

Local metabolic rate during whole body vibration

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Keywords: near-infrared spectroscopy; oxygen utilization; metabolism; training

Whole body vibration (WBV) platforms are currently used for muscle training and rehabilitation. However, the effectiveness of WBV training remains elusive, since scientific studies vary largely in the vibration parameters used. The origin of this issue may be related to a lack in understanding of the training intensity that is imposed on individual muscles by WBV. Therefore, this study evaluates the training intensity in terms of metabolic rate of two lower-extremity muscles during WBV under different vibration parameters. Fourteen healthy male subjects were randomly exposed to 0 (control)-, 10-, 17-, and 28-Hz vibrations while standing upright on a vibration platform. A near-infrared spectrometer was used to determine the gastrocnemius medialis (GM) and vastus lateralis (VL) muscles' metabolic rates during arterial occlusion. The metabolic rates during each vibration condition were significantly higher compared with control for both muscles ($P < 0.05$). Each increase in vibration frequency translated into a significantly higher metabolic rate than the previous lower frequency ($P < 0.05$) for both muscles. The current study showed that the local metabolic rate during WBV at 28 Hz was on average 5.4 times (GM) and 3.7 times (VL) of the control metabolic rate. The substantial changes in local metabolic rate indicate that WBV may represent a significant local training stimulus for particular leg muscles.

THE NUMBER OF APPLICATIONS incorporating whole body vibration (WBV) training has increased dramatically over the last two decades. Researchers have investigated the effects of WBV interventions on bone quality (14, 15, 34, 37, 38), muscle performance and training adaptation (9, 11, 33, 36), responses of the neuromuscular system (1, 5, 7, 20, 32), hormonal responses (2, 13, 21), as well as diseases such as Parkinson's (12, 16) and multiple sclerosis (19, 35). Considering this broad scope, it is not surprising that training protocols incorporating WBV differ substantially. Nevertheless, numerous long-term WBV studies with similar research questions, albeit using different training protocols and different vibration platform settings, have been compared in the literature (27, 28). As a consequence, the validity and conclusions drawn within those reviews may be uncertain, given the importance of platform protocols and settings.

A notable reason for the large variety of platform settings that are currently used in long-term studies may be the apparent absence of WBV training standards. One approach to address this problem is to gain a thorough understanding of acute physiological effects of WBV. By understanding the acute effects, one would have more information about the training

intensity that is imposed by WBV on the body, so that the appropriate vibration settings needed to trigger training effects can be determined. However, with respect to muscle tissue, it is not known which training intensities, in form of the muscles' metabolic demand, correspond to the diverse WBV platform settings that are currently used.

The first attempts to understand the acute metabolic demand of the body when using WBV as an exercise intervention were made by systematically changing vibration platform frequencies (29), as well as amplitudes and carried loads (30). Whole body metabolic rate was estimated from whole body oxygen uptake, which was then used to assess the training intensity imposed on the body during WBV (29, 30). Although whole body training intensity is a valuable assessment, it yields quite general and undetailed information about the training intensity for individual muscles, since it is not possible to determine an individual muscle's contribution and change in metabolic rate. The metabolic rate of individual leg muscles is likely to be vastly different during WBV if it was compared with the metabolic rate of the entire body. To understand the effects of WBV on muscle tissue more specifically, it is imperative to collect metabolic information about individual muscles and muscle groups locally to determine which muscles are being exercised and at what intensity.

Recent technological advances have allowed for the use of near-infrared spectroscopy (NIRS) in quantifying the oxygen demand and thus metabolic rate of individual muscles. Some studies investigated the oxygen saturation (OS) during vibrations vs. a nonvibration control condition. For instance, NIRS was used to study OS of the vastus lateralis (VL) muscle while squatting on a WBV device (39), and it was shown that the OS was lower when vibrations were superimposed to the exercise compared with the control condition. Furthermore, changes in OS were tested in two leg muscles while standing on a WBV platform at different vibration frequencies (6). Arguably, quantifying local OS alone does not reflect the actual metabolic demand of these muscles. OS merely represents the sum of oxygen demand (by the muscles) and supply (by the blood stream) (3). To specifically quantify the oxygen demand of individual muscles in the leg, oxygen supply to the muscle must be stopped, for example, by inducing limb ischemia (8). The quantification of oxygen demand during ischemia then allows for the determination of the muscle's metabolic rate (3, 17, 18, 26). This method was already used for investigating oxygen demand of the gastrocnemius medialis (GM) during vibration exercise (10, 40). Therefore, the goal of this study was to quantify the metabolic rate of two different leg muscles during WBV at different vibration frequencies during limb ischemia. The muscles of interest were the GM and the VL, as they are important for daily activities like walking, lifting, and standing up from a chair.

It was hypothesized that the metabolic rate of each muscle would be higher during vibrations compared with a nonvibration control condition (H1) and that the metabolic rate would increase with higher vibration frequencies (H2).

METHODS

Subjects. Fourteen healthy, physically active male volunteers [age: 26.8 ± 3.4 yr; body mass: 74.9 ± 9.5 kg; height: 178.8 ± 8.1 cm (mean \pm SD)] were recruited for this study. All subjects gave their written informed consent to participate, and the University of Calgary's health research ethics board approved the study.

Vibration platform setup. The subjects were instructed to stand freely and without shoes or socks on a side-altering vibration platform (Galileo Advanced; Novotec) in an upright posture. The subjects' knees were flexed at $5\text{--}10^\circ$ (0° corresponding to full knee extension), and the flexion angles were controlled by means of templates given before each measurement (32). The feet were kept in a constant position 29.5 cm apart (heel-midlines) on the platform for each trial, corresponding to a 5-mm peak-to-peak vertical vibration displacement. The vibration frequencies tested were 0 (control), 10, 17, and 28 Hz. This combination of vibration frequencies and amplitude was chosen to encompass a range of commonly used vibration frequencies during WBV training and to closely correspond with parameters from previous systematic studies (6, 30). Adhesive tape with a rough surface was placed on the vibration platform to avoid skidding.

Near-infrared measurements. Muscle metabolic rates were estimated using data from NIRS, obtained with a NIRO 200-NX (Hamamatsu Photonics). After shaving and cleaning the skin with alcohol swabs, the spectrometer's optodes were placed over the belly of the GM and VL muscles. The distance between the emitter and detector was 4 cm. Baseline data for changes in oxyhemoglobin (O_2Hb) and estimated total hemoglobin index (nTHI) were collected with a sampling frequency of 20 Hz while the subjects were standing on the platform. Ischemia was induced by arterial occlusion using a pneumatic blood pressure cuff (width: 15.5 cm; Caliber large, Mabis/DMI) that was placed at the level of the gluteal tuberosity of the femur.

Protocol. Once the setup was completed, the participants were exposed to each vibration frequency for a period of 30 s to familiarize them with the procedure. Following familiarization, the four conditions were tested in a randomized order. Before vibration was commenced, the OS of the muscles was monitored carefully to confirm that a steady state was reached. Once steady-state OS was observed, the pressure cuff was rapidly (<10 s) inflated to a pressure of 300 mmHg. After inflation, the vibration platform was turned on for 60 s. After this time, the vibrations stopped, and the pressure cuff was released. At least 5 min of rest were given to the subjects between conditions to allow blood flow to reach homeostasis.

Data analysis. Muscle metabolic rate in this study was defined by the O_2Hb utilization rate during ischemia (4, 17, 26) and was determined by performing a regression analysis of the linear portion of the O_2Hb slope over a 30-s period for each tested vibration frequency (Fig. 1). Although the vibrations lasted for 60 s, only the center 30 s of that window were analyzed due to occasionally observed nonlinear changes of O_2Hb in the beginning and end of the trials. The O_2Hb readings are affected by changes in blood volume (BV), and therefore BV needs to be as constant as possible. The nTHI serves as an indicator of BV and was used to quantify the maximal change in BV as a percentage of the initial BV during the (30-s) data analysis window.

Statistical analysis. The metabolic rates of the GM and VL muscles were analyzed independently since interactions between the two muscles were not the focus of this study. Thus, a one-way repeated-measures analysis of variance (ANOVA) was used to analyze the two datasets. Mauchly's tests were used to satisfy the assumptions of sphericity, and, where violated, the degrees of freedom for the F -test

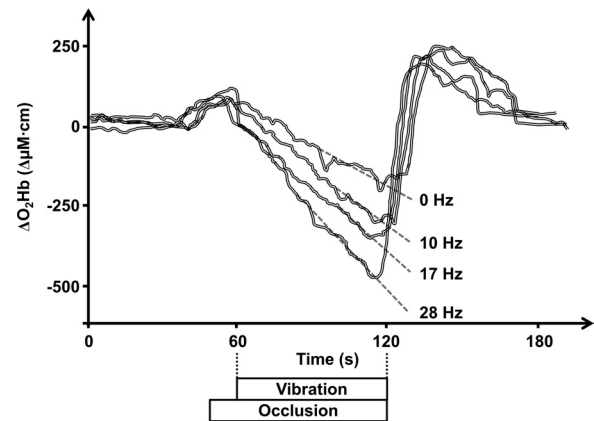


Fig. 1. Changes in vastus lateralis oxyhemoglobin (O_2Hb) concentration before (0–60 s), during (60–120 s), and after (120–180 s) the intervention at four different trials with different vibration frequencies for one subject. The dashed lines are a visual aid to represent the muscle's metabolic rate.

were adjusted using a Greenhouse-Geisser correction. If significant main effects were observed by the ANOVA (level of significance $\alpha = 0.05$), paired Student's t -tests were used to identify which of the four conditions within a dataset were significantly different. The level of significance for the post hoc Student's t -tests was adjusted using a Bonferroni correction for a total of six comparisons per dataset, and was $\alpha = 0.0083$. In the case of significant post hoc differences, effect sizes were calculated using Cohen's d procedure. All statistical analyses were conducted using SPSS (version 19.0.0; IBM SPSS).

RESULTS

The average changes in BV during the measurement period as indicated by nTHI were $6.51 \pm 5.17\%$ for the GM and $4.15 \pm 2.56\%$ for the VL. The metabolic rate of the GM and the VL at different vibration frequencies is shown in Fig. 2. Statistical analysis revealed a significant main effect for the metabolic rate of the GM [$F(1.54, 52) = 55.42$; $P < 0.01$] and the VL [$F(1.97, 52) = 39.32$; $P < 0.01$]. The following post hoc analysis showed significant increases in mean GM and VL metabolic rate with each increase in vibration frequency (Table 1 and Fig. 2). Effect sizes were large (>0.8) for the GM and inconsistent for the VL (0.42–2.28) for the post hoc comparisons (Table 1).

DISCUSSION

To the best of our knowledge, this is the first study to investigate the local metabolic demand during WBV at different vibration frequencies. The key findings of this study were that both muscles had significantly higher metabolic rates during vibration exposure at all vibration frequencies, compared with the control condition (0 Hz), in support of H1. Furthermore, metabolic rates in both muscles increased significantly with each higher vibration frequency, supporting H2 (see Table 1 and Fig. 2).

WBV platforms are currently being used for training, rehabilitation, and even weight loss at gyms, sports clubs, and clinics. In a study that investigated whole body metabolic rate during stance on a vibration platform (30), it was demonstrated that WBV increased the metabolic rate to about 2.0 times resting metabolic rate or metabolic equivalents (METs, i.e., work metabolic rate divided by resting metabolic rate) at 18 Hz. They furthermore showed that the metabolic rate increased

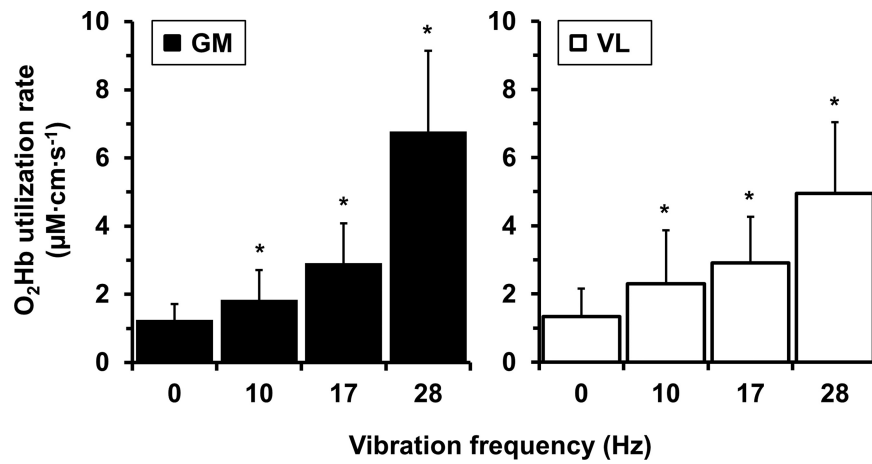


Fig. 2. Average O₂Hb utilization rate of the gastrocnemius medialis (GM, filled bars, mean \pm SD) and vastus lateralis (VL, open bars) at four different vibration frequencies for all subjects. Each increase in vibration frequency resulted in a significantly higher O₂Hb utilization rate for the GM and VL. *Significant differences ($P < 0.05$) from the next lowest frequency.

to 2.4 METs at 26 Hz and 2.8 METs at 34 Hz (30). However, according to the recommendations by the Centers for Disease Control and Prevention and the American College of Sports Medicine, every (United States) adult should daily accumulate 30 min or more of moderate-intensity physical activity. Moderate intensity is therein defined as exercising at 3 to 6 METs, corresponding to walking briskly at 4.8–6.4 km/h (24). This means that standing on a vibration platform may not exclusively fulfill the demands of moderate-intensity training for the whole body since, first, the minimum MET is not achieved and, second, most WBV training sessions take less than 30 min of net vibration time (23).

In the current study, however, the local metabolic rate at the highest frequency (28 Hz) was on average 537% (GM) and 369% (VL) of the control metabolic rate. This means that, on a local (muscular) level, WBV induced roughly 5.4 local metabolic equivalents (LMETs) for the GM and about 3.7 LMETs for the VL at 28 Hz. One may speculate that even higher LMETs could be observed in leg muscles that are involved in postural control (e.g., ankle-stabilizing muscles), since WBV creates an unstable standing environment. As a consequence, WBV training may not seem to be an effective training when considering the muscles of the whole body but may be sufficient to locally induce moderate-intensity training for some leg muscles. Specifically, improvements in muscle power (22) as well as in muscle strength (23) were shown in the literature and can be expected when using WBV platforms as a training intervention. This may be particularly relevant for people with balance or mobility issues due to age, disease, or

obesity, since WBV training is still possible under such conditions.

However, the estimated metabolic equivalents for whole body oxygen uptake (METs) may not be directly comparable to the previously discussed local metabolic equivalents (LMETs) since the work metabolic rate was not divided by the resting (sitting) metabolic rate, but rather the one during quiet standing. In addition, no comparative data for LMETs during typical movements such as walking or running exists but should be quantified in future studies to allow for valid comparisons to the MET scale and to common training regimes. Also, the reported LMETs may vary, depending on the tested population's muscle fiber type compositions. It may be speculated that people with predominantly fast-twitch fibers consume different amounts of oxygen during WBV training compared with people with predominantly slow-twitch fibers for the same vibration settings because of different metabolic characteristics of certain fiber types. Furthermore, the values of LMETs are based on changes in O₂Hb, and O₂Hb is directly affected by changes in BV. Therefore, the need to report these readings has to be strongly emphasized, and, in the current study, they were relatively small (4–7% on average), as indicated by nTHI readings, but no comparative values are available from previous studies.

The question that remains is how the current findings can help to overcome a major difficulty when designing a WBV study, which is the large number of vibration platform parameters that can be adjusted. This difficulty becomes obvious when considering the parameters that usually need

Table 1. *P* values with respect to H1 (comparison with control condition) and H2 (comparison with next lowest vibration frequency) and their respective effect sizes for each tested vibration frequency and muscle

Muscle	Frequency, Hz	<i>P</i> Value H1	Cohen's <i>d</i> for H1	<i>P</i> Value H2	Cohen's <i>d</i> for H2
Gastrocnemius medialis	0				
	10	0.046	0.83	0.046	0.83
	17	<0.01	1.85	0.048	1.03
	28	<0.01	3.23	<0.01	2.06
Vastus lateralis	0				
	10	0.046	0.76	0.046	0.76
	17	<0.01	1.41	0.032	0.42
	28	<0.01	2.28	<0.01	1.16

H1, hypothesis 1; H2, hypothesis 2.

to be set, involving: 1) vibration amplitude, 2) vibration frequency, 3) vibration duration, 4) training session frequency, 5) posture or exercise specificity during vibration, and 6) population. In addition, the metabolic demand and perceived comfort will also depend on the type of vibration platform used. It is known that side-altering platforms (as used in the current study) induce acceleration magnitudes two times as high compared with synchronous vibration platforms, in conjunction with a smaller vibration-dampening effect at the ankle joint and higher muscle activity (25, 31). Although the vibration type and platform parameters are a crucial factor when examining acute and long-term effects of WBV training, there are still no common recommendations for the most effective combinations. A long-term goal of WBV research should be to identify platform parameters that maximize the muscles' metabolic demand and are tolerable to establish standards and/or recommendations for the most effective vibration platform parameters. The current study was one step in this direction, but more muscles and conditions need to be tested systematically in the future. Once the acute effects are better understood, then more consistent, comparable, and effective long-term WBV intervention studies may be possible. This includes all other observed physiological benefits of WBV training, including improvements in bone quality, postural control, skin and muscle perfusion, flexibility, and pediatric rehabilitation (28).

In conclusion, this study showed an increase in local metabolic demand of two leg muscles with each increment in vibration frequency. On a local muscular level, WBV training may represent a significant training stimulus for particular muscles. Further systematic studies need to assess the local metabolic demand of muscles involved in WBV training to achieve and optimize long-term training benefits.

ACKNOWLEDGMENTS

We thank Rodrigo Lopez Atristain for help with data collection.

GRANTS

Financial support was provided by Alberta Innovates-Technology Futures, the Natural Sciences and Engineering Research Council of Canada CREATE Program, the da Vinci Foundation, Calgary, and adidas International.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: B.F. and B.M.N. conception and design of research; B.F. performed experiments; B.F. analyzed data; B.F. and J.F.D. interpreted results of experiments; B.F. prepared figures; B.F. drafted manuscript; B.F., B.M.N., and J.F.D. edited and revised manuscript; B.M.N. and J.F.D. approved final version of manuscript.

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