

Effect of four-month vertical whole body vibration on performance and balance

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ABSTRACT

TORVINEN, S., P. KANNUS, H. SIEVÄNEN, T. A. JÄRVINEN, M. PASANEN, S. KONTULAINEN, T. L. JÄRVINEN, M. JÄRVINEN, P. OJA, and I. VUORI. Effect of four-month vertical whole body vibration on performance and balance. *Med. Sci. Sports Exerc.*, Vol. 34, No. 9, pp. 1523–1528, 2002. **Purpose:** This randomized controlled study was designed to investigate the effects of a 4-month whole body vibration-intervention on muscle performance and body balance in young, healthy, nonathletic adults. **Methods:** Fifty-six volunteers (21 men and 35 women, aged 19–38 yr) were randomized to either the vibration group or control group. The vibration-intervention consisted of a 4-month whole body vibration training (4 min·d⁻¹, 3–5 times a week) employed by standing on a vertically vibrating platform. Five performance tests (vertical jump, isometric extension strength of the lower extremities, grip strength, shuttle run, and postural sway on a stability platform) were performed initially and at 2 and 4 months. **Results:** Four-month vibration intervention induced an 8.5% (95% CI, 3.7–13.5%, $P = 0.001$) net improvement in the jump height. Lower-limb extension strength increased after the 2-month vibration-intervention resulting in a 3.7% (95% CI, 0.3–7.2%, $P = 0.034$) net benefit for the vibration. This benefit, however, diminished by the end of the 4-month intervention. In the grip strength, shuttle run, or balance tests, the vibration-intervention showed no effect. **Conclusion:** The 4-month whole body vibration-intervention enhanced jumping power in young adults, suggesting neuromuscular adaptation to the vibration stimulus. On the other hand, the vibration-intervention showed no effect on dynamic or static balance of the subjects. Future studies should focus on comparing the performance-enhancing effects of a whole body vibration to those of conventional resistance training and, as a broader objective, on investigating the possible effects of vibration on structure and strength of bones, and perhaps, incidence of falls of elderly people. **Key Words:** VERTICAL JUMP, LOWER LIMB EXTENSION STRENGTH, SHUTTLE RUN, POSTURAL SWAY, YOUNG ADULTS

Mechanical vibration has recently aroused large interest because it has been hypothesized that a low-amplitude, high-frequency stimulation of the whole body could positively influence many risk factors of falling and related fractures by simultaneously improving muscle strength, body balance, and mechanical competence of bones (3–5,9,10,21,23–28,35). There is, however, very little scientific evidence about the effects of whole body vibration on these parameters. Bosco et al. showed that a single vibration bout resulted in a significant temporary increase in muscle strength of the lower extremities (5) and arm flexors (4). They also studied the effects of 10-d vibration on muscular performance of physically active subjects and showed that whole body vibration applied for 10 min·d⁻¹ induced an enhancement in explosive power (3). Runge et al., in turn, showed that whole body vibration

could enhance muscle performance in elderly people (2-month training program three times a week at the frequency of 27 Hz) (29). There is also some preliminary evidence that vibration-loading could stimulate trabecular bone formation and prevent postmenopausal and ovariectomy-induced bone loss (10,24,26).

Despite the above noted preliminarily positive findings and wide use of different vibration devices among athletes, conclusive evidence on the efficacy and safety of vibration training is lacking. This lack of data is especially clear concerning the long-term effects. The purpose of this study was, therefore, to investigate the effects of a 4-month whole body vibration intervention on muscle performance and body balance of young, healthy volunteers, using a randomized controlled study design.

MATERIALS AND METHODS

Subjects and Study Design

Fifty-six young, healthy, nonathletic volunteers (21 men and 35 women aged 19–38 yr) participated in the study. Half of the subjects were randomized to the vibration group

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and half to the control group. The men and women were randomized separately into the groups so that number of men and women would be approximately equal in both groups. The vibration protocol consisted of a 4-month whole body vibration training (see below). The performance tests were done at baseline (before randomization) and at 2 and 4 months.

The exclusion criteria from the study were: any cardiovascular, respiratory, abdominal, urinary, gynecological, neurological, musculoskeletal, or other chronic disease; pregnancy; prosthesis; medication that could affect the musculoskeletal system; menstrual irregularities; and regular participation in any exercise-inducing impact-type loading on the skeleton more than three times a week.

The subjects completed a questionnaire detailing their physical activity and calcium intake (from a 7-d calcium intake diary) (36) at the beginning of the study and at 2 and 4 months. All participants gave their informed written consent before enrollment, and the study protocol was approved by both the Institutional Review Board and the Ethics Committee of the UKK Institute.

Vibration Loading

Vibration loading was carried out in a standing position on a whole body vibration platform (Kuntotäry, Erka Oy, Kerava, Finland) and the subjects were asked to train with it 3 to 5 times a week. The duration of daily stimulus was 4 min. While standing on the platform, the subjects repeated four times a 60-s light exercise program according to instructions prepared earlier. The rationale of the exercise program was to provide a multidirectional vibration exposure on the body and make the standing on the platform less monotonous in a way that would be feasible for a long-term intervention trial. The program comprised of light squatting (0–10 s), standing in the erect position (10–20 s), standing in a relaxed position with slightly flexed knees (20–30 s), light jumping (30–40 s), alternating the body weight from one leg to another (40–50 s), and standing on the heels (50–60 s).

During the 4-min vibration exposure, the vibration frequency increased in one min intervals. During the first two weeks, the duration of the loading was 2 min, and the frequency of vibration was 25 Hz for the first minute and 30 Hz for the second minute (the practice period). During next 1.5 months, the duration of the vibration loading was 3 min and frequency 25 Hz/60 s + 30 Hz/60 s + 35 Hz/60 s. During the remaining 2 months, the length of exposure was 4 min, and the frequency was 25 Hz/60 s + 30 Hz/60 s + 35 Hz/60 s + 40/60 s. The peak-to-peak amplitude of the vertical vibration was 2 mm. Considering the amplitude and the sinusoidal nature of the loading, the theoretical maximal acceleration was some 2.5 g (where g is the Earth's gravitational field, or 9.81 ms⁻²) with 25 Hz loading, 3.6 g with 30 Hz loading, 4.9 g with 35 Hz loading, and 6.4 g with 40 Hz loading.

Performance Tests

At the beginning of each test session, a 4-min warm-up was performed on a bicycle ergometer (workload 40 W for women and 50 W for men). The subjects wore the same shoes during all three performance test sessions, and the order of the performance tests was the same in every test session (see below). Use of alcohol or strenuous physical activity was not allowed during the test-day nor the preceding day. Before each test, the subjects had one to two unintensified familiarization trials.

A vertical countermovement jump test was used to assess the lower-limb explosive performance capacity (2). The subject kept hands on the pelvis. The tests were performed on a contact platform (Newtest, Oulu, Finland), which measures the flying time. The obtained flight time (t) was used to estimate the height of the rise of body center of gravity (h) during the vertical jump (i.e., $h = gt^2/8$, where $g = 9.81 \text{ m}\cdot\text{s}^{-1}$) (2). The median value of three measurements was used as the test score.

A postural sway platform (Biodex Stability System, New York, NY) was used to assess static body balance (32). The subjects stood on a labile platform on both legs, with eyes opened and arms beside the trunk. The platform provides eight different stability-levels (level 8 is virtually stable and level 1 is the most labile). As a test, we employed a 40-s protocol in successive 10-s intervals [level 5 (0–10 s), level 4 (10–20 s), level 3 (20–30 s), and level 2 (30–40 s)]. This system provides a numerical stability index that reflects the body sway variation around the body's center of gravity so that the lower the index, the higher the level of stability (32). Each subject's feet position coordinates on the platform were recorded after the first stability measurement, and the same coordinates were used throughout the study to obtain consistency between the tests. The mean value of two stability indices was used as the test score.

Grip strength was measured using a standard grip strength meter (Digitest, Muurame, Finland). The median value of three readings was used as the test score.

Maximal isometric strength of the leg extensors was measured with a standard leg press dynamometer (12). The subjects sat on the dynamometer chair with their knees and ankles at an angle of 90° of flexion while pressing maximally against strain gauges (Tamtron, Tampere, Finland) under their feet. The isometric strength was recorded for three maximal efforts, and the median value of three readings was used as the test score.

A shuttle run test over a 30-m course was used to assess the dynamic balance or agility (1). The subjects were asked to run as fast as possible six times between markers placed four meters apart, to touch the floor after each 4-m run, and finally to run a 6-m course over the finish line. A single performance was done and the running time was recorded with photoelectric cells.

Safety

Possible side effects or adverse reactions were asked from the subjects of the vibration group monthly and from the

TABLE 1. Basic characteristics of the vibration and control groups.

	Vibration Group N = 26	Control Group N = 26
Women/Men	17/9	16/10
Age (yr)	23.2 (4.4)	25.5 (5.8)
Height (cm)	174.4 (8.0)	174.0 (7.7)
Weight (kg)		
Baseline	71.6 (13.3)	71.1 (12.8)
At 2 months	71.5 (13.6)	71.7 (12.4)
At 4 months	70.8 (13.0)	70.7 (12.4)

Values are mean (SD).

control group in 2-month intervals. The subjects also had the liberty of consulting the responsible study physician whenever needed.

Statistical Analysis

Means and standard deviations are given as descriptive statistics. The 2-month and 4-month effects of the whole body vibration on physical performance and balance were defined as absolute and relative mean differences [with 95% confidence intervals (CI)] between the vibration and control groups, respectively. The relative differences were achieved through log-transformation of the variables. The time-effect at 2 and 4 months was determined by one-way ANCOVA, using the baseline values as the covariate. In all tests, $P < 0.05$ was considered significant.

RESULTS

Twenty-six subjects in the vibration group and 26 controls completed the study without side effects or adverse reactions. Two participants in the control group withdrew from the study because of loss of interest, and two participants in the vibration group withdrew because of musculoskeletal problems that were independent from the vibration-loading (the first one for rib fracture; the second one for an orthopedic operation). The basic characteristics of the 52 subjects are given in Table 1.

The reported mean vibration-training frequency was 3.1 (± 0.9) times per week. Because there were no gender differences in the time-effect at the 2-month and 4-month tests, the data of women and men were pooled and analyzed together.

Muscle Performance and Body Balance

Power and strength tests. The vertical jump height increased an average of 2.0 cm after 2 months vibration as compared with a mean decrease of 0.6 cm in the control group, resulting in a significant 10.2% net benefit (95% CI, 5.6–15.1%, $P = 0.000$) in the vibration group. At the 4-month test, jump height had increased 2.5 cm (from the baseline) in the vibration group and 0.3 cm (from the baseline) in the control group, resulting in a significant 8.5% net benefit (95% CI, 3.7–13.5%, $P = 0.001$) in the vibration group (Table 2 and Figure 1A).

Isometric lower limb extension strength improved an average 11.2 kg after the 2-month vibration-intervention,

while in the control group a mean increase was 4.8 kg, resulting in a statistically significant 3.7% net benefit (95% CI, 0.3–7.2%, $P = 0.034$) for the vibration group. At the 4-month test, this net benefit had diminished to 2.5% ($P = 0.25$) (Table 2 and Fig. 1B). In this context it must be noted that the lower limb extension strength of one control subject was clearly higher than that of the other control subjects, thus increasing the standard deviations in the control group (Table 2). This had, however, no effect on the absolute or relative mean between-groups differences. As expected, in neither group were changes observed in the grip strength at the 2- and 4-month tests (Table 2 and Fig. 1C).

Performance and balance tests. There were no differences at the 2- and 4-month shuttle run tests between the vibration and control groups (the mean between-groups net difference -0.5% at both time points, $P = 0.52$ and $P = 0.57$, respectively) (Table 2 and Fig. 1D). Neither effect was observed in the postural sway at the 2-month or 4-month tests (Table 2 and Fig. 1E).

DISCUSSION

This randomized controlled study showed that a 4-month whole body vibration-loading was safe to use and induced a significant 8.5% mean increase in the jump height of young healthy adults. This improvement was already seen after 2 months of the vibration. Lower limb extension strength was also enhanced by the 2-month vibration-period. This increase, however, slowed down by the end of the intervention, and at 4 months the difference between the groups was no more statistically significant, mostly due to increased extension strength in the control group (learning effect). Concerning the dynamic and static body balance, the 4-month whole body vibration-intervention showed no effect.

Effects of resistance training on neuromuscular properties of skeletal muscle are well known (6,13–18), and their knowledge may help to interpret and understand the above noted vibration findings. First, structural changes within a skeletal muscle are of great importance when adapting to strength training. However, voluntary strength performance is determined not only by intramuscular factors but also by the extent of neural activation, since training-induced changes in the nervous system (neural adaptation) allow more complete activation of the prime movers of a specific movement and better coordination of the activation of the relevant muscles, both of which result in a greater force in the intended direction of movement (6,30).

The first adaptation mechanism of a skeletal muscle to resistance training is neural (6,18,30). Changes in the neural factors in response to training occur within a few months, whereas changes in the morphological structure of the muscle take longer (from several months to years). Specific adaptations to training depend much on the training program employed (6,30,31). In addition to pure maximal strength, explosive power is an important factor in several sport activities, and various stretch-shortening cycle (SSC) exercises (e.g. jumping or plyometric exercises) have been used

TABLE 2. The performance and balance test parameters at baseline and after 2-month and 4-month whole body vibration intervention.

	Vibration Group (N = 26)	Control Group (N = 26)	Mean Difference Between Groups ^a	Between Groups Difference for the Relative Change by Time		
				Mean	95 % CI ^a	P value
Vertical jump* (cm)						
Baseline	27.7 (7.9)	28.9 (8.2)				
2-month	29.7 (7.2)	28.3 (8.1)	2.5	10.2	5.6 to 15.1	<0.001
4-month	30.2 (7.6)	29.2 (8.5)	2.1	8.5	3.7 to 13.5	0.001
Lower limb extension strength (kg)						
Baseline	194.8 (64.5)	216.5 (103.4)				
2-month	206.0 (69.8)	221.3 (110.7)	7.8	3.7	0.3 to 7.2	0.034
4-month	207.8 (65.8)	227.7 (116.9)	3.6	2.5	-1.8 to 7.1	0.250
Grip strength (kg)*						
Baseline	30.8 (7.7)	32.4 (9.8)				
2-month	31.2 (8.1)	32.3 (9.8)	0.6	1.6	-1.0 to 4.4	0.228
4-month	30.5 (7.9)	32.5 (9.9)	-0.4	-1.3	-3.1 to 0.5	0.143
Shuttle run (s)*						
Baseline	11.0 (1.3)	11.2 (1.4)				
2-month	10.8 (1.4)	11.0 (1.4)	-0.05	-0.5	-2.0 to 1.0	0.516
4-month	10.7 (1.2)	10.9 (1.4)	-0.07	-0.5	-2.2 to 1.3	0.570
Postural sway (stability index)						
Baseline	3.1 (1.7)	3.5 (1.2)				
2-month	3.1 (1.7)	3.7 (1.5)	-0.3	-7.1	-21.7 to 10.0	0.385
4-month	3.0 (1.3)	3.4 (1.3)	-0.2	-1.7	-14.9 to 13.7	0.817

Mean (SD), mean difference between the vibration and control groups, and mean between-groups difference (95 % CI and P-value) for the relative change by time (%).

*N = 25 in the vibration group.

^aOne-way analysis of covariance.

to improve this performance trait. The exact mechanism by which the explosive power training can enhance neuromuscular activation is not known, but there are several possible explanations which could cause this enhancement, e.g., adaptation of certain reflex responses, increase in motor unit synchronization, co-contraction of the synergist muscles, or increased inhibition of the antagonist muscles. Strength and power training may also increase the ability of motor units to fire briefly at very high rates, which may induce an increase in the rate of force development even if the peak force does not necessarily increase (6,18,30).

Whole body vibration-induced improvements in muscle performance (3) have been suggested to be similar (and occur via similar pathways) to those after several weeks of resistance training (4,7,15). During a whole body vibration

loading, skeletal muscles undergo small changes in muscle length, most likely since mechanical vibration is able to induce a tonic excitatory influence on the muscles exposed to it (33). In other words, vibration elicits a response called “tonic vibration reflex,” including activation of muscle spindles, mediation of the neural signals by 1a afferents (11), and finally, activation of muscle fibers via large α -motoneurons. The tonic vibration reflex is also able to cause an increase in recruitment of the motor units through activation of muscle spindles and polysynaptic pathways (8).

In this study, neurogenic enhancement or changes in the morphological structure of the muscles could not be assessed directly because the study protocol included neither EMG recordings nor muscle biopsies. However, on the basis of the evidence mentioned above, it is likely that the given

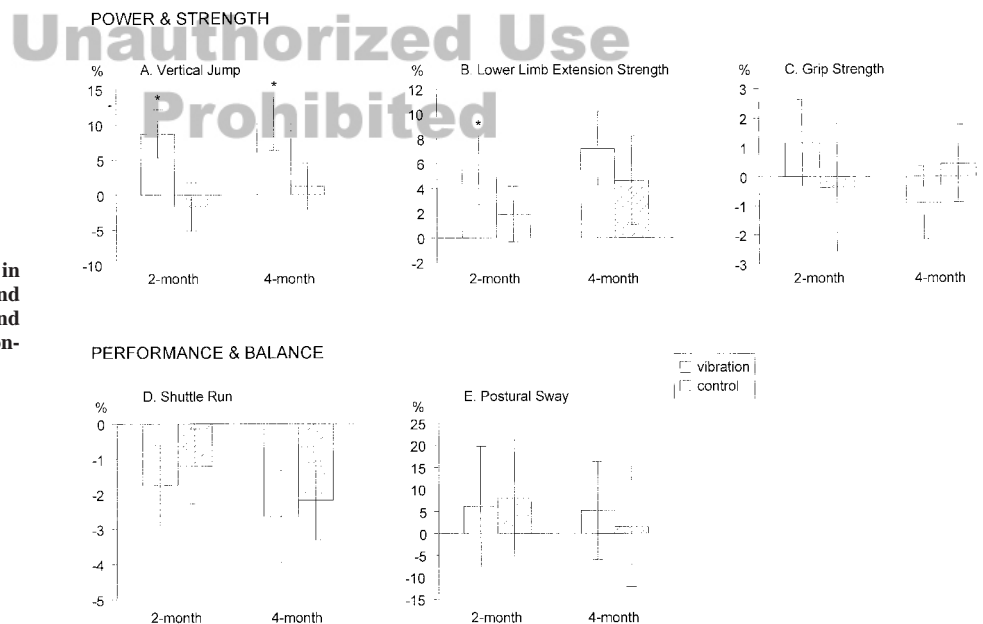


FIGURE 1—The percentage changes in the power, strength, performance, and balance tests after the 2-month and 4-month vibrations. Mean and 95% confidence interval. * Indicates P < 0.05.

whole body vibration training elicited neural adaptation. This was also supported by the results of the study; i.e., the quickly and clearly enhanced jump height suggested that neural adaptation did occur in response to the vibration-intervention. In addition, the lower-limb extension strength increased only after 2 months of vibration, thus also referring to neural potentiation. The rate of increase in the lower limb extension strength and difference between the intervention groups, however, diminished by the end of the 4-month intervention. This could be explained by general muscular adaptation to the vibration program. Further improvement in the extension strength might have required a greater change in the training stimulus.

When interpreting the results of the current study (the rise in vertical jump height), one has to remember that the training group subjects also did a light exercise program during the 4-min vibration exposure (see Materials and Methods), and thus, one could suspect that the improvement in the jump height was because of this exercise. However, it was very unlikely that these exercises were behind the clear rise in the jump height in that the exercises were very light.

REFERENCES

1. BAKER, J., R. RAMSBOTTOM, and R. HAZELDINE. Maximal shuttle running over 40 m as a measure of anaerobic performance. *Br. J. Sports Med.* 27:228–232, 1993.
2. BOSCO, C., P. LUHTANEN, and P. V. KOMI. A simple method for measurement of mechanical power in jumping. *Eur. J. Appl. Physiol.* 50:273–282, 1983.
3. BOSCO, C., M. CARDINALE, O. TSARPELA, R. COLLI, J. TIHANYI, S. VON DUVILLARD, and A. VIRU. The influence of whole body vibration on the mechanical behaviour of skeletal muscle. *Biol. Sport.* 153:157–164, 1998.
4. BOSCO, C., M. CARDINALE, and O. TSARPELA. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur. J. Appl. Physiol. Occup. Physiol.* 79:306–311, 1999a.
5. BOSCO, C., R. COLLI, E. INTROINI, et al. Adaptive responses of human skeletal muscle to vibration exposure. *Clin. Physiol.* 19: 183–187, 1999b.
6. CARROLL, T. J., S. RIEK, and R. G. CARSON. Neural adaptations to resistance training: implications for movement control. *Sports Med.* 31:829–840, 2001.
7. COYLE, E., C. FEIRIN, T. ROTKIS, R. COTE, F. ROBY, W. LEE, and J. WILMORE. Specificity of power improvements through slow and fast isokinetic training. *J. Appl. Physiol.* 51:1437–1442, 1981.
8. DE GAIL, P., J. W. LANCE, and P. D. NEILSON. Differential effects on tonic and phasic reflex mechanisms produced by vibration of muscles in man. *J. Neurol. Neurosurg. Psychiatry* 29:1–11, 1966.
9. FALEMPIN, M., S. F. IN-ALBON. Influence of brief daily tendon vibration on rat soleus muscle in non-weight-bearing situation. *J. Appl. Physiol.* 87:3–9, 1999.
10. FLIEGER, J., T. KARACHALIOS, L. KHALDI, P. RAPTOU, and G. LYRITIS. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif. Tissue Int.* 63:510–514, 1998.
11. HAGBARTH, K. E. The effect of muscle vibration in normal man and in patients with motor disease. In: *New Developments in Electromyography and Clinical Neurophysiology*. J. E. Desmedt (Ed.). Basel: Karger, 1973, pp. 428–443.
12. HEINONEN, A., H. SIEVÄNEN, J. VIITASALO, M. PASANEN, P. OJA, and I. VUORI. Reproducibility of computer measurement of maximal isometric strength and electromyography in sedentary middle-aged women. *Eur. J. Appl. Physiol.* 68:310–314, 1994.
13. HÄKKINEN, K., and P. KOMI. Electromyographic changes during strength training and detraining. *Med. Sci. Sports Exerc.* 15:455–460, 1983a.
14. HÄKKINEN, K., and P. KOMI. Changes in neuromuscular performance in voluntary and reflex contraction during strength training in man. *Int. J. Sports Med.* 4:282–288, 1983b.
15. HÄKKINEN, K., and P. KOMI. Effect of explosive type strength training on electromyographic and force production characteristics of leg extensors muscles during concentric and various stretch-shortening cycle exercises. *Scand. J. Sports Sci.* 7:65–76, 1985.
16. HÄKKINEN, K., M. ALLEN, and P. KOMI. Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol. Scand.* 125:573–585, 1985.
17. KOMI, P., J. VIITASALO, R. RAURAMAA, and V. VIHKO. Effect of isometric strength training on mechanical, electrical and metabolic aspects of muscle function. *Eur. J. Appl. Physiol.* 40:45–55, 1978.
18. MORITANI, T., and H. A. DeVRIES. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am. J. Phys. Med.* 58:115–130, 1979.
19. NEVITT, M. C., S. R. CUMMINGS, S. KIDD, and D. BLACK. Risk factors for recurrent nonsyncopal falls. A prospective study. *JAMA* 261:2663–2668, 1989.
20. NEVITT, M., and S. R. CUMMINGS. Falls and fractures in older women. In: *Falls, balance and gait disorders in elderly*. B. Vellas, M. Toupet, L. Rubenstein, J. Albaredo, and Y. Christen (Eds.). Paris:Elsevier, 1992, pp. 69–80.
21. RITTWEGER, J., G. BELLER, and D. FELSENBURG. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin. Physiol.* 20:134–142, 2000.
22. RUBENSTEIN, L. Z., K. R. JOSEPHSON, and A. S. ROBBINS. Falls in the nursing home. *Ann. Intern. Med.* 121:442–451, 1994.
23. RUBIN, C. and K. McLEOD. Promotion of bony ingrowth by frequency-specific, low-amplitude mechanical strain. *Clin. Orthop.* 298:165–174, 1994.
24. RUBIN, C., R. RECKER, D. CULLEN, J. RYABY, and K. McLEOD. Prevention of bone loss in a post-menopausal population by low-level biomechanical intervention. *Bone* 23:S174(Abstract), 1998a.
25. RUBIN, C., G. XU, and D. JUDEX. The anabolic activity of bone tissue, suppressed by disuse, is normalized by brief exposure to

Considering the effects of whole body vibration on falls and related fractures in elderly people, our study showed that the vibration-intervention had no direct influence on body balance. However, muscle power and strength are also important and independent predictors of functional performance and falls of older people (19,20,22,34); therefore, whole body vibration exercise may be efficient training stimulus for these people, too. Future studies should focus on comparing the performance-enhancing effects of whole body vibration to those of a conventional resistance training, and as a broader objective, on investigating the possible effects of vibration on structure and strength of bones, and perhaps on the incidence of falls of the elderly.

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- extremely low-magnitude mechanical stimuli. *FASEB J.* 15:2225–2229, 2001a.
26. RUBIN, C., S. TURNER, S. BAIN, C. MALLINCKRODT, and K. MCLEOD. Low mechanical signals strengthen long bones. *Nature* 412:603–604, 2001b.
 27. RUBIN, C., S. TURNER, R. MULLER, E. MITTRA, K. MCLEOD, W. LIN, and Y. QIN. Quantity and quality of trabecular bone in the femur are enhanced by a strongly anabolic, noninvasive mechanical intervention. *J. Bone Miner. Res.* 17:349–357, 2002a.
 28. RUBIN, C., S. TURNER, C. MALLINCKRODT, C. JEROME, K. MCLEOD, and S. BAIN. Mechanical strain, induced noninvasively in the high-frequency domain, is anabolic to cancellous bone, but not cortical bone. *Bone* 30:445–452, 2002b.
 29. RUNGE, M., G. REHFELD, and E. RESNICEK. Balance training and exercise in geriatric patients. *J. Musculoskel. Neuron. Interact.* 1:61–65, 2000.
 30. SALE, D. Neural adaptation to resistance training. *Med. Sci. Sports Exerc.* 20:135–145, 1988.
 31. SALE, D, and J. MACDOUGALL. Specificity in strength training: a review for the coach and the athlete. *Can. J. Appl. Sport Sci.* 6:87–92, 1981.
 32. SCHMITZ, R., and B. ARNOLD. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J. Sport Rehabil.* 7:95–101, 1998.
 33. SEIDEL, H. Myoelectrical reactions to ultra-low-frequency and low-frequency whole body vibration. *Eur. J. Appl. Physiol.* 57: 558–562, 1988.
 34. TINETT, M. E., and M. SPEECHLEY. Prevention of falls among the elderly. *N. Engl. J. Med.* 320:1055–1059, 1989.
 35. TORVINEN, S., P. KANNUS, H. STEVÄNEN, et al. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin. Physiol. Funct. Imaging* 22:145–152, 2002.
 36. UUSI-RASI, K., H. M. SALMI, and M. FOGELHOLM. Estimation of calcium and riboflavin intake by a short diary. *Scand. J. Nutr.* 38:122–124, 1994.



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