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RESEARCH ARTICLE

Cardiorespiratory responses in different types of squats and frequencies of whole body vibration in patients with chronic obstructive pulmonary disease

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Lage VK, Lacerda AC, Neves CD, Chaves MG, Soares AA, Lima LP, Matos MA, Leite HR, Fernandes JS, Oliveira VC, Mendonça VA. Cardiorespiratory responses in different types of squats and frequencies of whole body vibration in patients with chronic obstructive pulmonary disease. *J Appl Physiol* 126: 23–29, 2019. First published October 25, 2018; doi:10.1152/japplphysiol.00406.2018.—This study aims to investigate the cardiorespiratory responses to different vibration frequencies to characterize the intensity of exercise, as well as to compare the effect of two types of squatting exercises (static and dynamic) on the whole body vibration (WBV) exercise in individuals with chronic obstructive pulmonary disease (COPD). Twenty-six subjects were divided and paired into healthy and COPD groups that performed static squatting associated with WBV (frequencies: 30, 35, and 40 Hz; amplitude: 2 mm) and dynamic squatting associated with WBV (frequency: 35 Hz; amplitude 2 mm) on a vertical vibration platform. Oxygen consumption ($\dot{V}O_2$), heart rate (HR), minute ventilation ($\dot{V}E$), ratio of minute ventilation to oxygen production ($\dot{V}E/\dot{V}O_2$), ratio of minute ventilation to carbon dioxide production ($\dot{V}E/\dot{V}CO_2$), oxygen saturation (SpO_2), and rating of perceived exertion were measured. For both groups, there was a decrease in $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$ ratios during static and dynamic squats, as well as an increase in other cardiorespiratory parameters, and no significant difference existed between them. There was an effect of the type of squat on the HR variation; the values in the static squat were higher than those of the dynamic squat in both groups. There was a significant difference with a reduction in SpO_2 at 40 Hz frequency when compared with 30 Hz in the COPD group. The other variables behaved similarly between the frequencies. The WBV exercise, regardless of the frequencies used, represented a mild effort that promoted cardiorespiratory response in COPD, with greater responses in the static squat and no adverse effect.

NEW & NOTEWORTHY This study showed that an acute session of light exercise of whole body vibration (WBV) can increase the cardiorespiratory responses in patients with chronic obstructive pulmonary disease (COPD), reaching values similar to that of the control group. The results might contribute, therefore, to the elaboration of exercise protocols with WBV for the treatment of patients with COPD during rehabilitation. Thus, future studies referring to training on the vibratory platform could use these exercise parameters and demonstrate possible long-term benefits.

lung disease; metabolic equivalent; oxygen consumption; vibration exercise

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INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is characterized by a persistent airflow limitation that is usually progressive and is associated with an enhanced chronic inflammatory response in the airways and lungs (25). People with COPD have clinical and functional complications resulting from local and systemic structural changes that appear throughout the course of the disease. These changes impact on physical outcomes (e.g., reduction of peripheral muscle function and loss of lean body mass), worsening quality of life, and performance in activities of daily living (12, 25).

An alternative of non-pharmacological treatment for COPD is whole body vibration (WBV). WBV is an exercise performed on a vibrating platform that generates vertical sinusoidal vibrations. Previous studies showed that WBV improved muscle strength, exercise capacity, and quality of life in patients with COPD (7, 13, 22). Physiological effects of WBV are explained by greater muscle activation, leading to improved cardiorespiratory responses and muscular activity during exercise (5, 9, 10, 24). Some of these physiological effects [i.e., increased oxygen consumption ($\dot{V}O_2$) and heart rate (HR) during WBV] are corroborated by recent studies using WBV (5, 10). Besides these benefits, studies have shown that WBV does not seem to aggravate patients' symptoms of dyspnea and fatigue in COPD (13, 14, 22).

WBV may be an effective treatment in COPD because of its tolerance and applicability (14, 16, 22). However, there are gaps in the current literature regarding cardiorespiratory demands of WBV in the COPD population, particularly regarding exercise intensity. It is unknown whether different frequencies of WBV elicit similar or different cardiorespiratory responses. Furthermore, studies investigating WBV in COPD used different types of squats in their exercise protocols, and it is unclear whether static and dynamic squatting elicit similar responses in this health condition. These limitations are particularly relevant because previous studies suggested that posture adopted during WBV is associated with different physiological responses, such as neuromuscular activation and postural control adjustment (1, 4).

The aim of the present study was to investigate cardiorespiratory responses to WBV in different types of squats and vibration frequencies in people with COPD compared with healthy controls. Our hypothesis is that WBV will promote greater cardiorespiratory responses in people with COPD when compared with healthy people, and it will be associated with a greater vibration frequency, and static squatting will be superior to dynamic squatting.

MATERIALS AND METHODS

Study Design and Sample

This study involved COPD and healthy participants aged 45–80 yr old. Participants were recruited from May 2015 to September 2016 by convenience from the local community in Diamantina, Brazil. To be eligible, they (i.e., male or female) fulfilled our inclusion criteria: no practice of exercise in the last 3 mo; no exacerbation or hospitalization in the last 4 wk; women had to be in the postmenopausal period; no severe comorbidity; and no self-reported contraindication for WBV (i.e., deep vein thrombosis, metal implants, pacemaker, epilepsy, tumors, arterial aneurysm, or arrhythmia). Moreover, healthy participants had to present a normal lung function by spirometry exam.

This study was conducted in accordance with the Resolution number 466/12 of the National Health Council and the Declaration of Helsinki and was approved by the local ethics committee (Universidade Federal dos Vales do Jequitinhonha e Mucuri; identification number 649.332).

Clinical Assessments

Pulmonary function, body composition, and smoking history were collected. Pulmonary function was assessed by spirometry for confirming the presence and absence of airway limitations in people with COPD and healthy ones, respectively. Forced expiratory volume in the first second (FEV_1), forced vital capacity, and FEV_1/forced vital capacity were measured in accordance with the methods of the American Thoracic Society and the European Respiratory Society (19). The percentages of predicted spirometry values were calculated from Brazilian population data (21). The classification of airflow limitation severity in COPD was based on the Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria, and participants were classified from mild to very severe according to post-bronchodilator FEV_1 (GOLD I–IV) (25).

Total body mass, fat body mass, lean body mass, and bone mineral density were collected using dual-energy X-ray absorptiometry (Lunar, DPX, Madison, WI). The body mass index was determined from the total body mass divided by the square of the height (kg/m^2) (6). Smoking history and former subjects was collected using a self-reporting of the number of pack-years, calculated as the number of smoked cigarettes per day/20 and multiplied by the number of years of smoking (23).

Stages of the Study

To meet the objectives, this study was divided into two stages. The first stage sought to evaluate the cardiorespiratory responses to different types of squats. The second stage aimed to evaluate the cardiorespiratory responses to different vibration frequencies and characterize the exercise intensity.

The WBV exercise was performed on a synchronic vibrating platform (FitVibe Excel Pro, GymnaUniphy NV, Bilzen, Belgium) in both stages. Patients exercised in a squatting position with their feet 28 cm apart, barefoot, and with the upper limbs holding the platform bars, and performed 6 series of 30 s with 60 s of rest interval between each series. During the WBV exercise in the two stages, the exhaled gases were collected breath-by-breath using a gas analyzer (K4b2, Cosmed, Rome, Italy). The cardiorespiratory responses were determined by evaluation of $\dot{V}O_2$, minute ventilation ($\dot{V}E$), ratio of minute ventilation to oxygen production ($\dot{V}E/\dot{V}O_2$), and ratio of minute ventilation to carbon dioxide production ($\dot{V}E/\dot{V}CO_2$). In addition, HR (measured by an HR monitor), oxygen saturation (SpO_2; measured by a pulse oximeter), and rating of perceived exertion (measured by the Borg scale, range 0–10) were monitored and registered immediately before and after each series of exercises.

The stages of the study were performed on days intercalated by 48 h (20). On the day before the evaluation, the participants were familiarized with the procedures of the study (platform vibration, gas analyzer, and position of squatting). All the evaluations and interventions were performed during the same period of the day.

First stage: cardiorespiratory responses in different squat positions. The WBV was applied in association with static squatting or dynamic squatting on two alternate days. The static squatting was performed with participants maintaining a posture with 30° of knee flexion. The dynamic squatting began with a posture with 30° of knee flexion, and the posture was held for 3 s. Then the participant slowly squatted until ~10° of knee flexion was achieved. After holding the knee at 10° flexion for 3 s, the participant was instructed to return slowly to the starting position. This cycle was repeated during the total exercise time (30 s). A supervisor controlled the phases and time of the flexion and extension movements using verbal commands. For the static and dynamic squatting, the vibratory stimulus was offered at an amplitude of 2 mm and frequency of 35 Hz. The angulation and exercise protocol were adapted from previous studies (20, 22).

Second stage: cardiorespiratory responses in different frequencies of vibration and characterization of the exercise intensity. In this stage, the participants performed the WBV exercise at different frequencies of vibration on 3 alternate days (48 h) and in a random manner: 30 or 35 or 40 Hz. The exercise was performed in a posture of static squatting with 30° of knee flexion. The amplitude of the platform vibration was maintained at 2 mm. The American College of Sports Medicine guidelines (14a) were used for classification of exercise intensity on the basis of the metabolic equivalent (MET) values obtained during the exercise, classified as "very light" ($<$ 2 METs), "light" (2–2.9 METs), "moderate" (3–5.9 METs), "vigorous" (6–8.7 METs), and "near to maximum or at maximum" ($\geq$8.8 METs).

Statistical Analysis

Frequencies, central tendencies, and variability measures characterized sample. For central tendency and variability, we reported means and standard deviations for parametric variables, and medians and interquartile ranges for nonparametric data. Shapiro-Wilk's test investigated normal distribution. To investigate whether COPD and healthy groups were similar at baseline, independent *t*-test and Mann-Whitney test were used for parametric and nonparametric data, respectively.

The cardiorespiratory responses to different squats were evaluated by variation (delta) of the data (before and during exercise moments). The two-way ANOVA for repeated measurements with a post hoc Tukey was used for this analysis. The cardiorespiratory responses to different frequencies of vibration were evaluated by a paired *t*-test (parametric data) or Wilcoxon test (nonparametric data) for within-group analysis and two-way ANOVA of repeated measurements for evaluation of interaction between the time (before and during exercise) and groups (healthy $\times$ COPD). Furthermore, the within-group, one-way ANOVA with post hoc Tukey was used to evaluate differences (delta) between the frequencies of vibration. All analyses were conducted using the Graph-Pad Prism, version 5.0 (GraphPad Software, San Diego, CA).

In the current study, sample size was calculated using piloted data of our primary outcome of interest, $\dot{V}O_2$, during WBV with static squatting at a frequency of 35 Hz. For calculation, we used a paired *t*-test and the two-tail alpha level, considering an effect size of 1.132, alpha error of 0.05, and a power of 0.8 calculated sample of nine participants per group, with level of statistical significance of 0.05.

RESULTS

The study included 13 participants with COPD (COPD group) who were matched with 13 healthy participants for anthropometrics (i.e., body mass, height, body mass index) and age. The participants differed by at least 2 cm in height, 2 kg in weight, and 2 years of age. Characteristics of healthy and COPD groups are presented in Table 1. There were no significant differences between groups for anthropometric, clinical, and body composition variables. Participants with COPD presented moderate airway obstruction (FEV_1 = 58.1%) and greater number of pack-years. Eight participants with COPD used inhalation medication, including the classes of bronchodilators and corticosteroids.

Cardiorespiratory responses to different types of squats (i.e., static and dynamic) are presented in Fig. 1. No statistically significant difference was found between healthy and COPD groups on all cardiorespiratory responses ($P > 0.05$). Static squatting had a greater impact on HR ($P = 0.01$) when compared with dynamic squatting in both groups (i.e., COPD and healthy groups).

Table 2 presented cardiorespiratory responses to different vibration frequencies in healthy and COPD groups. With the exception of $\dot{V}E/\dot{V}O_2$ at 30 Hz, no statistically significant differences were found between healthy and COPD groups, or among different vibration frequencies, for all investigated cardiorespiratory responses. In healthy and COPD groups, vibration frequencies of 30 Hz, 35 Hz, and 40 Hz had significantly greater $\dot{V}O_2$, lower $\dot{V}E/\dot{V}O_2$, and $\dot{V}E/\dot{V}CO_2$. The healthy group had greater $\dot{V}E$ at 40 Hz. Additionally, within-group analysis showed that the HR increased significantly in all frequencies of vibration for the healthy group and in the COPD group at 35 and 40 Hz. Furthermore, the SpO_2 increased significantly in the frequency of 35 Hz in healthy and COPD at 30 Hz. The rating of perceived exertion in both groups remained unchanged after WBV exposure.

Comparison among different vibration frequencies is presented in Table 3. No statistically significant difference was found among the frequencies in the healthy group for all investigated responses. A significant variation (decrease) in the SpO_2 variable at 40 Hz presented when compared with 30 Hz. The MET values were similar ($P = 0.17$) at the three frequencies and types of squatting in both groups. Thus, the exercise was classified as being of "very light" intensity (<2 METS) according to the American College of Sports Medicine guidelines (2011) (14a).

Table 1. *Clinical and demographic characteristics of healthy and COPD groups*

Characteristics	Healthy Group $n = 13$	COPD $n = 13$	P Value
Sex, M/F	9/4	9/4	1.00
Age, yr	63.4 (6.9)	65.2 (7.6)	0.52
BMI, kg/m^2	24.3 (2.6)	22.6 (3.4)	0.17
% Fat	28.9 (7.9)	27.0 (7.8)	0.53
Lean body mass, kg	41.7 (8.3)	39.2 (8.4)	0.44
Fat body mass, kg	16.9 (4.8)	14.5 (4.3)	0.19
Bone mass, g/cm^2	1.1 (0.1)	1.0 (0.1)	0.23
FEV_1, liters	2.6 (0.3)	1.5 (0.6)	<0.001*
FVC, liters	3.4 (0.5)	2.1 (0.8)	0.01*
$FEV_{1\ postBD}$, % pred	99.6 (12.5)	58.1 (19.2)	<0.001*
FEV_1/FVC, %	76.9 (3.5)	57.6 (9.1)	<0.001*
Pack-years, n	12.5 (4.2)	35.9 (6.3)	0.006*

Data are means (SD); n = number of participants. BD, bronchodilator; BMI, body mass index; COPD, chronic obstructive pulmonary disease; F, female; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; M, male; pred, predicted. *$P \leq 0.05$.

DISCUSSION

The current study compared cardiorespiratory responses between two different types of squats and among different WBV frequencies in people with COPD and healthy people. To the best of our knowledge, this is the first study investigating these responses in COPD. We have shown that WBV promotes low-intensity and similar cardiorespiratory changes among healthy people and COPD. There was no influence of the vibration frequencies change; however, the type of squat influenced the HR response.

Static squatting had a greater variation (i.e., 39.2%) on HR when compared with dynamic squatting, and this response was consistent in healthy and COPD groups. It is possible that this response was mediated by greater neuromuscular activation during the static squatting. Previous study supported our findings showing that neuromuscular activation required during static squatting is greater when compared with the dynamic one (1, 18). Isometric muscle contractions in the static squatting promote obstruction of muscle blood flow, which leads to an accumulation of local metabolites and a consequent increase on sympathetic responses due to metaboreflex activation, and an increase on HR (8).

Recently, Gloeckl et al. (16) suggested that a WBV protocol with dynamic squatting seems to be preferable to isometric exercise in people with COPD. This suggestion was based on a significant, but only moderate, increase on cardiopulmonary responses when people with COPD performed WBV in a static position (i.e., standing on the platform without any squat exercise) when compared with dynamic squatting (16). However, it is important to mention that posture adopted on the platform may change transmissibility of vibration energy to the body. Other previous studies suggested that protocols should maintain knees in flexion during WBV exercise to minimize transmission of mechanical energy to the head and the negative side effects (1, 24). Furthermore, a previous study demonstrated that the ability of leg muscles to dampen and dissipate mechanical energy may decrease when the WBV is performed in knee angles above 30° (2). This decrease probably reduces physiological effects of vibration and the magnitude of neuromuscular responses (1). This was confirmed by Gloeckl et al. (16), with no differences on cardiopulmonary responses when people with COPD performed dynamic squatting with and without WBV at knee flexion of 90°–100°. Our findings suggested that static squatting at small knee angles during WBV exercise maximizes cardiorespiratory responses of pa-

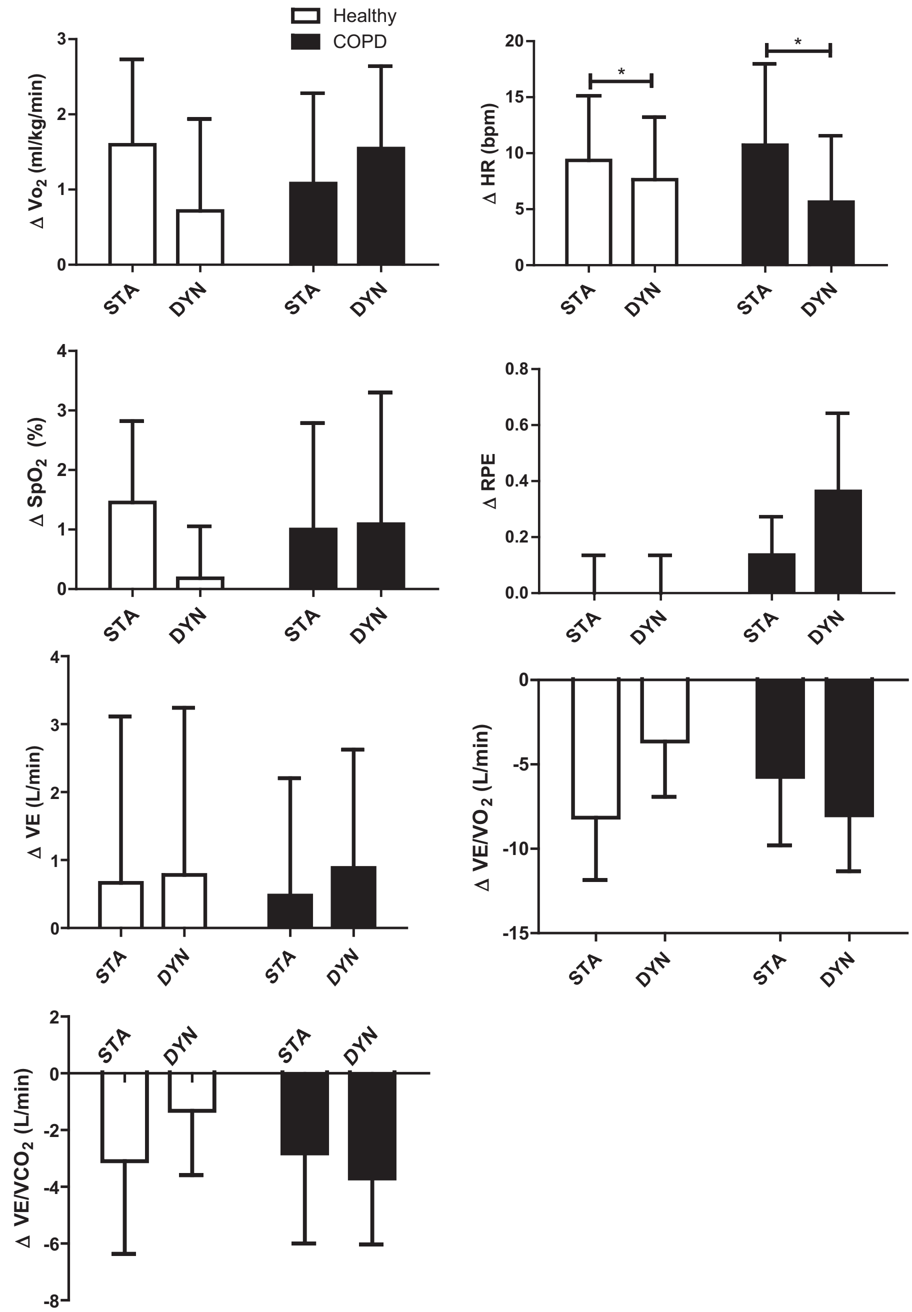

Fig. 1. Comparison of static (STA) and dynamic (DYN) squatting on cardiorespiratory responses in people with COPD and a matched healthy group. Data as mean and standard deviation. Two-way ANOVA for repeated measures and the Tukey post hoc test. Significance: $*P < 0.05$. COPD, chronic obstructive pulmonary disease; HR, heart rate; RPE, rating of perceived exertion; SpO_2, oxygen saturation; $\dot{V}CO_2$, carbon dioxide production; $\dot{V}E$, minute ventilation; $\dot{V}O_2$, oxygen consumption.

tients with COPD. Finally, we believe that protocols should consider goals of the treatment and people's specifics.

In the present study, cardiorespiratory responses during WBV were characterized mainly by the increased $\dot{V}O_2$ and HR in healthy and COPD groups, corresponding to a walking at a speed of less than 3.2 km/h on a flat and horizontal surface (5). During the vibratory stimulus, there is an increase in the muscular perfusion associated with a peripheral vasodilatation to supply the metabolic demand during the exercise. In addition, the increase in the ejected volume as a result of the increase in the venous return are factors that might be related to the regulation of acute adaptations to exercise, such as an increase in cardiac output and a consequent increase in $\dot{V}O_2$ (17, 24).

Our data demonstrated that WBV was performed at an intensity corresponding to ~50.9%–53.5% of the predicted HR maximum for the age in the healthy group and 49.0%– 56.9% of the HR maximum in the COPD group. Although not significant, the exercise when performed at the frequency of 35 Hz showed a greater HR variation in the COPD group. In this context, studies demonstrated that transmissions of vibrational stimuli to soft tissues seem to suffer an attenuation of the stimulus in the hip and spine joints at frequencies above 35 Hz (11). Pleguezuelos et al. (22) adopted a WBV protocol with frequency of 35 Hz and demonstrated that there was an increase of 15 beats during each session of WBV in people with severe COPD. In the present study, the mean HR increase in the COPD group was close to 4, 10, and 8 beats at

Table 2. *Comparison of moments before (rest) and during exercise (WBV) in different frequencies of WBV in the COPD and healthy groups*

Variables	Frequency, Hz	Healthy-Rest	Healthy- WBV	*P* Value	COPD-Rest	COPD-WBV	*P* Value	Between Groups - *P*	Cohen's δ	Power
$\dot{V}O_2$, ml·kg^{-1}·min^{-1}	30	4.7 (3.9–5.4)	6.2 (5.2–7.3)	0.01	5.2 (4.4–6.1)	6.6 (5.5–7.6)	0.01	0.78	1.01	1.00
	35	5.1 (4.1–6.1)	6.5 (5.1–7.9)	0.01	5.1 (4.5–5.6)	6.2 (5.5–6.9)	0.01	0.60	1.06	1.00
	40	4.5 (3.9–5.1)	6.3 (5.2–7.3)	0.01	4.9 (4.3–5.6)	6.3 (5.3–7.3)	0.01	0.49	1.03	1.00
$\dot{V}E$, l/min	30	9.4 (8.4–10.3)	11.3 (9.3–13.3)	0.05	12.5 (10.1–14.9)	12.7 (10.3–15.2)	0.70	0.13	1.04	1.00
	35	11.4 (9.6–13.2)	12.1 (9.2–15.0)	0.42	11.8 (10.2–13.5)	12.0 (10.1–14.0)	0.68	0.60	1.02	1.00
	40	9.9 (8.7–11.2)	11.7 (9.6–13.7)	0.01	11.3 (9.9–12.6)	12.3 (10.1–14.6)	0.07	0.44	1.03	1.00
$\dot{V}E/\dot{V}O_2$, l/min	30	34.5 (32.4–36.7)	29.4 (27.3–31.6)	<0.01	43.1 (38.4–47.8)	34.6 (31.1–38.2)	0.01	0.03	1.06	1.00
	35	36.7 (33.7–39.7)	29.3 (27.4–31.2)	0.01	40.2 (36.4–44.1)	34.7 (31.7–37.7)	0.01	0.29	1.00	1.00
	40	36.2 (33.4–38.9)	30.9 (28.2–33.6)	0.01	41.2 (36.8–45.6)	35.3 (32.4–38.1)	0.01	0.70	1.03	1.00
$\dot{V}E/\dot{V}CO_2$, l/min	30	37.9 (35.9–39.9)	34.7 (32.5–37.0)	0.01	44.2 (40.5–47.9)	39.8 (36.8–42.7)	0.01	0.29	1.02	1.00
	35	38.0 (35.4–40.5)	34.8 (32.8–36.9)	0.01	42.0 (39.1–45.0)	39.3 (37.3–41.4)	0.01	0.71	1.01	1.00
	40	38.8 (36.6–41.0)	35.4 (33.3–37.4)	0.01	42.2 (38.6–45.8)	39.6 (37.0–42.2)	0.02	0.48	1.02	1.00
HR, beats/min	30	71.2 (65.6–76.7)	78.8 (72.3–85.3)	0.01	79.1 (73.5–84.6)	82.5 (77.3–87.7)	0.12	0.06	1.00	1.00
	35	73.5 (65.9–81.1)	82.0 (75.5–88.5)	0.01	77.5 (70.5–84.4)	87.6 (82.2–94.1)	0.01	0.55	1.00	1.00
	40	71.3 (65.1–77.6)	80.0 (74.5–85.5)	0.01	76.0 (68.7–83.3)	83.8 (76.7–90.9)	0.01	0.49	1.01	1.00
SpO_2, %	30	95.2 (94.3–96.1)	95.7 (94.6–96.7)	0.24	93.5 (91.8–94.2)	94.4 (93.0–95.8)	0.02	0.14	1.01	1.00
	35	94.2 (93.4–94.9)	95.7 (94.7–96.6)	0.01	93.5 (92.1–94.9)	94.4 (93.2–95.7)	0.09	0.36	1.02	1.00
	40	95.1 (94.6–95.6)	95.7 (94.8–96.5)	0.14	94.2 (92.8–95.5)	93.9 (92.4–95.4)	0.43	0.09	1.07	1.00
RPE, points	30	0.0 (0.0–0.0)	0.0 (0.0–0.0)	1.00	0.6 (0.1–1.3)	0.0 (0.0–0.0)	0.13	0.18	1.46	1.00
	35	0.5 (−0.1–1.1)	0.5 (−0.1–1.1)	1.00	0.7 (0.04–1.4)	0.8 (0.1–1.6)	0.41	0.48	1.00	1.00
	40	0.1 (−0.1–0.3)	0.1 (−01–0.3)	1.00	0.5 (0.1–0.9)	0.9 (0.1–1.8)	1.00	0.18	1.21	1.00

Data are mean (95% confidence interval); *P* values are significance levels between rest and WBV (paired *t*-test or Wilcoxon test) and between groups (healthy and COPD) in each frequency (ANOVA two-way for repeated measures). COPD, chronic obstructive pulmonary disease; HR, heart rate; RPE, subjective perception of exertion; SpO_2, oxygen saturation; $\dot{V}E$, minute ventilation; $\dot{V}CO_2$, carbon dioxide production; $\dot{V}O_2$, oxygen uptake; WBV, whole body vibration.

frequencies of 30 Hz, 35 Hz, and 40 Hz, respectively. The lower HR variation in the present study would be explained by participants presenting moderate COPD. Although WBV produces mild cardiorespiratory responses, this result might be important for patients with pulmonary disease.

In general, there is a physiological decline in ventilatory efficiency ($\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$) associated with a higher ventilation per min ($\dot{V}E$) during exercises (19). There was an increase in the $\dot{V}E$ only in the frequency of 40 Hz for healthy participants; in the other frequencies, there was a nonsignificant increase in our studies. We believe that this increase was due to a higher ventilatory demand with an increase in exercise intensity in the frequency of 40 Hz. However, a decrease during exercise was observed for $\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$, which reflects the decrease in O_2 uptake and CO_2 exhalation rates, respectively. This decrease occurs as a compensatory mechanism for increased metabolism during exercise. In addition, patients with COPD have an inadequate relationship between ventilation and pulmonary perfusion (increase in physiological dead space), ventilate inefficiently, and have elevated $\dot{V}E/\dot{V}O_2$ values. An increase in the values of this ratio in patients with COPD was observed in our study, although it was not statistically significant (8, 19)

Our results demonstrated that the three investigated frequencies of WBV did not differ on cardiorespiratory responses. We believe that these results are due to the low intensity of the exercise in all frequencies, and this protocol has been shown to be applicable and safe in COPD as already demonstrated in other studies with similar methodology (20, 22). In the analysis of parameter variation, only SpO_2 presented a significant reduction in the frequency of 40 Hz in the COPD group; however, it is important to note that this variation was not >2% and the values remained above 90%. Therefore, it is without clinical relevance.

Some authors have demonstrated that increase in $\dot{V}O_2$ and HR does not seem to be sufficient to generate long-term cardiovascular adaptation in young and older healthy populations, although WBV is capable of causing an increase on

Table 3. *Comparison among the three different frequencies of WBV in COPD and healthy groups*

Variables	Healthy				COPD			
	30 Hz	35 Hz	40 Hz	*P* Value	30 Hz	35 Hz	40 Hz	*P* Value
Δ VO_2, ml·kg^{-1}·min^{-1}	1.3 (0.4; 2.2)	1.4 (0.6; 22)	1.6 (0.8; 2.5)	0.82	1.4 (0.4; 2.3)	1.2 (0.4; 1.9)	1.3 (0.4; 2.2)	0.98
Δ HR, beats/min	6.8 (5.1; 8.6)	8.5 (4.5; 12.5)	7.9 (5.5; 10.3)	0.65	3.4 (−1.0; 7.8)	10.2 (6.3; 14.1)	7.8 (4.8; 10.9)	0.06
Δ $\dot{V}E$, l/min	1.9 (0.0; 3.7)	0.7 (−0.8; 2.2)	1.6 (0.3; 2.9)	0.23	0.3 (−1.2; 1.7)	0.2 (−0.9; 1.4)	1.1 (−0.1; 2.3)	0.54
Δ $\dot{V}E/\dot{V}O_2$, l/min	−4.3 (−6.2; −2.4)	−7.3 (−10.2; −4.5)	−5.8 (−8.0; −3.6)	0.15	−8.6 (−11.3; −5.7)	−5.5 (−8.0; −3.0)	−5.9 (−9.1; −2.8)	0.16
Δ $\dot{V}E/\dot{V}CO_2$, l/min	−2.5 (−4.1; −0.9)	−2.6 (−4.8; −0.4)	−3.7 (−5.3; −2.1)	0.52	−4.0 (−6.1; −2.0)	−2.5 (−4.6; −0.5)	−2.6 (−4.6; −0.6)	0.42
Δ SpO_2, %	0.7 (−0.2; 1.5)	1.5 (0.7; 2.3)	0.3 (−0.6; 1.2)	0.12	1.4 (0.4; 2.4)	1.1 (−0.01; 2.2)	−0.2 (−0.9; 0.4)	0.02*
Δ RPE, points	0.0 (0.0; 0.0)	0.0 (−0.3; 0.3)	0.0 (−0.3; 0.3)	1.00	0.3 (−0.2; 0.9)	0.1 (−0.1; 0.4)	0.5 (−0.2; 1.2)	0.70

Data are means (95% confidence interval). COPD, chronic obstructive pulmonary disease; HR, heart rate; RPE, subjective perception of exertion; SpO_2, oxygen saturation; $\dot{V}E$, minute ventilation; $\dot{V}CO_2$, carbon dioxide production; $\dot{V}O_2$, oxygen uptake; WBV, whole body vibration. *P* values are significance levels between frequencies in each group (one-way ANOVA and Tukey's post hoc test); *Significance between 30 and 40 Hz.

cardiorespiratory responses (5, 10). A recent study that conducted a 3-mo WBV training in COPD patients used the same exercise protocol as that proposed in the present study. The authors showed that WBV training promoted clinical benefits in patients with COPD, with higher functional capacity, muscular strength, and quality of life (21). Therefore, although the proposed exercise is of a low intensity, its application in people with COPD, mainly the most severe cases, seems to be an exercise that leads to cardiorespiratory gains in these patients.

As to limitations, we can emphasize that the population, the frequencies, and the amplitudes used were specific; however, these parameters were determined from previous studies with this population that demonstrated improvements in physical and functional aspects of COPD. Therefore, the results cannot be extrapolated to other vibrational parameters or to other populations. In addition, dynamic squatting was performed at a single frequency of vibration.

The principal findings for patients with moderate COPD: *1*) WBV exercise, at different vibration frequencies, leads to an increase in $\dot{V}O_2$, HR, and SpO_2 in subjects with COPD similar to those of healthy individuals, without worsening of dyspnea symptoms; *2*) vibration exercise at different vibration frequencies, as well as two different types of squats, were classified as being of very light intensity; and *3*) static squats caused a higher variation in HR than dynamic squats, with no difference between groups. Furthermore, WBV exercise in patients with COPD has been shown to be a safe exercise at all frequencies and types of squats evaluated, without causing dyspnea and fatigue.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

V.K.S.L., C.D.C.N., conceived and designed research; V.K.S.L., C.D.C.N., M.G.A.C., A.A.S., and L.P.L. performed experiments; V.K.S.L. and J.S.C.F. analyzed data; V.K.S.L., A.C.R.L., M.A.M., H.R.L., J.S.C.F., and V.A.M. interpreted results of experiments; V.K.S.L. prepared figures; V.K.S.L. drafted manuscript; V.K.S.L., A.C.R.L., C.D.C.N., M.A.M., H.R.L., V.C.O., and V.A.M. edited and revised manuscript; V.K.S.L., A.C.R.L., C.D.C.N., M.G.A.C., A.A.S., L.P.L., M.A.M., H.R.L., J.S.C.F., V.C.O., and V.A.M. approved final version of manuscript.

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