THE JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE
Volume 22, Number 12, 2016, pp. 970–976

DOI: 10.1089/acm.2016.0124

JACM

Whole-Body Vibration Exercise Therapy Improves Cardiac Autonomic Function and Blood Pressure in Obese Pre- and Stage 1 Hypertensive Postmenopausal Women

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Abstract

Objective: Whole-body vibration (WBV) is an unconventional exercise therapy that appears to provide the same benefits of resistance training in postmenopausal women while being more safe and gentle on the joints. This study evaluated the effect of an 8-week WBV exercise regimen on heart rate variability (HRV) and blood pressure (BP) in obese postmenopausal women.

Design: Randomized controlled study with two parallel groups.

Participants: Twenty-five (age 50–65 years) obese (body–mass index >30 and <40 kg/m^2) postmenopausal women.

Intervention: Participants were randomly assigned to a WBV training group or nonexercising control group. Participants in the WBV group completed the supervised training 3 times a week. WBV training consisted of four static and four dynamic leg exercises (normal, high, and wide-stance squats and calf-raises) with vertical vibration (25–40 Hz and low-high amplitude) progressed throughout the 8 weeks.

Outcome measures: Brachial systolic BP (SBP) and diastolic BP (DBP) and HRV: sympathovagal balance (natural logarithm of low frequency [LnLF]/natural logarithm of high frequency [LnHF]; normalized low frequency [nLF]/normalized high frequency [nHF]), parasympathetic tone (LnHF, nHF, natural logarithm of root mean square of successive differences [LnRMSSD]), sympathetic tone (LnLF, nLF), natural logarithm of total power, and heart rate (HR).

Results: There were significant group × time interactions ($p < 0.05$) for brachial SBP, DBP, LnLF/LnHF, and nLF/nHF that significantly decreased ($p < 0.01$) after WBV, compared with no changes after control. There was a significant ($p < 0.05$) increase in nHF and decrease in nLF in the WBV group compared with baseline, yet the changes were not different than those in the control group. No significant changes were observed in LnTP, LnLF, LnHF, LnRMSSD, or HR after 8 weeks in either group.

Conclusions: WBV training for 8 weeks is an adequate unconventional exercise intervention for improving sympathovagal balance and BP in previously sedentary obese postmenopausal women.

Keywords: heart rate variability, menopause, exercise, alternative therapy

Introduction

Heart rate variability (HRV) is a noninvasive tool for the evaluation of cardiac autonomic function and provides information on the risk for cardiovascular disease and all-cause mortality.[1,2] Menopause and obesity increase blood pressure (BP) and the risk for cardiovascular complications,[3,4] which may be, in part, due to cardiac autonomic dysfunction.[5–7] Consequently, HRV is adversely influenced by menopause[5] and obesity in women[7] due to an increase in sympathovagal balance that results from a reduction in parasympathetic (vagal) activity and enhancement of sympathetic activity. Moreover,

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increased sympathovagal balance plays an important role in the development of prehypertension and clinical hypertension in obese and postmenopausal women.[8–11] Therefore, the promotion of interventions that improve HRV and BP, such as exercise therapy, may have important clinical implications.[12]

Decreased HRV and vagal activity are associated with low muscle mass in overweight individuals.[13] Resistance training is well established as an effective exercise modality for improving muscle mass and strength in postmenopausal women.[14–16] However, a previous study by Gerage et al. showed no changes in HRV indices after a resistance training regimen in postmenopausal women.[17] Additionally, because of musculoskeletal discomfort, lack of time, and physical limitations, many obese postmenopausal women lack self-motivation to adhere to conventional resistance exercise programs, especially at high intensities.[18,19]

An alternative exercise modality for improvements in muscle strength in postmenopausal women[20–22] is whole-body vibration (WBV) training, which involves exercising on a vibrating platform that stimulates reflexive muscle contractions.[23] Compared with conventional resistance training, WBV training requires less time and provides similar increases in leg strength in postmenopausal women, indicating that WBV training is an efficient strength training method.[24] To the best of the authors' knowledge, only one study has investigated the effects of WBV training on HRV. This study showed that 6-week WBV training decreased systolic BP (SBP) and cardiac sympathovagal balance in young overweight/obese normotensive women via simultaneous improvements in sympathetic and parasympathetic modulation.[25] However, whether WBV training improves HRV in obese postmenopausal women is currently unknown. Because obese postmenopausal women have a high prevalence of cardiac autonomic dysfunction,[5–7] a condition associated with increased mortality in individuals with high cardiovascular risk,[26] examining the effects of WBV training on HRV in this population is clinically relevant. The purpose of this study was to evaluate the effect of an 8-week WBV training program on HRV and BP in obese postmenopausal women. The study hypothesis is that WBV training would improve HRV and BP in obese postmenopausal women.

Materials and Methods

Participants

Twenty-five (age 50–65 years) obese (body–mass index [BMI] >30 and <40 kg/m^2) postmenopausal women participated in the present study. Menopause was defined as the absence of menstruation for at least 1 year. Exclusion criteria included smoking, cardiovascular diseases, diabetes, other diseases that can influence the autonomic nervous system, musculoskeletal problems that would limit WBV exercises, and the use of medication or hormone replacement therapy during the 6 months before the study. All women were sedentary, defined as performing less than 1 hour of regular exercise per week in the previous year. Participants were recruited from Tallahassee, Florida, and surrounding areas through flyers and word of mouth. All participants gave written informed consent before their inclusion in the study. The study protocol was approved by the Institutional Human Subject committee and registered in ClinicalTrials.gov (NCT02143817).

Study design

Before baseline measurements, participants were familiarized with the study tests and procedures and were randomly assigned to a WBV training group ($n = 13$) or a nonexercising control group ($n = 12$). Allocation was stratified for BMI [>30.0 < 35 kg/m^2 ($n = 6$ in WBV and $n = 7$ in control group) or ≥35 < 40 kg/m^2 ($n = 7$ in WBV and $n = 5$ in control)], and the sequence was generated by a computer-based number. Measurements were collected at baseline and after 8 weeks during the same time of day (±1 hour) in the morning after an overnight fast and abstinence from caffeinated drinks, alcohol, and between 48 and 72 hours after the last exercise session. Participants were instructed not to alter their regular lifestyle habits during the study. Physical activity levels were estimated by the use of the physical activity scale for the elderly questionnaire (PASE). In addition, to minimize dietary variability the participants were required to submit 3-day food records. Both the PASE and the 3-day food records were submitted by the participants at baseline and at 8 weeks of the assigned intervention.

WBV training

Participants in the WBV group completed the supervised training 3 times a week, separated by at least 48 hours for 8 weeks. Participants performed four static and four dynamic leg exercises on a vibration platform (pro5 AIRdaptive; Performance Health Systems, Northbrook, IL) which delivers vertical vibrations at different selected frequencies with low or high amplitude. Considering 180° as full knee extension, exercises were squats at 90° and 120° knee angle with normal stance, squat at 120° knee angle with wide stance, and calf raises with maximal heel elevation. Static exercises were performed with maintaining the joint angles without movement.[21] Dynamic exercises were performed with slow-controlled movements starting from an upright position to the assigned knee angles (90° and 120°) described for the three types of squat and also with moving the heels from maximal elevation to below the platform for the calf raises. The movement during dynamic exercises was controlled by the use of a metronome at a rate of 3 seconds eccentric/2 seconds concentric phases. The exercises were performed without shoes (wearing socks only) in order to standardize the dampening of the vibration and consequently maximize muscle contractions through the tonic vibration reflex. Training intensity and volume were progressed by increasing the intensity of vibration (25–40 Hz of frequency and low to high amplitude, resulting in peak acceleration between 4.3 and 21.3 g[27]), duration of the exercise set (30–60 seconds), number of sets (1–5 seconds), total duration of the training session (11–60 minutes), and decreasing the duration of rest periods (60–30 seconds). The training protocol was based on previous studies that showed improvements in HRV, BP, and arterial function in young and postmenopausal obese women.[20,25,28] Additionally, the control group did not participate in any supervised exercise.

Heart rate variability

Resting R-R interval measurements were performed in the supine position after at least 10 minutes of rest in a quiet, temperature-controlled room (23 ± 1°C). R-R intervals were

Table 1. Participant Characteristics, Physical Activity Levels, and Dietary Composition Before and After 8 weeks of Whole-Body Vibration or Control

Variable	*Control* Before	*Control* After	*WBV training* Before	*WBV training* After
Age (yr)	59 ± 1	–	58 ± 1	–
Height (m)	1.64 ± 0.02	–	1.60 ± 0.02	–
Body weight (kg)	91.1 ± 4.1	90.7 ± 4.0	88.9 ± 3.0	89.4 ± 3.2
BMI (kg/m^2)	33.7 ± 1.2	33.6 ± 1.2	34.9 ± 1.0	35.1 ± 1.1
Systolic BP (mm Hg)	137 ± 4	137 ± 4	139 ± 3	131 ± 4[a,b]
Diastolic BP (mm Hg)	80 ± 2	79 ± 2	80 ± 3	74 ± 4[a,b]
PASE score	126 ± 3	128 ± 4	125 ± 4	127 ± 4
Total kcal/d	2640 ± 79	2644 ± 66	2720 ± 83	2741 ± 80

[a]$p < 0.01$ compared with before intervention.
[b]$p < 0.05$ compared with control.
WBV, whole-body vibration; BMI, body mass index; BP, blood pressure; PASE, Physical Activity Scale for the Elderly.

collected during 6 minutes using a validated wireless monitor[29] (Polar 800CX; Polar Electro OY, Kempele, Finland) via a chest strap interfaced with a PC. All R-R intervals were inspected for artifacts and premature beats. HRV was quantified from 5-minute segments free of artifacts. As a time domain index of HRV, the root mean square of successive differences (RMSSD), which reflects parasympathetic modulation, was calculated.[30] The autoregressive model was used to estimate the power spectrum in the total power (TP; 0.00–0.40 Hz) and its main components: low frequency (LF; 0.04–0.15 Hz) and high frequency (HF, 0.15–0.40 Hz). TP of HRV is an estimation of the global activity of the autonomic nervous system. The HF power is a marker of cardiac parasympathetic activity.[31,32] The LF component of HRV in absolute units is mediated by both sympathetic and parasympathetic activities.[32]

The HF and LF were normalized (nHF and nLF) and expressed as a percentage of the TP, considered as HF+LF.[32] The nHF and nLF are defined as HF or LF/(LF+HF), expressing the spectral power as the relative (percentage) contribution of the sympathetic (nLF) and parasympathetic (nHF) activities on the sinoatrial node. Additionally, it removes most of the very large within- and across-participant variability in the total raw HRV spectral power.[33] The ratio of LF to HF (LF/HF) could be used to quantify the relationship between sympathetic and parasympathetic nerve activities (sympathovagal balance).[31] Increased sympathovagal balance was considered a reflection of sympathetic predominance.[31] The standards for the measurement and interpretation of the HRV were followed.[32] Controlled breathing (12 breaths/min) was maintained by following a metronome.

Blood pressure

Resting brachial BP was measured by using an automatic device (VP-2000; Omron Healthcare, Vernon Hills, IL). Two measurements at 1-minute interval were collected and averaged at each time point. In the authors' laboratory, the intraclass correlation coefficient for resting BP collected on two separate days is 0.95.

Statistical analysis

Data were examined for normality with the Shapiro–Wilk test. Because TP, RMSSD, LF, HF, and LF/HF were not normally distributed, a logarithmic transformation (Ln) was performed for these variables. The Student *t*-test was used to detect possible difference in parameters between groups at baseline. A two-way analysis of variance with repeated measures (group [control and WBV] × time [before and after 8 weeks]) was used to determine the effects of the intervention over time. If a significant interaction or main effect was noted, a paired *t*-test was used for post hoc comparisons. Data are shown as means ± standard error of the mean. Statistical significance was defined a priori as $p < 0.05$. Statistical analyses were performed by using SPSS software, version 21.0 (IBM SPSS Analytics, Armonk, NY). A power calculation done a priori determined that a population of 24 participants would allow the observation of a difference of 3%–5% between the groups (WBV versus control) on the primary study outcome variables of HF and LF/HF with a power of 80%.[25]

Results

Age, height, anthropometry, brachial BP, physical activity levels, and dietary composition values before and after 8 weeks for the control and WBV groups are presented in Table 1. Baseline parameters in the two groups were not significantly different. There were no significant changes in body weight, BMI, PASE score, and dietary composition after WBV or control.

Autonomic variables at baseline and after 8 weeks for the control and WBV groups are presented in Table 2. There was a significant group × time interaction ($p < 0.05$) for LnLF/LnHF and nLF/nHF, which significantly decreased ($p < 0.05$) following WBV, compared with no changes after control. There were a significant ($p < 0.05$) increase in nHF and decrease in nLF in the WBV group in comparison with baseline, but the changes were not different compared with the control. LnTP, LnRMSSD, LnLF, LnHF, and HR did not significantly differ after WBV or control. There was a significant group × time interaction ($p < 0.05$) for brachial SBP and DBP, which significantly decreased ($p < 0.01$) following WBV compared with no changes after control.

Discussion

This study evaluated the effects of an 8-week WBV training program on HRV in obese postmenopausal women. The major finding of this study is that 8 weeks of WBV

TABLE 2. HEART RATE AND HEART RATE VARIABILITY MEASUREMENTS BEFORE AND AFTER 8 WEEKS OF WBV TRAINING OR CONTROL

	Control		*WBV training*	
Variable	*Before*	*After*	*Before*	*After*
Heart rate (beats/min)	66 ± 2	66 ± 2	67 ± 2	65 ± 2
Frequency domain				
LnTP (msec^2)	6.70 ± 0.23	6.68 ± 0.21	6.61 ± 0.22	6.73 ± 0.19
nLF (%)	55.9 ± 4.3	54.2 ± 3.9	51.5 ± 6.1	43.3 ± 6.3[a]
nHF (%)	43.6 ± 4.1	45.7 ± 3.9	48.4 ± 6.2	56.6 ± 6.5[a]
nLF/nHF	1.2 ± 0.4	1.2 ± 0.3	1.1 ± 0.4	0.8 ± 0.4[a,b]
LnLF (msec^2)	5.56 ± 0.22	5.65 ± 0.21	5.28 ± 0.29	5.08 ± 0.31
LnHF (msec^2)	5.18 ± 0.25	5.26 ± 0.23	5.26 ± 0.27	5.48 ± 0.22
LnLF/LnHF	1.09 ± 0.04	1.08 ± 0.03	1.02 ± 0.05	0.93 ± 0.06[b,c]
Time domain				
LnRMSSD (msec)	3.31 ± 0.13	3.37 ± 0.13	3.28 ± 0.11	3.37 ± 0.10

Data are mean ± standard error of mean.
[a]$p < 0.05$ compared with before intervention.
[b]$p < 0.05$ compared with control.
[c]$p < 0.01$ compared with before intervention.
Ln, natural logarithm; TP, total power; n, normalized to TP; LF, low frequency; HF, high frequency; LF/HF, LF to HF ratio; RMSSD, root mean square of successive differences.

training improved the cardiac sympathovagal balance by a simultaneous increase in nHF power and decrease in nLF power. These findings suggest that WBV improves cardiac autonomic modulation by increasing vagal tone and decreasing sympathetic activity in obese postmenopausal women. Moreover, WBV training induced an important antihypertensive effect in women with prehypertension and stage 1 hypertension.

The findings indicate that WBV produced a significant increase in nHF (although a time effect only), reflecting an improved cardiovagal modulation. This observation is consistent with the authors' previous work, which showed increases in HF after WBV training in obese premenopausal women.[25] WBV training may be considered a resistance training modality because its improvements in muscle strength and mass are similar to those of conventional resistance training.[22,24] Although resistance training may improve cardiovagal activity, as shown through increases in RMSSD in middle-aged and older adults,[34,35] some studies have not found increases in HF power after 8 weeks and 8 months in young[36] and older healthy adults.[37] In contrast, two studies found negative effects of high-intensity resistance training on HRV in middle-aged prehypertensive individuals and healthy older men.[38,39] Since many obese postmenopausal women may not be willing to perform intense resistance exercise because of a lack of self-motivation and discomfort,[18] WBV might be an alternative intervention to improve cardiovagal activity in postmenopausal women.

WBV training produced a significant decrease in the nLF (time effect) and LnLF/LnHF ratio. The authors previously reported similar decreases in LF and LF/HF in premenopausal women after 6 weeks of WBV training.[25] In addition, WBV training prevented the increase in sympathovagal balance induced by 60 days of head-down bed rest in young Asian men.[40] In contrast to the current findings, previous studies showed no changes in nLF and LF/HF ratio following resistance[41] or aerobic[42] exercise training in postmenopausal women. The current results have important clinical implications because a reduced sympathovagal balance is associated with greater longevity[43] and lower risk for hypertension.[8–11,44] Thus, decreased sympathovagal balance after WBV may reduce cardiovascular risk in obese postmenopausal women.

Although not significant, HR showed a slight decrease after 8 weeks of WBV training (approximately 2 beats/min; $p = 0.08$), which may have physiologic significance. This finding agrees with those of the authors' previous study, which found a nonsignificant decrease (approximately 1 beat/min) in resting HR after 6 weeks of WBV training (1–2 sets per exercise) in postmenopausal women.[20] In contrast, the authors have previously reported significant decreases in HR (approximately 3 beats/min) after 12 weeks of WBV training (1–6 sets per exercise) in the same population.[45] Thus, it appears that the decrease in resting HR induced by WBV in postmenopausal women is influenced by the volume and duration of training. Indeed, the authors' previous reports have demonstrated decreases in resting HR following 6 weeks of WBV in premenopausal[25] but not in postmenopausal[20] women, suggesting that longer training periods are required to decrease resting HR in older women. Decreases in resting HR with training also appear to be influenced by exercise intensity because light-intensity interventions (aerobic or resistance)[46,47] have no effect on resting HR in postmenopausal women. WBV training is considered a low-intensity exercise modality because middle-aged adults can perform 15–20 repetitions per set.[48]

This study found decreases in brachial SBP and DBP after WBV training. This observation is consistent with a previous study by Figueroa et al., who found reductions on brachial SBP in overweight/obese normotensive young women who underwent 6 weeks of WBV training.[25] In addition, previous studies by the current authors found significant decreases in brachial SBP and DBP after 6[20] and 12[28] weeks of WBV training in obese postmenopausal women with prehypertension and hypertension. Therefore, the current study reemphasizes the notion that WBV training is an effective intervention for improving BP in obese postmenopausal women.

The potential mechanisms underlying the effect of WBV training on HRV may be an increase in baroreflex sensitivity.[38,49] Certainly, evidence suggests that WBV training limits the decrease of the spontaneous baroreflex sensitivity induced by prolonged head-down bed rest in young healthy men.[40] Another potential mechanism could be an increase in nitric oxide (NO) levels. Several lines of evidence point out that NO may play a role in cardiac autonomic function by increasing vagal and decreasing sympathetic activity.[50–52] In fact, WBV training has been shown to increase circulating NO in women.[53] Hence, increases in NO via WBV training may, to some extent, improve cardiac autonomic activity. Another potential mechanism for a shift toward vagal dominance may be a decrease in circulating angiotensin II, which is known to inhibit cardiac vagal activity.[54] Exercise training reduces the sympatho-excitatory process by reducing angiotensin II.[55] Additionally, researchers have also reported that daily vibration for 2 months in rats produced decreases in angiotensin II levels, along with suppression of the renin-angiotensin-aldosterone system.[56] Because decreased NO and increased angiotensin II levels play a major role in hypertension after menopause[57] and the current study showed improvements in BP, it is possible that the effect of WBV training on cardiac autonomic activity can be mediated, at least in part, by these two major regulators of vascular function.

Potential limitations of this study include the lack of measurements of baroreflex sensitivity and plasma catecholamines and angiotensin II, which would have helped explain the results. The study evaluated cardiac autonomic function in obese postmenopausal women, and, hence, the results cannot be generalized to other populations. It could be argued that the effects of WBV training are due to exercise without vibration. Acute decreases in BP and arterial stiffness have been demonstrated after a session of squat exercise with but not without WBV.[58] Moreover, reductions in arterial stiffness and BP have been shown in obese young and postmenopausal women after WBV training.[25,59] Because aortic stiffness is associated with reduced cardiovagal baroreflex function,[60] decreases in arterial stiffness and BP may explain the reduction in LF/HF observed after WBV training in obese young women.[25] However, the effects of exercise without WBV or passive vibration training on cardiovascular function are currently unknown.

Conclusions

The data from this study indicate that WBV for 8 weeks improves sympathovagal balance and BP in sedentary obese postmenopausal women with prehypertension and stage 1 hypertension. This appears to be the first investigation reporting the effects of WBV training on HRV in this population. In conclusion, WBV training may be a feasible adjuvant treatment to improve cardiac autonomic function and moderately high BP in obese postmenopausal women.

Acknowledgments

The authors thank the trainers and are grateful to the participants. They also thank Performance Health Systems for providing the vibration machines. A.W.K. was supported by T32DK062710 during the final Journal preparation of this manuscript.

Author Disclosure Statement

No competing financial interests exist.

References

1. Tsuji H, Larson MG, Venditti FJ, et al. Impact of reduced heart rate variability on risk for cardiac events: the Framingham Heart Study. Circulation 1996;94:2850–285.
2. Dekker MKJ, Schouten EG, Klootwijk P, Pool J, Cees A, Kromhout D. Heart rate variability from short electrocardiographic recordings predicts mortality from all causes in middle-aged and elderly men. Am J Epidemiol 1997;145:899–908.
3. Hubert HB, Feinleib M, McNamara PM, Castelli WP. Obesity as an independent risk factor for cardiovascular disease: a 26-year follow-up of participants in the Framingham Heart Study. Circulation 1983;67:968–977.
4. Rosano GMC, Vitale C, Marazzi G, Volterrani M. Menopause and cardiovascular disease: the evidence. Climacteric 2007;10 Suppl 1:19–24.
5. Brockbank CL, Chatterjee F, Bruce SA, Woledge RC. Heart rate and its variability change after the menopause. Exp Physiol 2000;85:327–330.
6. Gao Y, Lovejoy J, Sparti A, Bray G, Keys L, Partington C. Autonomic activity assessed by heart rate spectral analysis varies with fat distribution in obese women. Obes Res 1996;4:55–63.
7. Zahorska-Markiewicz B, Kuagowska E, Kucio C, Klin M. Heart rate variability in obesity. Int J Obes Relat Metab Disord 1993;17:21–23.
8. Kim JA, Park Y-G, Cho K-H, et al. Heart rate variability and obesity indices: emphasis on the response to noise and standing. J Am Board Fam Pract 2005;18:97–103.
9. Moodithaya SS, Avadhany ST. Comparison of cardiac autonomic activity between pre and post menopausal women using heart rate variability. Indian J Physiol Pharmacol 2009;53:227–234.
10. Pal G, Chandrasekaran A, Hariharan A, et al. Body mass index contributes to sympathovagal imbalance in prehypertensives. BMC Cardiovasc Disord 2012;12:54.
11. Pal GK, Adithan C, Amudharaj D, et al. Assessment of sympathovagal imbalance by spectral analysis of heart rate variability in prehypertensive and hypertensive patients in Indian population. Clin Exp Hypertens 2011;33:478–483.
12. Routledge FS, Campbell TS, McFetridge-Durdle JA, Bacon SL. Improvements in heart rate variability with exercise therapy. Can J Cardiol 2010;26:303–312.
13. Baek J, Park D, Kim I, Won J-U, Hwang J, Roh J. Autonomic dysfunction of overweight combined with low muscle mass. Clin Auton Res 2013;23:325–331.
14. Figueroa A, Going SB, Milliken LA, et al. Effects of exercise training and hormone replacement therapy on lean and fat mass in postmenopausal women. J Gerontol A Biol Sci Med Sci 2003;58:266–270.
15. Casey DP, Pierce GL, Howe KS, Mering MC, Braith RW. Effect of resistance training on arterial wave reflection and brachial artery reactivity in normotensive postmenopausal women. Eur J Appl Physiol 2007;100:403–408.
16. Fjeldstad C, Palmer IJ, Bemben MG, Bemben DA. Whole-body vibration augments resistance training effects on body composition in postmenopausal women. Maturitas 2009;63: 79–83.
17. Gerage AM, Forjaz CLM, Nascimento MA, Januário RSB, Polito MD, Cyrino ES. Cardiovascular adaptations to resistance training in elderly postmenopausal women. Int J Sports Med 2013;34:806–813.

18. Guérin E, Fortier MS. Situational motivation and perceived intensity: their interaction in predicting changes in positive affect from physical activity. J Obes 2012;2012: 269320.
19. O'Neill K, Reid G. Perceived barriers to physical activity by older adults. Can J Public Health 1991;82:392–396.
20. Figueroa A, Kalfon R, Madzima TA, Wong A. Whole-body vibration exercise training reduces arterial stiffness in postmenopausal women with prehypertension and hypertension. Menopause 2014;21:131–136.
21. Machado A, García-López D, González-Gallego J, Garatachea N. Whole-body vibration training increases muscle strength and mass in older women: a randomized-controlled trial. Scand J Med Sci Sports 2010;20:200–207.
22. 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.
23. Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. J Strength Cond Res 2003;17:621–624.
24. Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. Int J Sport Med 2004;25:1–5.
25. Figueroa A, Gil R, Wong A, et al. Whole-body vibration training reduces arterial stiffness, blood pressure and sympathovagal balance in young overweight/obese women. Hypertens Res 2012;35:667–672.
26. Schwartz PJ, La Rovere MT, Vanoli E. Autonomic nervous system and sudden cardiac death. Experimental basis and clinical observations for post-myocardial infarction risk stratification. Circulation 1992;85(1 Suppl):I77-I91.
27. Muir J, Kiel DP, Rubin CT. Safety and severity of accelerations delivered from whole body vibration exercise devices to standing adults. J Sci Med Sport 2013;16: 526–531.
28. Figueroa A, Kalfon R, Madzima TA, Wong A. Effects of whole-body vibration exercise training on aortic wave reflection and muscle strength in postmenopausal women with prehypertension and hypertension. J Hum Hypertens 2014;28:118–122.
29. Nunan D, Gay D, Jakovljevic DG, Hodges LD, Sandercock GRH, Brodie DA. Validity and reliability of short-term heart-rate variability from the Polar S810. Med Sci Sports Exerc 2009;41:243–250.
30. Kleiger RE, Stein PK, Bosner MS, Rottman JN. Time domain measurements of heart rate variability. Cardiol Clin 1992;10:487–498.
31. Pagani M, Lombardi F, Guzzetti S, et al. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympatho-vagal interaction in man and conscious dog. Circ Res 1986;59:178–193.
32. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 1996; 93:1043–1065.
33. Burr RL. Interpretation of normalized spectral heart rate variability indices in sleep research: a critical review. Sleep 2007;30:913–919.
34. Caruso FR, Arena R, Phillips SA, et al. Resistance exercise training improves heart rate variability and muscle performance: a randomized controlled trial in coronary artery disease patients. Eur J Phys Rehabil Med 2015;51: 281–289.
35. Figueroa A, Kingsley JD, McMillan V, Panton LB. Resistance exercise training improves heart rate variability in women with fibromyalgia. Clin Physiol Funct Imaging 2008; 28:49–54.
36. Carter JR, Ray CA, Downs EM, Cooke WH. Strength training reduces arterial blood pressure but not sympathetic neural activity in young normotensive subjects. J Appl Physiol 2003;94:2212–2216.
37. Wanderley FAC, Moreira A, Sokhatska O, et al. Differential responses of adiposity, inflammation and autonomic function to aerobic versus resistance training in older adults. Exp Gerontol 2013;48:326–333.
38. Collier SR, Kanaley JA, Carhart R, et al. Cardiac autonomic function and baroreflex changes following 4 weeks of resistance versus aerobic training in individuals with prehypertension. Acta Physiol 2009;195:339–348.
39. Melo RC, Quitério RJ, Takahashi ACM, Silva E, Martins LEB, Catai AM. High eccentric strength training reduces heart rate variability in healthy older men. Br J Sports Med 2008;42:59–63.
40. Coupé M, Yuan M, Demiot C, et al. Low-magnitude whole body vibration with resistive exercise as a countermeasure against cardiovascular deconditioning after 60 days of head-down bed rest. Am J Physiol Regul Integr Comp Physiol 2011;301:R1748–R1754.
41. Ryan AS, Pratley RE, Elahi D, Goldberg AP. Resistive training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women. J Appl Physiol 1995;79:818–823.
42. Jurca R, Church TS, Morss GM, Jordan AN, Earnest CP. Eight weeks of moderate-intensity exercise training increases heart rate variability in sedentary postmenopausal women. Am Heart J 2004;147:e21.
43. Piccirillo G, Bucca C, Bauco C, et al. Power spectral analysis of heart rate in subjects over a hundred years old. Int J Cardiol 1998;63:53–61.
44. Tadic M, Cuspidi C, Pencic B, Marjanovic T, Celic V. The association between heart rate variability and biatrial phasic function in arterial hypertension. J Am Soc Hypertens 2014; 8:699–708.
45. Figueroa A, Wong A, Kalfon R. Effects of watermelon supplementation on aortic hemodynamic responses to the cold pressor test in obese hypertensive adults. Am J Hypertens 2014;27:899–906.
46. Figueroa A, Alvarez-Alvarado S, Ormsbee MJ, Madzima TA, Campbell JC, Wong A. Impact of L-citrulline supplementation and whole-body vibration training on arterial stiffness and leg muscle function in obese postmenopausal women with high blood pressure. Exp Gerontol 2015;63:35–40.
47. Sugawara J, Inoue H, Hayashi K, Yokoi T, Kono I. Effect of low-intensity aerobic exercise training on arterial compliance in postmenopausal women. Hypertens Res 2004;27: 897–901.
48. Tapp LR, Signorile JF. Efficacy of WBV as a modality for inducing changes in body composition, aerobic fitness, and muscular strength: a pilot study. Clin Interv Aging 2014;9: 63–72.
49. Kouidi E, Vergoulas G, Anifanti M, Deligiannis A. A randomized controlled trial of exercise training on cardiovascular and autonomic function among renal transplant recipients. Nephrol Dial Transplant 2013;28:1294–1305.

50. Conlon K, Collins T, Kidd C. Modulation of vagal actions on heart rate produced by inhibition of nitric oxide synthase in the anaesthetized ferret. Exp Physiol 1996;81:547–550.
51. Hare JM, Keaney JF, Balligand JL, Loscalzo J, Smith TW, Colucci WS. Role of nitric oxide in parasympathetic modulation of beta-adrenergic myocardial contractility in normal dogs. J Clin Invest 1995;95:360–366.
52. Zanzinger J, Czachurski J, Seller H. Inhibition of basal and reflex-mediated sympathetic activity in the RVLM by nitric oxide. Am J Physiol 1995;268(4 Pt 2):R958–R962.
53. Humphries B, Fenning A, Dugan E, Guinane J, MacRae K. Whole-body vibration effects on bone mineral density in women with or without resistance training. Aviat Space Environ Med 2009;80:1025–1031.
54. Townend JN, al-Ani M, West JN, Littler WA, Coote JH. Modulation of cardiac autonomic control in humans by angiotensin II. Hypertension 1995;25:1270–1275.
55. Zucker IH, Schultz HD, Patel KP, Wang H. Modulation of angiotensin II signaling following exercise training in heart failure. Am J Physiol Heart Circ Physiol 2015;308:H781–H791.
56. Kapanadze NA. [Changes of concentration of renin-angiotensin system components during vibration and their correction in experiment]. Georgian Med News 2007;(145):85–87.
57. Hernandez Schulman I, Raij L. Salt sensitivity and hypertension after menopause: role of nitric oxide and angiotensin II. Am J Nephrol 2006;26:170–180.
58. Figueroa A, Vicil F, Sanchez-Gonzalez MA. Acute exercise with whole-body vibration decreases wave reflection and leg arterial stiffness. Am J Cardiovasc Dis 2011;1:60–67.
59. Figueroa A, Kalfon R, Wong A. Whole-body vibration training decreases ankle systolic blood pressure and leg arterial stiffness in obese postmenopausal women with high blood pressure. Menopause 2014;22:1–5.
60. Mattace-Raso FU, van den Meiracker AH, Bos WJ, et al. Arterial stiffness, cardiovagal baroreflex sensitivity and postural blood pressure changes in older adults: the Rotterdam Study. J Hypertens 2007;25:1421–1426.

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