibration increases voluntary muscle strength transiently in patients with stroke. Clin Rehabil 2007; 21: 782–793.
12. Ahlborg L, Andersson C, Julin P. Whole-body vibration training compared with resistance training: effect on spasticity, muscle strength and motor performance in adults with cerebral palsy. J Rehabil Med 2006; 38: 302–308.
13. Kent-Braun JA, Ng AV, Castro M, Weiner MW, Gelinas D, Dudley GA, et al. Strength, skeletal muscle composition, and enzyme activity in multiple sclerosis. J Appl Physiol 1997; 83: 1998–2004.
14. Rice CL, Vollmer TL, Bigland-Ritchie B. Neuromuscular responses of patients with multiple sclerosis. Muscle Nerve 1992; 15: 1123–1132.
15. van der KW, Maertens de NA, Thompson PD, Rothwell JC, Day BL, Marsden CD. Correlation of phasic muscle strength and corticomotoneuron conduction time in multiple sclerosis. Ann Neurol 1991; 29: 6–12.
16. Jackson KJ, Merriman HL, Vanderburgh PM, Brahler CJ. Acute effects of whole-body vibration on lower extremity muscle performance in persons with multiple sclerosis. J Neurol Phys Ther 2008; 32: 171–176.
17. Schuhfried O, Mittermaier C, Jovanovic T, Pieber K, Paternostro-Sluga T. Effects of whole-body vibration in patients with multiple sclerosis: a pilot study. Clin Rehabil 2005; 19: 834–842.
18. Schyns F, Paul L, Finlay K, Ferguson C, Noble E. Vibration therapy in multiple sclerosis: a pilot study exploring its effects on tone, muscle force, sensation and functional performance. Clin Rehabil 2009; 23: 771–781.
19. 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: 901–908.
20. Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. Med Sci Sports Exerc 2003; 35: 1033–1041.
21. Roelants M, Verschueren SM, Delecluse C, Levin O, Stijnen V. Whole-body-vibration-induced increase in leg muscle activity during different squat exercises. J Strength Cond Res 2006; 20: 124–129.
22. Kurtzke JF. Rating neurologic impairment in multiple sclerosis: an expanded disability status scale (EDSS). Neurology 1983; 33: 1444–1452.
23. Ansari NN, Naghdi S, Younesian P, Shayeghan M. Inter- and intrarater reliability of the Modified Modified Ashworth Scale in patients with knee extensor poststroke spasticity. Physiother Theory Pract 2008; 24: 205–213.
24. Schwid SR, Tyler CM, Scheid EA, Weinstein A, Goodman AD, McDermott MP. Cognitive fatigue during a test requiring sustained attention: a pilot study. Mult Scler 2003; 9: 503–508.
25. Mollaoglu M, Ustun E. Fatigue in multiple sclerosis patients. J Clin Nurs 2009; 18: 1231–1238.
26. Gearhart RE, Goss FL, Lagally KM, Jakicic JM, Gallagher J, Robertson RJ. Standardized scaling procedures for rating perceived exertion during resistance exercise. J Strength Cond Res 2001; 15: 320–325.
27. Drouin JM, Valovich-McLeod TC, Shultz SJ, Gansneder BM, Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. Eur J Appl Physiol 2004; 91: 22–29.
28. Lambert CP, Archer RL, Evans WJ. Muscle strength and fatigue during isokinetic exercise in individuals with multiple sclerosis. Med Sci Sports Exerc 2001; 33: 1613–1619.
29. Dalgas U, Stenager E, Jakobsen J, Petersen T, Hansen HJ, Knudsen C, et al. Resistance training improves muscle strength and functional capacity in multiple sclerosis. Neurology 2009; 73: 1478–1484.
30. Berg KO, Wood-Dauphinee SL, Williams JI, Maki B. Measuring balance in the elderly: validation of an instrument. Can J Public Health 1992; 83: 7–11.
31. Podsiadlo D, Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc 1991; 39: 142–148.
32. Butland RJ, Pang J, Gross ER, Woodcock AA, Geddes DM. Two-, six-, and 12-minute walking tests in respiratory disease. Br Med J (Clin Res Ed) 1982; 284: 1607–1608.
33. Nilsagard Y, Lundholm C, Gunnarsson LG, Dcnison E. Clinical relevance using timed walk tests and 'timed up and go' testing in persons with multiple sclerosis. Physiother Res Int 2007; 12: 105–114.
34. Bogaerts AC, Delecluse C, Claessens AL, Troosters T, Boonen S, Verschueren SM. Effects of whole body vibration training on cardiorespiratory fitness and muscle strength in older individuals (a 1-year randomised controlled trial). Age Ageing 2009; 38: 448–454.
35. Bogaerts A, Delecluse C, Claessens AL, Coudyzer W, Boonen S, Verschueren SM. 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: 630–635.
36. Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. J Bone Miner Res 2004; 19: 352–359.
37. Russo CR, Lauretani F, Bandinelli S, Bartali B, Cavazzini C, Guralnik JM, et al. High-frequency vibration training increases muscle power in postmenopausal women. Arch Phys Med Rehabil 2003; 84: 1854–1857.
38. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, et al. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2002; 34: 364–380.
39. Baladay GJ, Berra KA, Golding LA, Gordon NF, Mahler DA, Myers JN, et al. Chapter 4 Physical fitness testing and interpretation. ACSM's Guidelines for Exercise Testing and Prescrition 2000: 57–85.
40. Motl RW, Gosney JL. Effect of exercise training on quality of life in multiple sclerosis: a meta-analysis. Mult Scler 2008; 14: 129–135.
41. Motl RW, McAuley E, Snook EM, Gliottoni RC. Physical activ-

ity and quality of life in multiple sclerosis: intermediary roles of disability, fatigue, mood, pain, self-efficacy and social support. Psychol Health Med 2009; 14: 111–124.
42. Gutierrez GM, Chow JW, Tillman MD, McCoy SC, Castellano V, White LJ. Resistance training improves gait kinematics in persons with multiple sclerosis. Arch Phys Med Rehab 2005; 86: 1824–1829.
43. Solari A, Filippini G, Gasco P, Colla L, Salmaggi A, La Mantia L, et al. Physical rehabilitation has a positive effect on disability in multiple sclerosis patients. Neurology 1999; 52: 57–62.
44. White LJ, McCoy SC, Castellano V, Gutierrez G, Stevens JE, Walter GA, et al. Resistance training improves strength and functional capacity in persons with multiple sclerosis. Multiple Sclerosis 2004; 10: 668–674.
45. Seguin R, Nelson ME. The benefits of strength training for older adults. Am J Prev Med 2003; 25: 141–149.
46. Eijnde BO, Van LM, Goris M, Labarque V, Taes Y, Verbessem P, et al. Effects of creatine supplementation and exercise training on fitness in men 55–75 yr old. J Appl Physiol 2003; 95: 818–828.
47. Motl RW, McAuley E, Snook EM. Physical activity and multiple sclerosis: a meta-analysis. Mult Scler 2005; 11: 459–463.
48. Hass CJ, Feigenbaum MS, Franklin BA. Prescription of resistance training for healthy populations. Sports Med 2001; 31: 953–964.
49. Thoumie P, Mevellec E. Relation between walking speed and muscle strength is affected by somatosensory loss in multiple sclerosis. J Neurol Neurosurg Psychiatry 2002; 73: 313–315.