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Research article

Loading and Concurrent Synchronous Whole-Body Vibration Interaction Increases Oxygen Consumption during Resistance Exercise

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Abstract
Exercise is commonly used as an intervention to increase caloric output and positively affect body composition. A major challenge is the low compliance often seen when the prescribed exercise is associated with high levels of exertion. Whole-body vibration (WBV) may allow increased caloric output with reduced effort; however, there is limited information concerning the effect of WBV on oxygen consumption (VO_2). Therefore, this study assessed the synergistic effects of resistance training and WBV on VO_2. We examined VO_2 at different loads (0%, 20%, and 40% body weight (BW)) and vibration intensities (No vibration (NV), 35HZ, 2-3mm (35L), 50Hz, 57mm (50H)) in ten men (26.5 ± 5.1 years). Data were collected during different stages (rest, six 30s sets of squatting, and recovery). Repeated measures ANOVA showed a stage x load x vibration interaction. Post hoc analysis revealed no differences during rest; however, a significant vibration x load interaction occurred during exercise. Both 35L and 50H produced greater VO_2 than NV at a moderate load of 20%BW. Although 40%BW produced greater VO_2 than 20%BW or 0%BW using NV, no significant difference in VO_2 was seen among vibratory conditions at 40%BW. Moreover, no significant differences were seen between 50H and 35L at 20%BW and NV at 40%BW. During recovery there was a main effect for load. Post hoc analyses revealed that VO_2 at 40%BW was significantly higher than 20%BW or 0%BW, and 20%BW produced higher VO_2 than no load. Minute-by-minute analysis revealed a significant impact on VO_2 due to load but not to vibratory condition. We conclude that the synergistic effect of WBV and active squatting with a moderate load is as effective at increasing VO_2 as doubling the external load during squatting without WBV.

Key words: Energy expenditure, weight loss, exercise prescription.

Introduction

The search for time-efficient, as well as engaging, exercises appears as important as the type of physical activity selected when designing effective interventions for increasing caloric expenditure (Willis et al., 1215). A popular choice is resistance training, which has been shown to be effective at increasing energy expenditure (Paoli et al., 2012); however, the intensity and/or time commitment needed to increase energy expenditure to a level that effectively combats obesity often limits compliance (Burgomaster et al., 2008). An answer to this dilemma may be found in studies demonstrating that the combination of whole-body vibration (WBV) and resistance training can increase oxygen consumption (VO_2) to a greater extent than resistance training alone (Hazell, Lemon, 2012). Early studies reported that the elevation of VO_2 that occurred during squatting with an external load of 40% of body weight (40%BW) was further increased by the addition of WBV (Rittweger et al., 2000; 2001). Additionally, Cochrane et al., using a vibrating leg press machine, reported progressive increases in VO_2 across loading conditions of 0%, 20% and 40%BW that exceeded non-vibratory conditions using the same loads (Cochrane et al., 2008). Results of this study also indicated that the degree of change seen was attenuated with age. These results reflect those seen in earlier studies where isometrics were the most common exercise modality (Da Silva et al., 2007). Finally, increases in movement speed have also been shown to elevate energy expenditure during WBV on a vertical plate (Garatachea et al., 2007).

The parameters used during WBV can impact VO_2. During side-alternating WBV, frequency increases have been shown to cause a linear rise in VO_2, while amplitude increases produced an exponential rise in VO_2 (Da Silva et al., 2007, International Organization for Standardization, 1997). An increase in muscle electrical activity with WBV compared to a non-vibratory condition has also been reported with specific contribution of the vibration frequency on a vertical displacement plate (Cardinale and Lim, 2003). Additionally, significantly greater increases in VO_2 were seen when external loads were applied at the shoulders rather than at waist level (Maikala et al., 2006; Rittweger et al., 2001).

It should be recognized, however, that the natures of the vibratory stimuli vary considerably between vertical, side-alternating, and synchronous plates. For example the plate being used in the current study (Model Pro-5, Power Plate North America, Northbrook, IL) sequentially presents vertical, lateral and forward/backward displacements that are approximately 70%, 20% and 10% of the overall exposure time, respectively, while side-alternating platforms only move in the frontal plane and vertical displacement plates, by definition move up and down. Since no previous studies have examined the impact of varying frequency and/or displacement on VO_2 using synchronous plates, we reasoned oxygen consumption would be affected by the load applied and that the impact

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of the load would vary depending on the nature of the vibratory stimulus. Given the published results using side-alternating and vertical-displacement WBV platforms, as well as specially constructed vibratory devices, we chose to examine the combined effects of moderate-load resistance training and synchronous WBV on VO_2. We hypothesized that the application of WBV during active squatting using 20%BW would produce an increase in VO_2 similar to that produced during active squatting without WBV at 40%BW, and that the 40%BW condition would produce a greater increase in VO_2 than the 20%BW condition during WBV.

Methods

Experimental approach to the problem

Since WBV may have a synergistic effect on VO_2 when coupled with resistance training, we examined the interactive effects of nine squatting conditions using combinations of three loading and three vibratory conditions in healthy active young adult males. Tests were performed on separate days with a minimum of 48 h recovery between testing sessions. All testing sessions were preceded by a 12 h fast. A repeated-measures analysis of variance (ANOVA) was used to assess differences in VO_2 among these conditions, before during and after each testing bout.

Subjects

A power analysis based on the results of Da Silva et al (2007) (f = 0.82 (8, 16); power = 0.95) produced a required sample size of 5 subjects; therefore, ten active male graduate and undergraduate students (26.50 ± 5.06 years old, weight 83.18 ± 9.46 kg, height 184.0 ± 8.95 cm), not currently training and with no WBV experience, recruited from the University using flyers, participated in the study. Exclusion criteria were cardiovascular, neuromuscular, or metabolic conditions that would prohibit exercise, lower-body surgery within the past year, use of medications for chronic cardiovascular or neuromuscular conditions, and any conditions that made WBV training ill-advised. Other factors which prevented participation fresh wounds, serious heart and/or vascular disease, wearing a pacemaker, recent hip or knee replacement, acute hernia, discopathy, spondylolysis, diabetes (type 1 or 2), epilepsy, tumors, and acute migraine. Before participation all subjects signed an informed consent approved by the University's Subcommittee for the Use and Protection of Human Subjects. All research was conducted according to the principals of the Declaration of Helsinki as set forth in the current editorial by Harris and Atkinson (2009).

Procedures

Each subject made ten visits to the laboratory for testing over a three to four week period. Before WBV testing participants refrained from strenuous physical activity for 24 h and fasted for 12 h. The first testing day was used to explain the study, obtain informed consent, and familiarize subjects with the WBV platform, squatting technique, and VO_2 measurement procedures. Descriptive data were also collected (health questionnaire, height, body weight) for all participants.

Subjects performed nine different exercise protocols during subsequent testing days. To reduce any potential order effect, we randomized the order in which participants performed the exercise protocols. Upon arriving at the laboratory, subjects sat for 30 min to reduce the effects of activity that may have occurred prior to their arrival. They then sat for 15 min during which resting VO_2 was measured. They then actively squatted on the WBV platform for 8 min (exercise) and after the exercise sat for 15 min (recovery). VO_2 was collected throughout the procedure. Subject performed the squat exercise wearing the same shoes across all conditions.

Exercise condition: Six 30 s sets of active squatting, using a range of motion from slightly below full extension to 1.57 rad, were performed at a speed of one squat per 3 s (controlled by a metronome). Squat angle was controlled by setting a horizontal stick as a limit at the lower end of the motion for subject reference. A one min period of passive recovery was provided between sets. The nine training protocols represented different combinations of external load applied at shoulder level using a backpack (0%, 20%, and 40%BW) and vibratory condition (see Figure 1). Vibratory conditions ranged from no vibration (NV) to 35Hz at 2–3 mm (35L; 1.89g) and 50Hz at 5–6 mm (50H; 7.7g) (Pel, B. 2009). The vibratory conditions reflect the frequency–displacement relationships found to maximize neuromuscular performance in our earlier study (Adams et al., 2009). All exercises were performed on a synchronous WBV plate (Model Pro-5, Power Plate North America, Northbrook, IL). The external load was added at the shoulders using a backpack and sand bags.

Figure 1. Subject performing active squatting exercise on the synchronous WBV plate.

Physiological variables: Respiratory gases were collected continuously via a portable ergorespirometry device (Oxycon Mobile, Hoechberg, Germany) throughout the rest, exercise, and recovery stages of the test. A full face mask was used during the collection process. VO_2 relative to body weight ($ml \cdot kg^{-1} \cdot min^{-1}$) was analyzed across 30 s intervals. In addition, respiratory exchange ratio (RER) values were computed for the same time intervals, and heart rate (HR) data were continuously collected throughout the testing session.

Statistical analysis

Separate 3 (vibratory condition) x 3 (load) x 3 (stage) repeated-measures ANOVA were used to determine the differences in VO_2, HR, and RER among training protocols. Statistical significance was established a priori at $p < 0.05$. When significant main effects or interactions were detected, a Bonferoni post hoc test was used to establish the source of the differences. All analyses were performed on SPSS, Version 15 (SPSS Inc., Chicago, IL).

Results

Oxygen consumption

Repeated-measures analysis for VO_2 revealed a significant stage x load x vibration interaction ($F(8, 72) = 4.669$, $p < 0.001$, $\eta_p^2 = 0.342$). Post hoc analyses revealed no significant differences in VO_2 ($p > 0.05$) among conditions during rest. During exercise, we found a significant vibration x load interaction ($F(4, 36) = 5.653$, $p = 0.001$, $\eta_p^2 = 0.386$). Post hoc analysis of vibratory conditions across loads revealed that at 20% BW, the 50H and 35L vibratory conditions produced significantly higher VO_2 than NV ($p = 0.046$; $p = 0.040$, respectively) (see Figure 2). Moreover, no significant differences in VO_2 were observed between the 50H and 35L 20%BW conditions and the 40%BW condition with NV.

Analysis of load across vibratory conditions revealed that during NV, 40%BW produced significantly higher VO_2 than 20%BW ($p = 0.001$) and 0%BW ($p < 0.001$). For 35L, VO_2 was significantly higher for 40%BW and 20%BW than for 0%BW ($p < 0.001$). For 50H, 40%BW produced significantly higher VO_2 than 20%BW ($p = 0.003$) and 0%BW ($p = 0.001$), while VO_2 at 20%BW was significantly higher than at 0%BW ($p = 0.014$).

No significant differences were observed in recovery VO_2 due to vibratory conditions; however, a significant main effect was detected for load ($F(2, 18) = 24.697$, $p < 0.001$, $\eta_p^2 = 0.733$). Post hoc analyses revealed that VO_2 at 40%BW was significantly higher than at 0%BW ($p = 0.001$) or 20%BW ($p = 0.007$), and 20%BW had higher VO_2 than 0%BW ($p = 0.012$) (see Figure 3).

Respiratory exchange ratio

Table 1 presents means and standard deviations for respiratory exchange ratio (RER) across loading and vibratory conditions. No significant differences were seen in RER among loading or vibratory conditions during any stage of testing.

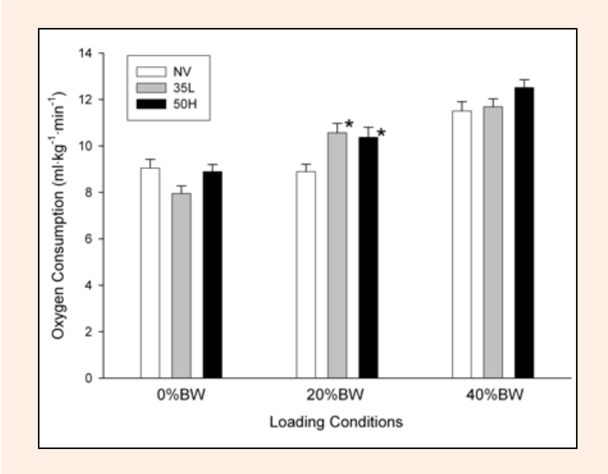

Figure 2. Oxygen consumption values due to vibratory and loading conditions during the exercise stage. * significantly different from the NV condition at 20%BW ($p < 0.05$).

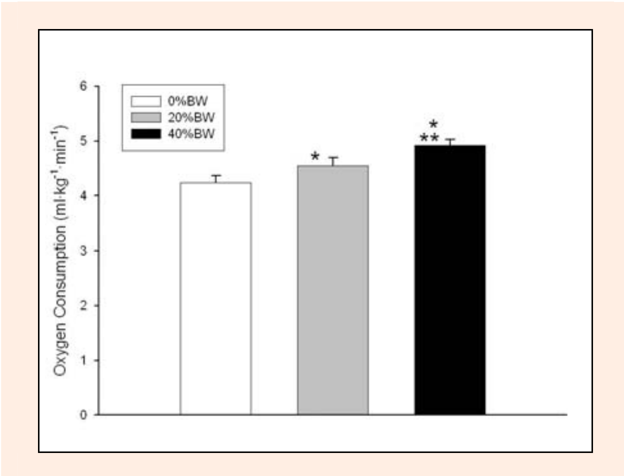

Figure 3. Recovery oxygen consumption due to vibratory conditions. *significantly different from the NV condition ($p<0.05$). **significantly different than 20%BW ($p < 0.05$).

Heart rate

Table 1 presents means and standard deviations for heart rate (HR) across loading and vibratory conditions. Repeated measures analysis for HR revealed two-way interactions between stage and load ($F(4,32) = 18.321$, $p < 0.001$, $\eta_p^2 = 0.696$) and between stage and vibratory conditions ($F(4,32) = 3.165$, $p = 0.027$, $\eta_p^2 = .283$).

During the resting and recovery stages, there were no significant differences in HR among loading conditions. During the exercise stage, a significant main effect

Table 1. Respiratory exchange ratio (RER) and heart rate (HR) responses due to loading and vibratory conditions. Data are means (SD).

	0% - 50H		0% - 35L		0% - NV		20% -50H		20% -35L		20% - NV		40% -50H		40% - 35L		40% - NV	
	RER	HR	RER	HR	RER	HR	RER	HR	RER	HR	RER	HR	RER	HR	RER	HR	RER	HR
Resting	.85	60.0	.86	61.0	.84	60.5	.86	58.8	.86	62.1	.86	60.4	.85	63.3	.83	59.1	.84	59.9
	(.03)	(8.3)	(.05)	(8.4)	(.04)	(8.3)	(.05)	(8.1)	(.05)	(5.2)	(.06)	(6.4)	(.03)	(8.1)	(.04)	(8.5)	(.05)	(9.4)
Exercise	.84	76.3	.84	77.3	.83	77.6	.85	80.7	.85	73.9	.84	77.8	.86	92.3	.85	88.9	.84	76.1
	(.04)	(7.4)	(.05)	(7.8)	(.05)	(9.5)	(.06)	(8.9)	(.05)	(25.6)	(.03)	(5.8)	(.06)	(8.6)	(.05)	(9.8)	(.05)	(25.5)
Recovery	.88	63.0	.88	63.9	.87	63.6	.89	63.5	.90	66.9	.90	63.4	.91	68.5	.90	65.4	.90	64.1
	(.05)	(9.4)	(.07)	(9.0)	(.05)	(10.0)	(.05)	(7.5)	(.06)	(6.5)	(.06)	(6.3)	(.07)	(8.8)	(.03)	(9.9)	(.05)	(11.4)

was detected for load ($F(2,16) = 16.908$, $p < 0.001$, $\eta_p^2 = 0.679$). Post hoc analysis showed that 40%BW resulted in a significantly higher HR (89.9 ± 3.4) than 20%BW (81.2 ± 2.1; $p = 0.011$) and 0%BW, (77.6 ± 2.6, $p = 0.007$).

No significant differences due to vibration were seen during the resting or recovery stage; however, a significant main effect of vibration was seen during exercise ($F(2,16) = 3.826$, $p = .044$, $\eta_p^2 = 0.324$). Post hoc analysis showed that differences between 50H (83.5 ± 2.6) and NV (81.4 ± 2.5) and between 35L (83.8 ± 2.3) and NV (81.4 ± 2.5) approached statistical significance ($p = 0.053$ and $p = 0.067$, respectively).

Discussion

This study demonstrated that squatting during WBV using 20%BW could increase VO_2 by 16.6% and 18.9% for the 35L and 50H, respectively, producing similar increases to those produced without vibration using 40%BW. This is particularly relevant since squatting using 40%BW may be too difficult for untrained individuals, especially if they are obese or elderly. Additionally, applying WBV during a squatting at 20%BW produced higher VO_2 values than the same load without vibration. We also found that load alone determined VO_2 during recovery, although previous studies have shown an additional increase in oxygen consumption over a 24-h period following a WBV exercise intervention (Hazell and Lemon, 2012) .

Our results showing a significant difference in VO_2 between the vibratory (50H, 35L) and NV conditions at 20%BW are similar to those reported by Rittweger and colleagues (2002), using a side-alternating WBV platform and an external load of 40% lean body mass applied at shoulder level. However, our results differ from earlier findings by this group showing a significant increase in VO_2 using a 40%BW load during side-alternating WBV (Rittweger et al., 2000; 2001). Methodological differences may explain these divergent results. The use of a rotational movement on the side-alternating platform may have required greater recruitment of the core musculature; increasing VO_2 (Willardson et al., 2009) as indicated by the increased physiological response using side-alternating compared to synchronous WBV (Gojanovic and Henchoz, 2012). Second, the volumes and patterns of work performed differed, since the present protocol used 6 sets of 30s with 60s recovery, while Rittweger's protocols used a single set until exhaustion (Rittweger et al., 2000; 2001) or a 3 minute set (Rittweger et al., 2001; 2002). In addition, during two of the studies by Rittweger et al., the load was applied at the hips (Rittweger et al., 2000; 2001), while we applied the load at shoulder level, which has been shown to have a greater impact on VO_2 (Rittweger et al., 2002). Finally, the squatting exercise was performed more slowly during the studies by Rittweger et al. compared to ours (6s versus 3s cycle) and movement velocity has been shown to have a specific impact on energy expenditure (Garatachea et al., 2007).

Increased VO_2 when a 20%BW load was added during WBV was reported by Cochrane et al. (2008); however, these researchers also noted a significant increase in VO_2 between the vibratory and non-vibratory conditions at a load of 40%BW while we found none. One protocol differences that may have caused these divergent results was the use of a modified isometric leg press rather than dynamic squatting. Additionally, the use of only one vibratory condition (30Hz, 1 mm) on a device which applied vertical rather than multiple synchronous WBVconditions (35, 2-3mm; 50Hz, 4-6 mm), may have increased these differences. Finally, the protocols differed since Cochrane et al. (2008) used a four minute isometric contraction; while the current study used six 30 s work intervals separated by 1 min passive recoveries. Perhaps the most apparent difference between the two studies was in loading. Cochrane et al. (2008) used loads of 20 and 40%BW while our loading was actually 120 and 140%BW since body weight is included as resistance during the squat. Given these factors an exacting comparison between studies is not possible.

Our findings also differ somewhat from those of Da Silva et al. (2007), who reported a significant increase in energy expenditure when combining WBV and an external load of approximately 74%BW. Although we did not see an increase in VO_2 when external load was increased from 20%BW to 40%BW; this does not negate the possibility that a higher load, similar to that used by Da Silva et al. (2007), could have produced a significantly higher VO_2 than that seen with our 20%BW or 40%BW loading conditions. Additionally, differences between the studies noted above, including the use of vertical versus synchronous WBV (affecting exposure time and loading vectors), performance speed ($3\ s\cdot rep^{-1}$ vs. $4\ s\cdot rep^{-1}$), the number of sets performed (6 sets vs. 5 sets), and the recovery provided between sets (1 min vs. 2 min).

Our finding that there was no impact of WBV on post-exercise VO_2 differs from that of Da Silva et al. (2007), who reported a significant increase in energy expenditure during a 4-minute recovery after adding WBV to a loaded squat. Moreover, Hazell et al. (2012) found that a WBV session increased the 24-h oxygen consumption by 10% compared to non-WBV exercise. Once again, these differences may be attributable to the factors mentioned previously (Thornton, 2002).

We found no significant changes in RER due to WBV, while Da Silva and colleagues (2007) reported a significant increase. On the other hand, both studies showed no significant RER increase regardless of load in the NV condition (Da Silva et al., 2007). It is possible that the high loads in conjunction with the use of vertical rather than synchronous displacement WBV can account for the higher RER reported by Da Silva et al. (2007).

Our results, showing increases in HR when combining WBV and load during squatting, but no increases in HR with WBV under unloaded conditions, are in agreement with those reported in the literature (Garatachea et al., 2007, Willardson et al., 2009). On the other hand, Hazell et al. (2012) showed increases in HR when using side-alternating WBV.

This study demonstrates that WBV may be an effective training tool for weight control when combined with moderate-load dynamic squatting exercise. In the current study, the addition of WBV to active squatting at a load of 20%BW produced a 16.6% and 18.9% increase in VO_2 for the 50H and 35L conditions. Given the lack of significant differences in RER seen across the resting, exercise and recovery stages, the increases in VO_2 seen with WBV reflect increased caloric outputs. This finding could be especially important when prescribing exercise for overweight individuals or older persons with sarcopenic obesity who are unable or unwilling to use traditional loads or who show poor exercise compliance.

Our finding that no significant differences in VO_2 were seen among the WBV and non-vibration conditions at 40%BW is difficult to explain, and we suggest that this study be repeated using similar loads with the addition of a higher 70-80%BW loading condition to see if further increases are seen. Additional benefits may be revealed if electromyographic data are collected simultaneously with VO_2 to ascertain if the differences in muscle activity between the non-vibration and WBV condition do indeed decrease with increasing loads. Additionally, we recommend examining these loading conditions using different training volumes to ascertain if longer duration protocols will allow greater time for differences between the non-vibration and WBV conditions to emerge. Finally, when using external loading accelerometer measurements should be incorporated to quantify plate movement due to the potential for vibration dampening as loads increase, especially using WBV devise which do not compensate for external loading conditions.

In summary, a discussion of the benefits of WBV would not be complete without addressing the issue of safety. The estimated vibration dose values for both vibratory conditions used in the present study exceed the ISO 2631-1 guidelines (International Organization for Standardization, 1997). However, Abercromby et al. (2007) state that due to the intermittent nature of WBV as a treatment modality and the fact that subjects experience vibration during standing rather than sitting, the ISO 2631-1 guidelines may be an overestimate of the actual dose value to which the body is exposed. Additionally, unless the knees are fully extended, the level of force transfer is greatly reduced as it passes through the body tissues. Therefore, accelerations at the spine and the head can be expected to be small compared to those measured at the plate itself. For example, Pel et al. (2009) reported that vibration is reduced 6-10 times when comparing values at the knee and hip to those measured at the ankle. Regardless of the findings presented in these papers, we feel that there may be an unknown and potential risk of injury, which may be even greater in overweight or older populations.

The limitations of this study were mainly related to the capacity to control physical activity and nutrition prior to each testing day. The use of accelerometers and the provision of meals would improve the control over physical activity and nutrition. Also, the measurement of body composition would add value to the interpretation of the physiological response to WBV.

Conclusion

In conclusion, our results indicate that the application of WBV can increase oxygen consumption when used in conjunction with moderate loading (20%BW) during the parallel squat; however, additional loading (40%BW) produced no further increases. The positive impact on body composition when using these moderate loads may be especially important in obese individuals, especially those with reduced muscle mass such as elderly or highly sedentary individuals. Although our results may not be generalizable to other WBV devices, and the impact of other factors, such as number of sets and work/recovery duty cycle structure, have yet to be determined, our findings do demonstrate that further examination of WBV in the context of weight reduction is warranted.

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Key points

- Synchronous whole body vibration in conjunction with moderate external loading (app 20% BW) can increase oxygen consumption to the same extent as heavier loading (40% BW) during performance of the parallel squat.
- While the application of synchronous whole body vibration had no effect on recovery oxygen, under bot vibratory and non-vibratory conditions, the heavier the external load the greater the recovery oxygen consumption levels.
- Regardless of vibratory condition, during the squatting exercise bout 40% BW produced higher heart rates than 20%BW or 0% BW, and 20% BW produced higher heart rates than 0% BW.
- There were strong trends toward higher heart rates in both vibratory conditions (50 Hz, 5-6mm; 35 Hz, 2-3 mm) than in the non-vibratory condition regardless of external loading.

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