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Original article

Acute effects of whole-body vibration with resistance exercise on postexercise blood pressure and oxygen consumption in prehypertensive adults

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Abstract

Background/Objective: Research on the acute health effects of whole-body vibration with resistance exercise (WBV + RE) for clinical populations is limited. This randomized crossover trial evaluated postexercise hypotension and excess postexercise oxygen consumption (EPOC) in response to three conditions: WBV + RE, RE alone, and control (CON) in 11 prehypertensive (systolic/diastolic blood pressure: 120–139/80–89 mmHg) adults.

Methods: Following a 12-hour fast with no exercise for the previous 24 hours, resting VO_2 and blood pressure (BP) were measured. WBV + RE was performed while standing barefoot on a vibration platform (Pneumex Pro-Vibe) and lifting a bar of 10% body weight. Fifteen repetitions of nine exercises were performed using a 1-minute-to-30-second exercise:rest ratio. RE was identical to WBV + RE but without vibration. During CON, participants remained seated for 15 minutes. Following exercise, VO_2 was measured continuously and BP every 15 minutes for 3 hours.

Results: Postexercise hypotension and EPOC were significantly different for WBV + RE compared with RE and CON ($p < 0.001$). Postexercise systolic BP was significantly lower for WBV + RE as compared with RE or CON, while diastolic BP was lower for both WBV + RE and RE compared with CON ($p < 0.001$; WBV + RE: $124 \pm 2/72 \pm 6$ mmHg; RE: $126 \pm 2/71 \pm 6$ mmHg; CON: $128 \pm 2/73 \pm 6$ mmHg). EPOC was significantly ($p < 0.001$) higher at 15 minutes postexercise for WBV + RE as compared with RE.

Conclusion: Compared with RE alone, a single bout of WBV + RE resulted in a greater postexercise hypotension response and higher EPOC. Copyright © 2016, The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Keywords: Excess postexercise oxygen consumption; Hypertension; Postexercise hypotension; Prehypertension

Introduction

According to the World Health Organization,¹ more than a third of the world's deaths can be attributed to a few inter-related factors such as physical inactivity, hypertension, and obesity. Furthermore, United States(US) data¹ indicate that only 26% of US adults engage in the recommended levels

of physical activity. This inactivity compounds the risk of obesity and hypertension, and is a clear precursor of other health risk factors. Additionally, although hypertension is a major independent risk factor for cardiovascular disease, in fact, those with *prehypertension*, defined as slightly elevated resting blood pressure (BP) values [systolic BP (SBP) 120–139 mmHg or diastolic BP (DBP) 80–89 mmHg], are also at higher risk of stroke,² end-stage renal disease,³ and cardiovascular morbidity and mortality.⁴ Currently, the *only* recommended treatment for prehypertension is to modify lifestyle, typically in the form of a physical activity intervention.⁵ Unfortunately, the often cited reason for those

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who do not engage in physical activity is a “lack of time.”⁶ Thus, studies examining the efficacy of novel, time-efficient, exercise interventions [such as whole-body vibration (WBV) exercise] to increase physical activity while reducing BP burden and optimizing energy expenditure are warranted.

WBV exercise is a novel exercise training option that can reduce the time requirement for achieving significant musculoskeletal gains. WBV exercise is performed while standing on a platform that generates repeated and rapid oscillations, promoting automatic body adaptations.⁷ These dynamic oscillations generate repeated and intense eccentric–concentric muscular contractions that enhance the normal muscular work being performed. Adding resistance exercise (RE; i.e., weight lifting) to WBV (WBV + RE) has been shown to increase the oxygen cost of exercise compared with RE alone.^{8–10} In addition, compared with traditional exercise training programs, a WBV + RE program requires less time, allowing it to be more appealing to previously inactive people.

It is well established that following exercise, oxygen consumption is increased beyond that of resting levels.^{11,12} This excess postexercise oxygen consumption (EPOC) has been implicated as a possible contributor to weight loss success in response to exercise programs.¹³ EPOC has been shown to increase in a linear fashion with exercise intensity.¹⁴ As WBV exercise has been speculated to be more intense than traditional RE, the magnitude and duration of EPOC may be greater with WBV exercise than with traditional RE.

It is well documented that acute moderate- to vigorous-intensity exercise (aerobic or resistance) can result in post-exercise hypotension (PEH).^{15–17} Evaluating the BP response following exercise is important because it is often predictive of chronic hypertension and cardiovascular health.¹⁸ PEH is defined as a sustained reduction in SBP, DBP, or both below control levels after a single bout of exercise,¹⁹ and results primarily from changes in cardiac output, total peripheral resistance, or both.¹⁹ Exercise such as WBV, which causes an increase in muscle perfusion to the lower extremities,²⁰ may acutely²¹ as well as chronically²² result in a decrease in arterial stiffness, which should induce a BP-lowering effect following exercise.

Assessments of the health effects of WBV in clinical settings are in their infancy. Moreover, the results from the literature are difficult to compare because of nonstandardized vibration conditions and/or variable RE formats. The standardized RE prescription for public health²³ is known to induce many beneficial responses; however, the response to an acute WBV routine that adds RE to approximate this standardized prescription is unknown.

The purpose of this study was to compare acute effects of three conditions: WBV + RE, RE alone, and control (CON) on differences in PEH and EPOC in prehypertensive adults. It was hypothesized that WBV + RE would invoke a greater reduction in BP (both magnitude and duration) and would elicit greater EPOC following exercise as compared with RE or CON.

Methods

Experimental approach to the problem

The acute differences in postexercise VO_2 and BP were investigated using a randomized crossover design with three conditions. Following participant consent, baseline height, weight, and resting BP were measured. Body composition was assessed using whole body air displacement plethysmography (Bod Pod, Cosmed USA Inc, Concord, CA). Participants performed a graded treadmill test, which is used to assess peak oxygen consumption (VO_2 peak), and then were scheduled for the three experimental conditions. The protocol was approved by the Institutional Review Board of Arizona State University, Phoenix, AZ, USA and each participant signed a written informed consent prior to participation in the study.

Participants

Eleven prehypertensive (SBP >120–<140 mmHg and/or DBP >80–<90 mmHg) men ($n = 9$) and women ($n = 2$) aged 20–65 years were randomly assigned to complete each of the three conditions: nonexercise control day (CON), resistance exercise alone (RE), and whole-body vibration plus resistance exercise (WBV + RE). Individuals were excluded from the study if they (1) had known cardiovascular, pulmonary, renal, or metabolic disease; (2) had symptoms suggestive of these diseases; (3) were current smokers; (4) had orthopedic limitations for performing physical activity; and (5) had obesity to the extent that the largest BP cuff would not fit properly.

Procedures

The three conditions were separated by 1 week, and performed at exactly the same time and day of the week to minimize differences in a participant's daily routine and to account for diurnal variation. During all three visits, the participants were asked not to change activity or eating habits between trials, and they were asked to eat and drink the same items in the same amount during the day prior to each laboratory visit. A food recall was used to assess a participant's compliance with these dietary requests. Finally, for each condition, the participants were asked to refrain from prior physical activity for 24 hours and to come to the laboratory in a fasted state (8–12 hours without food).

Blood pressure screening

For all participants, three BP measurements were taken on two separate occasions 3 days apart with an automated BP monitor (Dinamap PRO 100 Vital Signs Monitor; GE Healthcare, Chicago, IL) according to the protocol described by the World Health Organization.²⁴ On the 1st day, BP was measured in both arms. The arm with the highest BP was used for screening on the 2nd day. A total of six measurements were averaged together and used for determining if the participants met the prehypertensive BP criteria. After meeting the

prehypertensive BP criteria, the participants completed physical activity and health history questionnaires, their height and weight were measured, and their body composition was assessed using whole-body air displacement plethysmography (BOD POD; Cosmed, Concord, CA, USA).

VO₂ peak assessment

A graded exercise treadmill test was administered to all the participants to assess peak oxygen consumption (VO₂ peak). The participants were fitted with a heart rate monitor and a two-way non-rebreathing valve and mask (Hans Rudolph, Shawnee, KS, USA). The protocol performed was a modified Bruce protocol. The participants were asked to begin walking at a rate of 45.6 m/min at a 0% incline. Every 3 minutes the walking speed or grade was increased, while expired gas was analyzed breath by breath using indirect calorimetry (TrueOne 2400 metabolic cart; ParvoMedics, Inc., Sandy, UT, USA). The test was stopped when a participant requested to stop or could no longer continue exercise.

Resistance exercise

The RE exercise routine used was based on American College of Sports Medicine public health guidelines for resistance training.²³ The participants were asked to hold a padded “body bar” in their hands that represented 10% of their body weight (i.e., a 90 kg person held a 9 kg bar). Each person was asked to perform one set of 15 repetitions of each of nine exercises. The nine exercises included dynamic squat, sumo squat, right and left lunge, push up (hands on platform, feet off), push press, bent over row, bicep curl, and triceps extension. A rest period of 30 seconds was allotted between exercises. The rate of perceived exertion (RPE) on a scale of 6–20 was assessed after each exercise. Proper body position, lifting form, and breathing were stressed throughout the exercise routine. Each eccentric and concentric phase of the exercise was timed at 2 seconds. Total time to completion was approximately 15 minutes (exercise + rest time). Each of the nine exercises were rotated between lower and upper body. For the RE condition, the participants performed exercises while standing barefoot on a rubber mat covering a 32'' × 40'' vibration platform (Pneu-Vibe Pro; Pneumex, Sandpoint, ID, USA) in the off position.

Whole-body vibration plus resistance

For the WBV + RE condition, the participants performed the same nine exercises previously described while being exposed to vertical sinusoidal vibration at a frequency of 35 Hz with a 5 mm amplitude. RPE was again assessed following each of the nine exercises.

Blood pressure measurement

The *Oscar 2* ABP system (SunTech Medical, Morrisville, NC, USA) was used to measure BP. This system has been

validated in accordance to the standards of British Hypertension Society.²⁵ The nondominant arm was used for BP monitoring in all participants. The participants were asked to sit quietly for 15 minutes upon arrival at the laboratory. Next, two BP measurements (if BP value differed by > 5 mmHg a third measurement was taken) were taken 10 minutes apart and averaged together to yield a baseline BP value. The *Oscar 2* was programmed to take measurements every 15 minutes throughout the 3-hour recovery period. The first postexercise measurement was taken 15 minutes after exercise. Participants were seated in an upright position during all measurements. They were allowed to read, surf the Internet, or perform personal work on the computer. They were instructed to relax and straighten out their arm with the BP cuff during the BP measurement.

VO₂ assessment

VO₂ was assessed prior to, during, and after exercise with a TrueOne 2400 metabolic cart (ParvoMedics, Inc.). Gas analyzers were calibrated with a certified mixture of oxygen at 17.01% and carbon dioxide at 5.00%, balanced with nitrogen. Flow and volume were calibrated with a 3-L syringe (Hans Rudolph). Upon arrival at the laboratory, the participants were fitted with a heart monitor and a two-way non-rebreathing valve and mask (Hans Rudolph). They were asked to sit quietly for 30 minutes while baseline VO₂ measurements were taken. For each condition, resting VO₂ was measured for 30 minutes; however, the first 15 minutes were discarded to allow the participants to adjust to the mask and apparatus. Thus, an average of the last 15 minutes of resting data was used to determine baseline VO₂. Indirect calorimetry was used to determine total oxygen cost of exercise and the respiratory exchange ratio (RER) during and following exercise. Upon completion of exercise, the participants were asked to sit down immediately. Gas collection continued for 3 hours following exercise and was averaged into 15-minute periods for analysis.

During CON, the participants were asked to sit quietly in the laboratory for 3.5 hours while continuous gas collection and analysis were performed. During this time, they were free to surf the Internet, watch a movie, or read. The participants were not allowed to walk or stand during this time period.

Calculations

Total net oxygen consumption (VO₂) during exercise was calculated as total VO₂ during exercise minus total VO₂ during the corresponding time of the CON trial. Total EPOC was calculated as the difference between oxygen consumption during the 3-hour postexercise period minus total oxygen consumption during the CON trial. Only the 2nd hour and 3rd hour (60–180 minutes after exercise) of postexercise RER data were included for the determination of substrate utilization due to potential instability of the plasma bicarbonate pools during the initial hour following exercise.²⁶

Statistical analysis

Sample size calculations to achieve statistical power were based on data from prior research published on physical activity and PEH. An estimated sample size of 10 participants was used to detect a 4 mmHg difference in SBP between the RE and the WBV + RE ($\alpha = 0.05$, $\beta = 0.80$).

All statistical analyses were performed using SPSS software version 19 (IBM Corporation, Armonk, NY, USA). Data are expressed as means \pm standard deviation unless otherwise specified. Data were analyzed for normality, and values with skewed distribution were transformed to achieve normality. Descriptive statistics was used for the demographics of the participants. All p values were calculated assuming two-tailed hypothesis; $p < 0.05$ was considered statistically significant. Linear mixed models were used to detect within- and between-group differences and time differences in SBP, DBP, and VO_2 by treatment condition during exercise and over the 3-hour postexercise measurement period. The analysis was conducted in a hierarchical fashion using the restricted maximum likelihood model and “variance components” covariance error structure. Both fixed and random effects were explored in the model. Treatment condition, baseline BP, time, age, sex, VO_2 peak, and body mass index were used as fixed effects, and time was also used as a random effect to account for both interindividual and diurnal variations in BP and oxygen consumption. *Post hoc* analyses were assessed using the least significant difference to examine group differences in BP and oxygen consumption. One-way analysis of variance was used to assess group differences in total EPOC and oxygen consumption (homogeneity of variance was analyzed and a correction was made if applicable). Paired t test was used to assess mean RPE differences between the two exercise conditions.

Results

Table 1 presents demographic characteristics of the participants. All the participants performed the same exercises, number of repetitions, and tempo, and had the same rest period between exercises. Total exercise, including rest intervals, lasted ~15 minutes and was compared with an analogous (at the same time of day, under the same setting, etc.) 15-minute period during CON.

Table 1
Demographic characteristics.

Characteristics	Mean \pm SD
Sex (male/female)	9/2
Age (y)	28 \pm 9
Body fat ^a (%)	23 \pm 9
BMI (kg/m ²)	26 \pm 2
Resting SBP/DBP (mmHg)	127 \pm 7/73 \pm 7
VO_2 peak (ml/kg/min)	43 \pm 10

BMI = body mass index; DBP = diastolic blood pressure; SBP = systolic blood pressure; SD = standard deviation.

^a Bod Pod.

Table 2
Rating of perceived exertion (RPE) following each of the nine exercises

Exercise	RPE for RE	RPE for WBV + RE	p
1	10 \pm 2	11 \pm 2	0.731
2	11 \pm 2	11 \pm 2	0.889
3	11 \pm 1	12 \pm 1	0.228
4	12 \pm 1	12 \pm 2	0.488
5	13 \pm 1	13 \pm 1	0.119
6	14 \pm 1	15 \pm 1	0.236
7	13 \pm 2	14 \pm 1	0.073
8	13 \pm 1	15 \pm 1	0.031*
9	12 \pm 2	14 \pm 1	0.007*

RE = resistance exercise; RPE = rate of perceived exertion; WBV = whole-body vibration.

* Significant differences in RPE between groups.

Rate of perceived exertion

The participants were asked to report their perceived exertion rating after each of the nine exercises. On average, they considered the WBV + RE condition to be more intense compared with the RE condition. For both Exercise 8 and Exercise 9, WBV rating of perceived exertion (RPE) values were significantly higher than those of RE alone. Table 2 shows the RPE values between each condition following each of the nine exercises.

VO_2 and EPOC

Table 3 indicates the average VO_2 data at each time point (rest, during exercise, and recovery) for each condition. Baseline VO_2 (in ml/kg/min) was not significantly different ($p = 0.175$) between the three conditions. The oxygen cost of CON was 3.6 ± 0.7 ml/kg/min across all time points. The average oxygen cost of both the exercise bouts, RE and WBV + RE conditions (including rest period between sets), were significantly ($p < 0.025$) elevated compared with CON, and WBV was higher ($p = 0.007$) compared with RE (14.2 ± 1.6 ml/kg/min vs. 11.7 ± 3.2 ml/kg/min). When total postexercise VO_2 (in liters) was analyzed, WBV + RE was significantly higher ($p = 0.036$; 58 ± 7 L) than RE (53 ± 8 L) or CON (49 ± 11 L).

Average oxygen cost over time between conditions is shown in Figure 1. A significant interaction between time and condition ($p < 0.001$) was noted between the three conditions. *Post hoc* analysis revealed that 15 minutes after exercise, average oxygen consumption for WBV + RE (6.9 ± 2.6 ml/kg/min) was higher ($p = 0.001$) than both CON and RE (3.3 ± 2.7 ml/kg/min and 5.3 ± 2.5 ml/kg/min, respectively). In addition, at 15 minutes, VO_2 for RE showed a trend to be higher than that for CON, although it did not reach statistical significance ($p = 0.074$). At 30 minutes, VO_2 had returned to baseline, and no other time point was significantly different between conditions.

Figure 2 illustrates total and net (net = total liters consumed after subtracting CON VO_2) VO_2 for each condition. Total VO_2 was not statistically ($p = 0.430$) different between the two exercise groups, but it was significantly

Table 3
Oxygen consumption during and after each condition.^a

Protocol	N	Baseline VO ₂ (ml/kg/min)	Exercise VO ₂ (ml/kg/min)	Postexercise VO ₂ (L)	Total VO ₂ (L)	Net VO ₂ (L)	EPOC (L)
CON	11	3.6 ± 0.6	3.6 ± 0.7	49 ± 11	55 ± 11		
RE	11	3.3 ± 0.4	11.6 ± 3.1*	53 ± 8	65 ± 14*	10 ± 4	4 ± 7*
WBV + RE	11	3.5 ± 0.5	14.2 ± 1.6**	58 ± 7	75 ± 12*	20 ± 4	9 ± 8*

* $p < 0.05$; significantly different from CON.

** $p < 0.05$; significantly different from CON and RE.

CON = control; EPOC = excess postexercise oxygen consumption; RE = resistance exercise; WBV = whole-body vibration.

^a Net VO₂ and Net kcal for RE and WBV + RE conditions calculated by subtraction from CON condition.

higher for both WBV + RE (75 ± 12 L; $p = 0.001$) and RE (65 ± 14 L; $p = 0.037$) than that for CON (55 ± 11 L). Likewise net VO₂ was not significantly ($p = 0.196$) different between exercise conditions.

Respiratory exchange ratio

There were no baseline differences in respiratory exchange ratio (RER) between the three conditions ($p = 0.223$). [Figure 3](#)

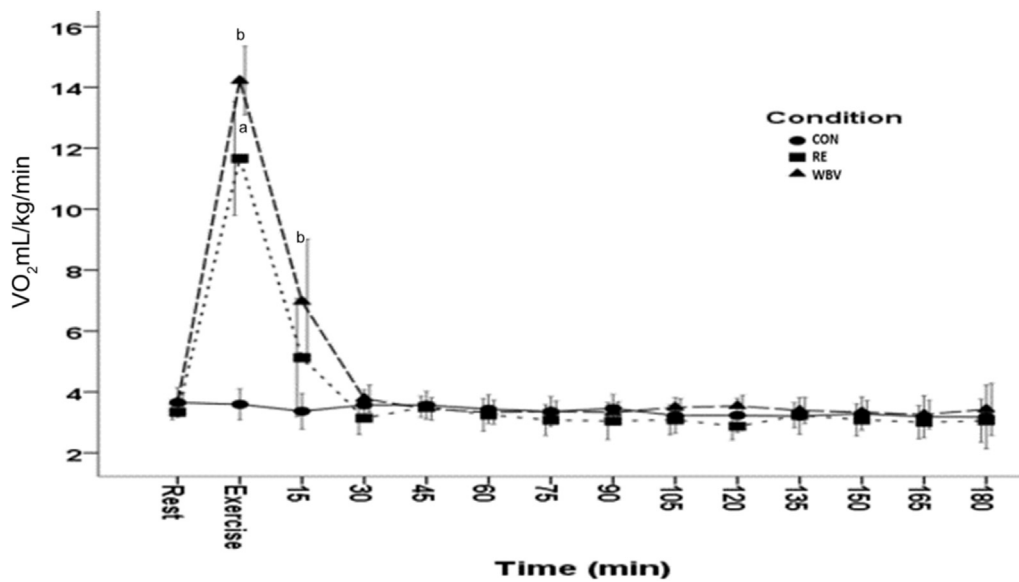


Figure 1. VO₂ (ml/kg/min) at rest, during exercise, and during recovery (180 minutes). Error bars represent 95% CI. ^a Statistically different from CON. ^b Statistically different from CON and RE ($p < 0.05$; LSD). LSD = least significant difference; CI = confidence interval; CON = control; RE = resistance exercise; WBVE = whole-body vibration exercise.

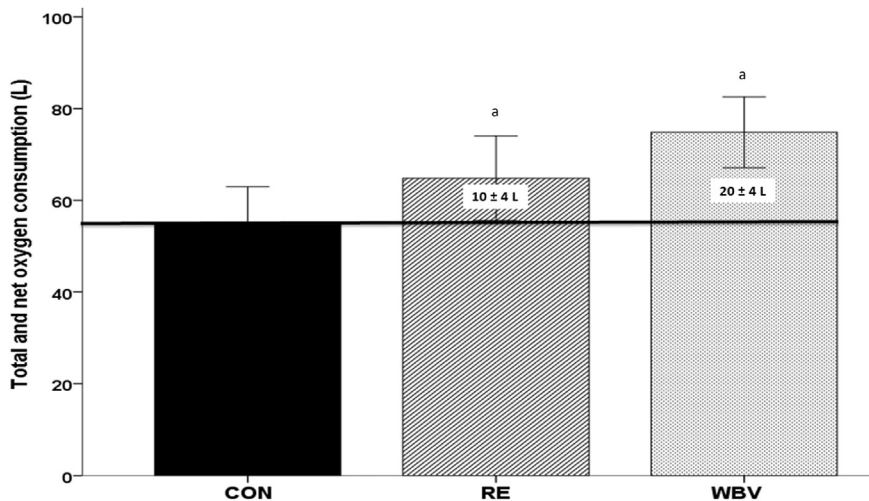


Figure 2. Total (including exercise) and net oxygen consumption (L) between the three conditions. Error bars represent 95% CI. ^a Statistically different from CON ($p < 0.05$). CI = confidence interval; CON = control; RE = resistance exercise; WBVE = whole-body vibration exercise.

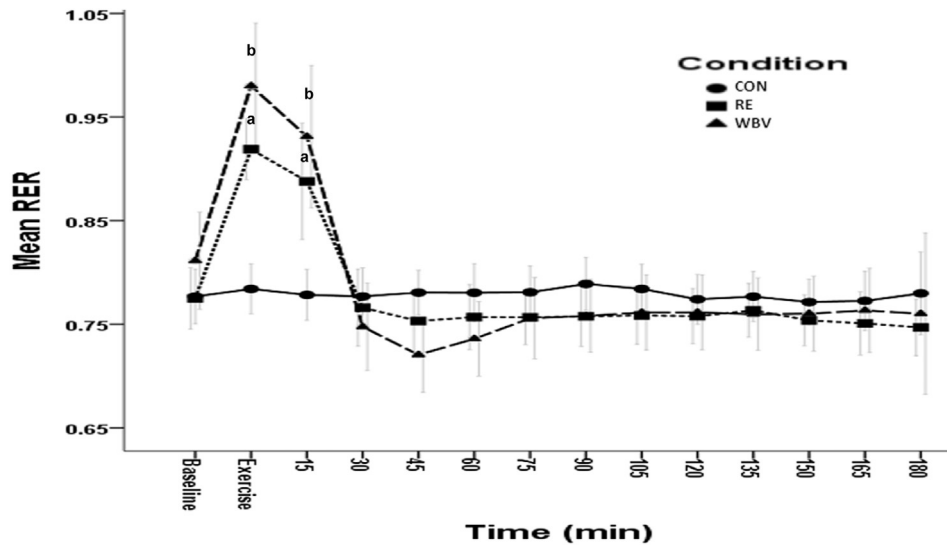


Figure 3. RER at rest, during exercise, and during recovery (180 minutes). ^a Statistically different from CON. Error bars represent 95% CI. ^b Statistically different from CON and RE ($p < 0.05$; LSD). LSD = Least significant difference; CI = confidence interval; CON = control; RE = resistance exercise; RER = respiratory exchange ratio; WBV = whole-body vibration exercise.

depicts the RER changes over time for the three conditions. Postexercise RER was different between conditions ($p < 0.001$), but there was no time effect ($p = 0.992$) or time \times condition interaction ($p = 0.998$). *Post hoc* analyses revealed that average RER during the 2nd hour and 3rd hour following exercise (60–180 minutes postexercise) was significantly lower ($p < 0.001$) for the WBV + RE (0.76 ± 0.03) and RE conditions (0.75 ± 0.03) compared with that for CON (0.78 ± 0.03). There was no significant difference in RER between WBV + RE and RE alone ($p = 0.227$).

Blood pressure

There were no significant baseline differences in resting SBP ($p = 0.112$) or DBP ($p = 0.826$). The difference in BP response between the two exercise conditions were compared with the CON condition for each time point following exercise. A significant ($p < 0.001$) difference in both SBP and DBP was evident between conditions over the entire 3½-hour measurement time period. *Post hoc* analysis revealed lower ($p < 0.001$) postexercise SBP with WBV + RE (124 ± 2 mmHg), compared with RE (126 ± 2 mmHg) and CON (128 ± 2 mmHg). Postexercise DBP was also significantly lower ($p = 0.001$) following both WBV (72 ± 6 mmHg) and RE (71 ± 6 mmHg) as compared with that following CON (73 ± 6 mmHg).

Table 4 also shows the changes in postexercise BP compared with pre-exercise baseline values for each condition. There was a significant within-group SBP and DBP time effect ($p < 0.001$) such that WBV + RE showed significant reductions in both postexercise SBP and postexercise DBP compared with baseline.

Figures 4 and 5 reveal the postexercise BP responses (SBP and DBP, respectively) for each condition over time. Compared with the baseline pre-exercise values, only

WBV + RE achieved a significant postexercise reduction in BP, resulting in a peak reduction in SBP of 8.7 ± 8 mmHg and a 5.8 ± 8 mmHg reduction in DBP. Additionally, both SBP and DBP remained statistically lower than pre-exercise BP for approximately 1.15 hours in the WBV + RE condition.

Discussion

The purpose of this study was to compare the acute effects of three conditions, WBV + RE, RE alone, and CON, on differences in postexercise VO_2 and BP in prehypertensive adults. The results indicate two main findings: (1) the exercise VO_2 of WBV + RE was significantly greater than that of RE

Table 4

Within- and between-group differences in blood pressure at baseline and post exercise.

	CON	RE	WBVE	<i>p</i>
SBP (mmHg)				
Baseline	127 \pm 6	125 \pm 6	130 \pm 6	0.112
Between group: mean 3 h post exercise	128 \pm 2	126 \pm 2	124 \pm 2**	0.001
Within group: average reduction from baseline	1 \pm 8	0 \pm 9	7 \pm 8*	0.001
> 75 min post exercise				
DBP (mmHg)				
Baseline	74 \pm 8	73 \pm 8	74 \pm 8	0.826
Between group: mean 3 h post exercise	73 \pm 6	71 \pm 6*	72 \pm 6*	0.004
Within group: 75 min average reduction from baseline	1 \pm 7	2 \pm 6	5 \pm 7*	0.001

* $p < 0.05$; significantly different from CON.

** $p < 0.05$; significantly different from CON and RE.

CON = control; DBP = diastolic blood pressure; RE = resistance exercise; SBP = systolic blood pressure; WBVE = whole-body vibration exercise.

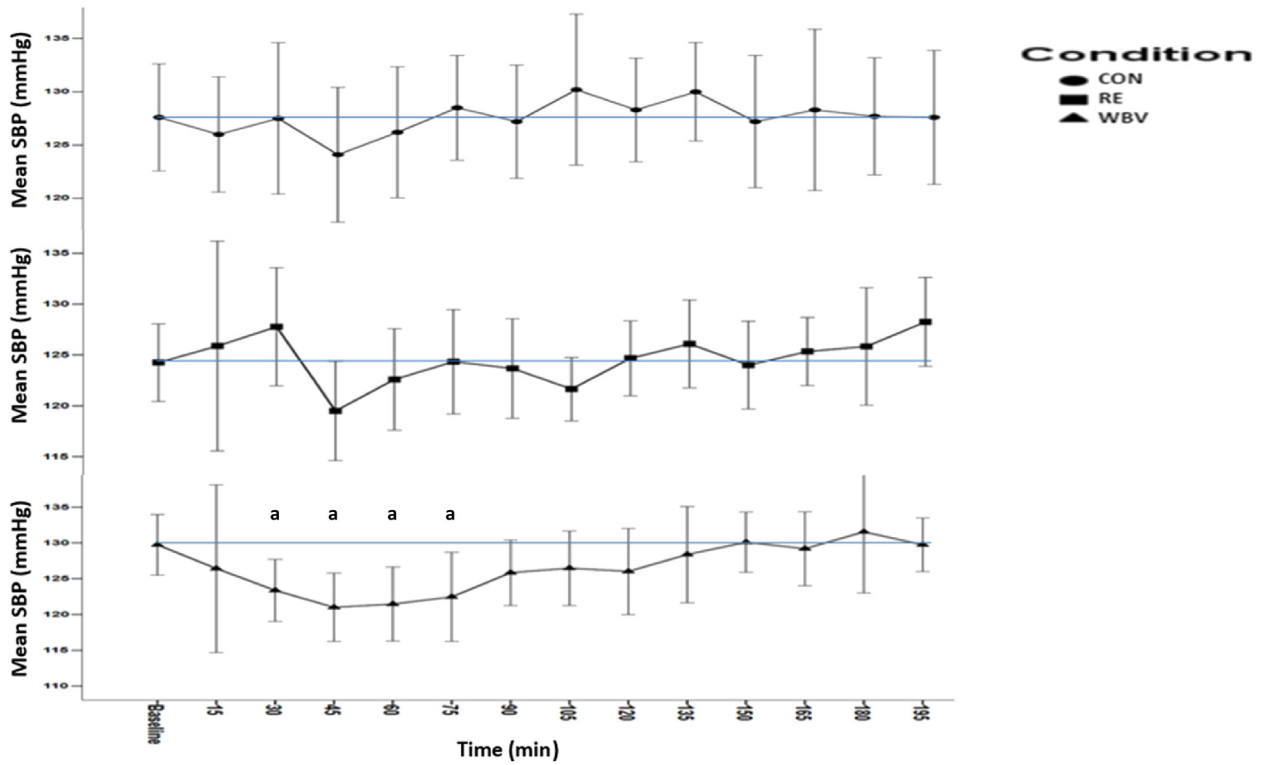


Figure 4. Within-group comparison of baseline SBP and postexercise SBP. Error bars represent 95% CI. ^a Statistically different from baseline ($p < 0.05$). CI = confidence interval; CON = control; RE = resistance exercise; SBP = systolic blood pressure; WBVE = whole-body vibration exercise.

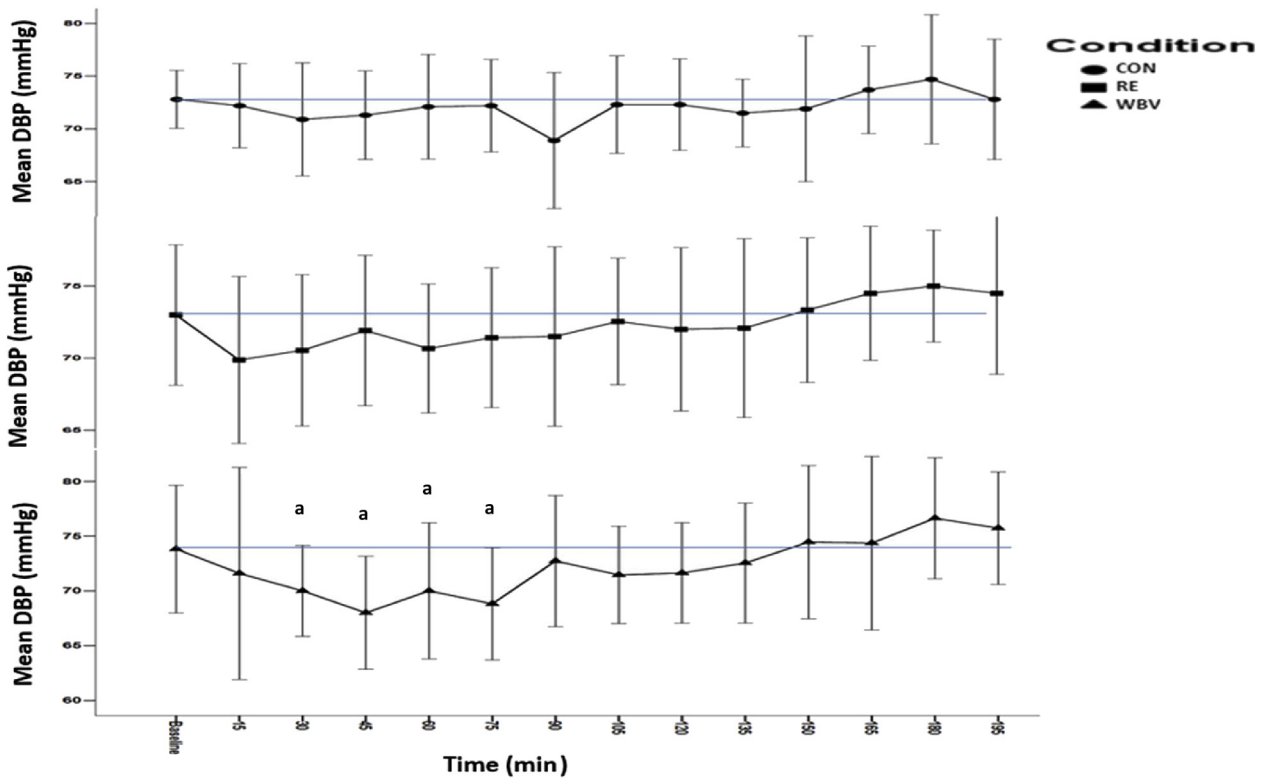


Figure 5. Within-group comparison of baseline DBP and postexercise DBP. Error bars represent 95% CI. ^a Statistically different from baseline ($p < 0.05$). CI = confidence interval; CON = control; DBP = diastolic blood pressure; RE = resistance exercise; WBVE = whole-body vibration exercise.

alone, and postexercise oxygen consumption was significantly higher at 15 minutes following vibration exercise compared with RE and CON; and (2) vibration exercise clearly induced a significant reduction in postexercise BP that was superior to RE alone for greater than an hour following exercise.

VO₂ and EPOC

WBV + RE imposed greater EPOC compared with RE at 15 minutes following exercise. Previous research has reported similar increases in VO₂ for vibration exercise.²⁴ For example, Rittweger et al⁹ reported that squatting while standing on a vibration platform increased VO₂ by 4.5 ml/kg/min when compared with squatting without vibration. Hazell and Lemon¹⁰ described an increase in VO₂ at 8 hours and 24 hours following WBV + RE when compared with RE alone. However, Hazell and Lemon¹⁰ used longer exercise time and more intense RE than what we used in the current study, which likely explains their findings. EPOC is known to increase in a linear fashion with exercise intensity.^{14,27} Indeed, in this study, the intensity of the WBV + RE exercise bout was higher than that of RE alone (e.g., VO₂ was 6% higher during WBV + RE compared with that during RE alone). In addition, a participants subjective RPE for the nine vibration exercises averaged one unit higher than that for RE.

EPOC has two components: the rapid and slow phases. The rapid EPOC component is well understood to be due to replenishment of O₂ stores in blood and muscle, resynthesis of adenosine triphosphate and creatine phosphate, lactate removal, and increased body temperature, circulation, and ventilation.^{11,12,28} In the current study, VO₂ was significantly increased at 15 minutes postexercise. This immediate effect was most likely caused by the rapid EPOC mechanisms listed above.

The slow phase of EPOC typically reflects the postexercise metabolic costs that support increased cardiorespiratory function, elevated body temperature, systemic hormone, and catecholamine increases, as well as the gradual conversion of lactate and pyruvate to replenish glucose stores. EPOC increases in a curvilinear fashion with exercise duration and in a linear fashion with exercise intensity.^{14,27} Thus, the slow phase of EPOC is reflective of the overall exercise intensity and duration. In this study, after 30 minutes following exercise, neither exercise condition (RE or WBV + RE) elicited a significant EPOC effect. The exercise bout in this study was only 15-minutes long, and on average, the exercise represented only about 30% of a participant's VO₂ peak (WBV + RE = 33% and RE = 27%). The absence of sustained EPOC after low-intensity exercise of a short duration is consistent with a prior research.¹⁴ Intensities above 50–60% VO₂ max are typically required to induce EPOC that lasts several hours.¹⁴ With RE, EPOC increases linearly with load.²⁹ In the current study, load was set at only 10% of the participants' body weight. In sum, the exercise bouts in this study were too low an intensity and were of too short a duration to elicit significant EPOC. It is likely that if longer and/or more intense WBV + RE were used, EPOC would be increased proportionally. However, a unique feature of this study was that

the WBV was combined with an RE routine that followed standardized guidelines recommended for public health.²³ Thus, the findings here can be generalized to what might be considered for a typical RE prescription in untrained individuals.

Respiratory exchange ratio

It was hypothesized that RER during WBV + RE recovery would be lower than that during the RE alone condition. This hypothesis was based on the assumption that the vibration exercise would provoke an additive increase in muscle contractions,⁷ requiring greater amount of overall carbohydrate as a fuel during exercise as compared with RE alone. Previous studies indicate that vibration exercise evokes high reliance on glucose as a fuel.⁸ Depending on the intensity of the exercise, glycogen depletion in the contracted muscle may result in a shift in substrate utilization to favor fat during the exercise recovery period. Although both exercise conditions resulted in lower RERs following exercise compared with CON, there were no differences in RER between the two exercise conditions.

Blood pressure

When assessing within-group BP differences, WBV + RE was clearly superior to RE alone or CON. Interestingly, the BP reductions observed following WBV + RE in this study are comparable with previous findings examining RE alone.³⁰ Cardinale et al³⁰ showed that three sets of 12 repetitions of RE at an intensity of 30% of one rep max provoked a significant SBP reduction of 6 mmHg from baseline BP. Our study, however, showed that a single set of nine exercises was all that was needed to elicit a significant PEH response. Previous evidence has shown that WBV + RE transiently increases muscle perfusion to the lower extremity²⁰ and decreases peripheral arterial stiffness.²¹ These vascular changes would reduce peripheral resistance without any increases in cardiac output, thereby reducing BP. No previous studies of WBV reported significant BP reductions following exercise.^{8,30–34} However, differences in the length of measurement following exercise may account for the conflicting results. In previous studies, BP measurements ranged from 4 minutes³¹ to 30 minutes³² postexercise. In the current study, peak BP reduction did not occur until approximately 45 minutes following exercise cessation. It must be noted that PEH is defined as the *sustained* BP reduction that occurs following exercise. BP reduction that typically occurs immediately following exercise is due to the acute increased muscle perfusion in the worked musculature.¹⁷ Sustained reductions in BP are a result of a complex of metabolic and hormonal physiological changes that evoke systemic vasodilation.¹⁶ The PEH from the WBV + RE bout in the current study was likely a result of both increased perfusion to the lower extremity and decreased arterial stiffness. However, these mechanisms were not measured in this study. Future studies need to be conducted to explore the mechanism of PEH following vibration exercise.

Limitations

Our study has certain limitations. First, although prehypertensive, our population was relatively young, healthy, and active. Divergent outcomes might have resulted had older, diseased, or deconditioned individuals participated. For example, the mechanisms for the PEH response of older adults may be different from that of younger individuals.³⁵ The mean age of the participants of this study was 28 ± 9 years. Although age could seriously confound the results, age was controlled both in our statistical analysis of BP and by our crossover and repeated-measures study design.

Additionally, subjects were asked not to change their physical activity or exercise habits during the course of the study and they were asked to eat the same foods prior to each visit. Although a dietary recall given prior to each session indicated no significant differences in macronutrient intake between conditions, in fact neither physical activity nor food intake were objectively monitored between trials. Thus, it remains unknown if unmeasured differences in dietary intake or physical activity between conditions influenced either EPOC or PEH results. Lastly, the findings of this study are only applicable to an acute response. It is not known how repeated training with WBV exercise would affect BP. Finally, although our study was powered satisfactorily, our sample size was relatively small, and therefore, larger studies and prospective clinical trials should be conducted to further explore the effects of WBV training on BP. Moreover, a study design with a larger number of participants would allow for analyses to be separated by sex.

Strengths

Our study has many strengths. First, the study population was prehypertensive, which is an important at-risk group for potential development of cardiovascular complications. In fact, it is likely that the PEH response would have been even greater in individuals with hypertension,^{33,34} suggesting that WBV + RE may be a beneficial modality for those with hypertension. Second, the use of a repeated-measures crossover study design provides powerful intraparticipant control, thereby decreasing the bias or error of confounding variables. Third, all measurements were time matched across conditions to control for diurnal variations. Fourth, the WBV + RE was compared with both a nonexercise CON group and an RE-alone condition so that differences in exercise mode could be explored. Finally, since PEH duration is prolonged with continued ambulatory activity,^{33,34} it is likely that we actually truncated the PEH effect by having our participants remain seated during the entire postexercise period. The PEH would have been greater had we measured ambulatory BP.

Conclusion

Recently, vibration exercise has gained popularity and has been publicized as a time-efficient way to lose weight and improve health. However, depending on the research design

and the comparison group employed, the outcomes vary.^{35–37} Findings from this well-controlled study provide significant evidence that WBV + RE can increase energy expenditure slightly as compared with no exercise or RE alone. At 3 hours postexercise, WBV + RE elicited a net increase of 50 kcal compared with RE and a net of 100 kcal more than CON. In theory, with all other factors being constant, a 15-minute bout of WBV + RE performed regularly would provide enough stimulus to induce a negative energy balance.

More importantly, although the BP reduction following WBV + RE was small, its potential clinical significance may be great. In fact, because the relationship between resting BP and disease risk is actually linear even at low or normal levels,³⁸ there is no threshold value of BP that dramatically increases disease risk.³⁹ Thus, lower is better when it comes to blood pressure. Even a small reduction of just 5 mmHg of SBP in the population can result in a 14% overall reduction in mortality due to stroke, a 9% reduction in mortality due to coronary heart disease, and a 7% decrease in all-cause mortality.⁵ Finally, because the exercise routine was of standardized intensity and followed recommended public health guidelines,²³ the findings of this study would be applicable to a wide population unaccustomed to exercise.

Compared with RE alone or CON, WBV + RE increased VO_2 during exercise and resulted in significant EPOC at 15 minutes postexercise. In addition, 15 minutes of low-intensity WBV + RE was adequate to promote a significant postexercise hypotensive response in adults with prehypertension.

Conflicts of interest

The authors declare no conflicts of interest.

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