Original Article

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Cardiopulmonary responses during dynamic squatting exercise with and without whole-body vibration in adolescents

Respostas cardiopulmonares durante o exercício de agachamento dinâmico com e sem vibração de corpo inteiro em adolescentes

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ABSTRACT | BACKGROUND: Whole-body vibration (WBV) has been widely used as a therapeutic resource in pediatric rehabilitation. However, the cardiopulmonary responses are still unknown. **OBJECTIVE:** To investigate the intensity of dynamic squatting exercise with and without WBV in healthy adolescents to characterize cardiorespiratory responses. **METHODS:** This was a quasi-experimental study. Twenty-five adolescents (14.1 ± 1.7 years), 10 girls and 15 boys, underwent into oxygen consumption (VO2) and heart rate (HR) assessments during a protocol of squatting with and without vibration. Inclusion criteria were age between 12 and 18 years old of both sexes, have normal weight according to BMI. Exclusion criteria were to present chronic or acute, neurological, orthopedic, respiratory, cardiac, and endocrine disease and no self-reported contraindication for WBV (i.e. deep vein thrombosis, metal implants, pacemaker, epilepsy, tumors, arterial aneurysm, or arrhythmia). **RESULTS:** WBV was able to significantly increase VO2, HR, and perceived exertion during squatting exercise when compared to rest and squatting without-WBV. WBV associated with squatting reached 24.7% of the VO2max and 56% of the HRmax predicted for the age. Subjects during WBV reported a perceived exertion score between somewhat hard and hard compared to between very light and light in the Without-WBV protocol. **CONCLUSION:** Squatting associated with WBV was considered a light-intensity exercise that can be tolerated by healthy adolescents. This study provided valid results of this training modality and could be used as a tool to define the energy consumption spent in this training modality.

KEYWORDS: Adolescents. Squatting. Whole-body vibration.

RESUMO | INTRODUÇÃO: A vibração de corpo inteiro (VCI) tem sido amplamente utilizada como recurso terapêutico na reabilitação pediátrica. Porém, as respostas cardiopulmonares ainda são desconhecidas nesta população. **OBJETIVOS:** Investigar a intensidade do exercício de agachamento dinâmico com e sem VCI em adolescentes saudáveis a fim de caracterizar as respostas cardiorrespiratórias. **MATERIAIS E MÉTODOS:** Trata-se de um estudo quase experimental. Vinte e cinco adolescentes (14,1 ± 1,7 anos), 10 meninas e 15 meninos, foram submetidos a avaliações do consumo de oxigênio (VO2) e frequência cardíaca (FC) durante um protocolo de agachamento com e sem vibração. Os critérios de inclusão foram idade entre 12 e 18 anos, ambos os sexos, IMC normal. Os critérios de exclusão foram apresentar doenças neurológicas, ortopédicas, respiratórias, cardíacas e endócrinas crônicas ou agudas ou alguma contraindicação autorreferida para VCI (trombose venosa profunda, implantes metálicos, marca-passo, epilepsia, tumores, aneurisma ou arritmia). **RESULTADOS:** A VCI aumentou significativamente o VO2, FC e a percepção do esforço durante o agachamento quando comparado ao repouso e agachamento sem-VCI. VCI associada ao agachamento atingiu 24,7% do VO2máx e 56% da FCmáx prevista para a idade. Os indivíduos durante a VCI relataram esforço entre ligeiramente cansativo e cansativo em comparação com entre muito fácil e fácil no protocolo Sem-VCI. **CONCLUSÃO:** O agachamento associado à VCI foi considerado de intensidade leve e foi tolerado por adolescentes saudáveis. Este estudo forneceu resultados válidos desta modalidade de exercício e pode ser utilizado como uma ferramenta para definir o consumo de energia gasto durante a prática deste tipo treinamento.

PALAVRAS-CHAVE: Adolescentes. Agachamento. Vibração de corpo inteiro.

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Introduction

The experience with physical activity in adolescence is among the main factors that favor the determination of a more active lifestyle during adult life[1], reducing the risk of chronic-degenerative diseases and helping in the control of obesity and cardiorespiratory parameters, besides being a strong component in the improvement of self-esteem and well-being[2]. New approaches have been used to improve physical activity engagement in this population such as the use of Whole-Body Vibration (WBV)[3].

WBV is a neuromuscular training method where the subject stands on a platform that generates a vertical sinusoidal vibration at a previously selected frequency. During WBV, mechanical stimuli are transmitted to the body through vibration, stimulating the sensory receptors in the muscle axes and initiating a greater muscular activation compared to the tonic vibration reflex[4]. Because of these muscle contractions, WBV is known to have an aerobic component that is increased when associated with squatting exercise[4] and has been used as a stimulus pre-physical activity to increase muscle performance in training in athlete adolescents[5,6].

The squatting exercise is indicated for adolescents due to its practicality since it does not demand a great deal of time due to the large muscle volume used during the exercises, which makes the practice of physical exercise more attractive[7]. Squatting mimics daily life activities, and such activity brings benefits associated with the gross motor function[8], which can be enhanced with WBV since it intensifies neuromuscular responses that improve the synchrony of motor units and provide greater neuromuscular efficiency[4,9]. When it comes to healthy children and adolescents, it is not known what cardiopulmonary responses WBV associated with squatting exercise presents, even though it is already used to improve body composition in some conditions such as Down Syndrome and other central nervous system disabilities[3].

Quantifying such parameters in healthy adolescents becomes important so that, with such values obtained, this training modality can be applied in the pediatric population and thus obtain more efficient training. This study could provide valid results that could be used as a tool to define the energy consumption spent, besides characterizing this population for a protocol with WBV. Therefore, to address this gap, we aim to investigate the intensity of dynamic squatting exercise with or without WBV in healthy adolescents. We hypothesized that WBV, associated with squatting, could significantly increase cardiopulmonary parameters, such as oxygen consumption (VO2) and heart rate (HR), in comparison to squatting without vibratory stimulation.

Materials and methods

Study design

That was a quasi-experimental study to compare the cardiopulmonary responses of a dynamic squatting protocol with and without WBV in the same group of healthy adolescents. The study was carried out from October 2018 to July 2019. In order to meet the aim, two experimental sessions were performed (squatting exercises with and without WBV) in a commercial vibratory platform model called FitVibe (GymnaUniphy NV) with sinusoidal and vertical movement, where the measurements of the VO2 measured breath by breath by a portable gas analysis system, and HR measured using an HR monitor. This study followed the declaration of Helsinki. The Ethics and Research Committee of Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM), Brazil, approved this study (Protocol number: 2.058.016, CAAE 65295617.0.0000.5108), with consent/assent from parents/adolescents respectively.

Subjects

This study included 25 healthy adolescents (15 boys and 10 girls) with the age of 14.1 ± 1.7 years and normal body mass index (BMI) of 19.7 ± 1.6, and 80% of them were in the adult stage according to Tanner Scale (stage V). They were recruited by convenience from private and public schools and only participated in school physical education class activities. All measurements were obtained in the Physiology of Exercise Laboratory (UFVJM) by trained researchers. Inclusion criteria were age between 12 and 18 years old of both sexes, have normal weight according to BMI. Exclusion criteria were to present chronic or acute, neurological, orthopedic, respiratory, cardiac, and endocrine disease and no self-reported contraindication for WBV (i.e. deep vein thrombosis, metal implants, pacemaker, epilepsy, tumors, arterial aneurysm, or arrhythmia). When attending the laboratory, before the tests, we questioned the subjects and parents about possible complications or modifications in the daily routine of the adolescents that occurred throughout the study with written consent and assent to participate with all risks and benefits. Adolescents were instructed to avoid the practice of strenuous and long-lasting activity, in addition to not ingesting caffeine 24 hours before the test and sleeping at least 8 hours the night before.

Procedures

All subjects underwent all experimental situations divided into four moments: Squatting + WBV, Squatting Without WBV, and two baseline moments that correspond to their days of squatting protocols (the resting moment before squatting protocols where subjects remained seated for 10 minutes, but only the last 5 minutes were evaluated).

The sessions were performed on two different days, with a minimum interval of 24 hours, always at the same time of day with a preliminary day of familiarization. The order in which each participant underwent the two different sessions was assigned randomly by lots with concealed allocation by a blinded therapist. Familiarization was performed on a preview day, and it consisted of performing one squatting set with and without WBV with the gas analyzer mask but without the gas analyzer being switched on. This phase aimed to mimic the test itself to minimize the learning effect so that the subject became familiar with the instruments and procedures to be performed on the day of the test, avoiding interference on VO2 and HR due to anxiety. On the same day of familiarization, anthropometric data collection (height and body mass) and self-reported maturation stage (Tanner Scale)[10] were evaluated. For maturation stage assessment, a set of photographs illustrating the phases of maturation for each sex was shown to the subjects. Breasts and pubic hair are evaluated in girls, and genital and pubic hair in boys, because adolescents may present different phases for each of the characteristics as they respond to different genetic and hormonal mechanisms with possible effects in physiological responses[10]. On the second and third day, the subject performed one of the protocols (i.e., squatting exercises with and without WBV). Data analysis was made by a blinded therapist.

Experimental situation

In both protocols (with and without WBV), the subject was instructed to perform 8 series of 40 seconds of dynamic squatting exercise, where there was a knee flexion for 3 seconds at 60˚ followed by 3 seconds with knee flexion at 10˚; such measurements were made with a universal goniometer and had an imposed barrier in the gluteus region to delimit the squat range. Subjects positioned themselves on the vibratory platform barefoot with their feet 14 cm from the vibration shaft to not interfere in acceleration values. Each repetition of the squat exercise required 8 seconds, since each change in position (up / down) required 1 second plus 3 seconds in squatting at 60˚ and 3 seconds held in 10˚, thus, 5 repetitions were performed in each set of 40 seconds plus 40 seconds of rest between sets[11].

WBV parameters

During the WBV protocol, subjects performed 8 sets of 5 squat reps kept for 40 seconds, on the programmed vibration platform with a frequency of 40 Hz and an amplitude of 4 mm with 40 seconds rest between sets[11]. Parameters were able to promote physiological responses[4].

Without Vibration parameters

During the squatting protocol without vibration, the volunteer performed the same number of sets and repetitions of squatting exercise over the vibration platform, but with it switched off. Verbal control of the time was given by the examiner to control repetitions.

Cardiorespiratory measurements

VO2 was continuously monitored breath by breath by direct analysis with open-circuit spirometry, the telemetry system of the K4b2® gas analyzer (COSMED, Rome, Italy). For this, the adolescents breathed wearing a face mask of the device itself. Collected data was transferred by radio transmitting to a computer near the test site. The system was calibrated following the manufacturer's recommendations. HR was monitored beat by beat by an HR monitor POLAR RS800sd (POLAR, Kempele, Finland). Both evaluations were measured before (Rest) with the mean of the last 5 minutes of rest and during squatting exercise (Without WBV and WBV) with the mean values evaluated every 40 seconds of dynamic squatting during the protocol. Perceived exertion was evaluated with Borg's scale which runs from 6 with no feeling of exertion to 20 with very, very hard exertion[12] asked after every 40 seconds dynamic squatting set.

Statistical Analysis

Sample size calculation totaled 25 subjects, which was made with the GPower 3.1 statistical software, considering a paired T-test with 80% power and alpha = 0.05, plus 20% of possible loss, based on the effect size of the study of Avelar et al.[11]. The data analysis was used in Prism Program 7.0. The normality of data was analyzed by the Shapiro-Wilk test. Continuous variables were presented as the mean and standard deviation (SD). The two-way ANOVA test was used considering the factors vibration stimuli (with and without WBV) and exercise moments (before and during squatting) with Bonferroni post hoc test to analyze the interaction between protocols. All data of protocols are presented as means ± SD. The significance level was p <0.05.

Results

The effects of the interventions in VO2 are demonstrated in Figure 1. There was a significant increase of the VO2 during both protocols in relation to the rest with significantly higher values during squatting with-WBV (p < 0,01). The increase of the VO2 during squatting with-WBV was 10.35 ± 2.61 mLkg-1min-1 (95%CI 9.26 – 11.43) and during squatting, without-WBV was 8.24 ± 1.85 mLkg-1min-1 (95%CI 7.48 – 9.01). There were: within-intervention difference (p < 0.01; F: 255.9), between-intervention difference (p = 0.01; F: 6.38) and interaction of the VO2 (p < 0.01; F: 14.79) (Table 1).

There was a significant increase of the VO2 during both protocols compared to the rest, with significantly higher values during squatting with-WBV (p < 0,01). The increase of the VO2 during squatting with-WBV was 10.35 ± 2.61 mLkg-1min-1 (95%CI 9.26 – 11.43), and during squatting, without-WBV was 8.24 ± 1.85 mLkg-1min-1 (95%CI 7.48 – 9.01). There were: within-intervention difference (p < 0.01; F: 255.9), between-intervention difference (p: 0.01; F: 6.38) and interaction of the VO2 (p < 0.01; F: 14.79) (Table 1).

Similar results were found for HR (Figure 2). A significant difference in HR was found in both protocols in comparison to corresponded rest with significantly higher values during squatting with-WBV (p < 0,01). The difference during squatting with- and without-WBV were 110.0 ± 11.0 bpm (95%CI 105.7– 114.8) and 99.0 ± 7.0 bpm (95%CI 76.6 – 83.3), respectively. There were: within-intervention difference (p < 0.01; F: 286.3), between-intervention difference (p < 0.01; F: 3.55) and interaction for HR (p: 0.06; F: 27.35).

Table 1. Cardiovascular responses during squatting with and without WBV

Varibles	Squatting Without WBV (n = 25)	Squatting with WBV (n = 25)	Within-Intervention		Between-Intervention		Interaction	
			p	F	P	F	p	F
VO_2,mlO2kg^{-1}min^{-1}								
Rest	5.10 ± 1.30	5.03 ± 0.86	<0.01	255.9	0.01	6.38	<0.01	14.79
During	8.24 ± 1.85*	10.35 ± 2.61*#						
Difference (95% CI)	3.14 (7.48 – 9.01)	5.32 (9.26 – 11.43)						
HR, bpm								
Rest	83.3 ± 7.8	80.0 ± 8.02	<0.01	286.3	<0.01	3.55	0.06	27.35
During	99.0 ± 7.0*	110.0 ± 11.0*#						
Difference (95% CI)	15.7 (76.6 – 83.3)	30.0 (105.7– 114.8)						

Data represented as mean ± SD. WBV: Whole Body Vibration.
*p<0.05 to Rest;
#p<0.05 to Squatting Without WBV.

Figure 1. Mean values of Oxygen Consumption (ml O2kg.-1.min-1) under the different test conditions (n = 25). * Significantly different from resting condition (p <0.01). ** Significantly different from squatting without vibration (p <0.01). VO2 Oxygen consumption, WBV Whole body vibration

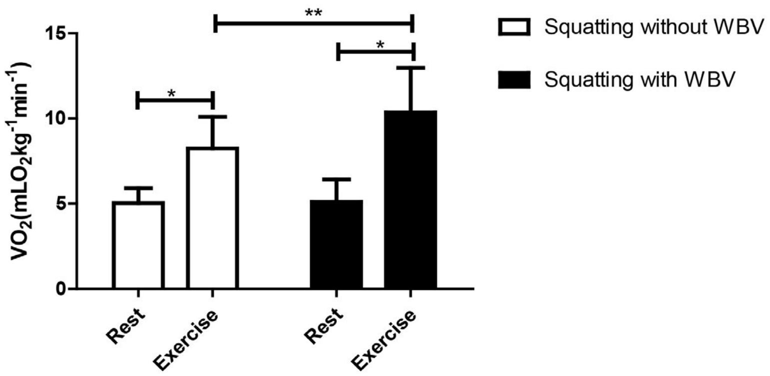
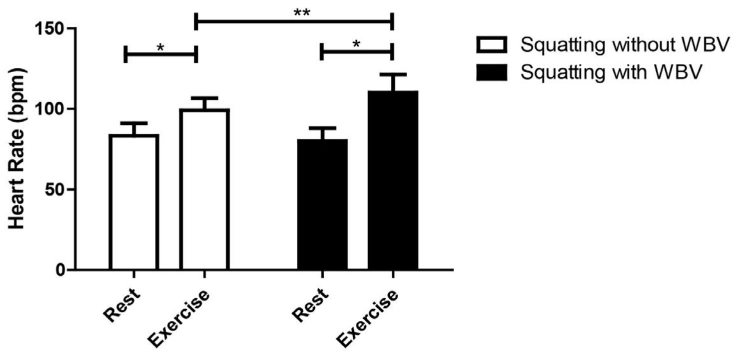


Figure 2. Mean values of Heart Rate (bpm) under the different test conditions (n = 25). * Significantly different from resting condition (p <0.01). ** Significantly different from squatting without vibration (p <0.01). WBV Whole body vibration

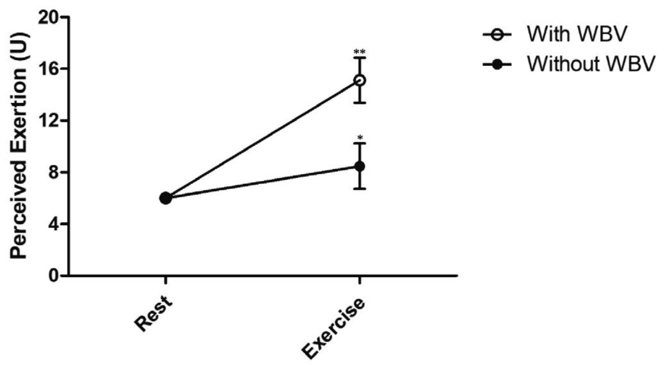


The predicted HR max for age in adolescents, determined by the equation HRmax = 208 - (0.7 x age)[13], was 198 bpm. Rest, squatting without vibration, and squatting with WBV were 42, 50, and 56 % (with means of 83; 99; 110 bpm respectively) of the HRmax predicted for age.

About the perceived exertion, the protocol with-WBV showed significant values compared with the protocol without-WBV with a mean score of 15.12 ± 1.7 (level hard of exertion), and the protocol without-WBV showed a mean score of 8.48 ± 1.7 (between extremely light and very light exertion) (Figure 3). There were: within-intervention difference ($p < 0.01$; F: 549.7), between-intervention difference ($p < 0.01$; F: 180.1) and interaction for perceived exertion ($p < 0.01$; F: 180.1).

The post hoc Bonferroni test confirmed the higher values of VO2, HR, and perceived exertion in the protocol of squatting with-WBV ($p < 0.01$).

Figure 3. Comparison between the mean values of perceived exertion (U) of Without-WBV and With-WBV protocols (n = 25). * Significantly different from resting condition (p <0.01). ** Significantly different from squatting without vibration (p <0.01). WBV Whole body vibration



Discussion

In the present study, the WBV was able to significantly increase VO2 and HR during squatting exercise. Such increase corresponded to 2.94 METS and 56% of HRmax that corresponds to light intensity exercise, such as walking (slowly), sitting (using a computer), standing (cooking and washing dishes)[14]. That is the first study investigating the impact of squatting exercise combined with WBV and raise important knowledge regarding the intensity of squatting exercise and WBV in healthy adolescents.

The mechanism related to the increment of VO2 after squatting exercise plus WBV can be explained because, during the vibratory stimulus, there is an increase in the muscular perfusion associated with peripheral vasodilatation to supply the metabolic demand during the exercise[15]. Also, 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 VO2[15-18].

The results of this study do not archive the minimum necessary to be considered as aerobic training to healthy adolescents, since it is necessary at least 30 minutes duration be considered aerobic training[17]. A protocol with a longer duration could increase even more VO2 and HR values in the protocol with-WBV. Thus, it is important to have a caution for the prescription of this training modality to aerobic gains, because of the low demands of VO2, even with WBV having effects on cardiovascular physiology[18].

Moreover, WBV was able to reach 24.7% of adolescents' VO2max, considering the mean values of VO2max found for boys (ranging from 42.95 to 49.55 mL.kg-1.min-1) and for girls (ranging from 36.76 to 38.29 mL.kg-1.min-1) in the literature19 and 56% of HRmax. These results are in agreement with the study that evaluated the same parameters in healthy elderly, with the same frequency and amplitude (40 Hz and 4 mm), where the squatting protocol associated with WBV was able to increase 20 % of VO2 and 7.5% of HR, corresponded to 2 METs and represented 56% of HRmax predicted for age[11].

It is worth noting that about the perceived exertion, subjects during WBV reported a score between somewhat hard and hard compared to between very light and light in the Without-WBV protocol. It is important to remember that a familiarization day was done before the exercise protocols to reduce anxiety during the test and minimize the bias in the results. That indicates that even with the values of VO2 and HR not being considered high, the vibration stimuli were able to generate greater perceived exertion with a possible greater muscular participation when squatting is associated with WBV, which should be evaluated in a future study.

WBV was able to increase cardiovascular demand in healthy adolescents with a significantly higher perceived exertion when compared to the protocol without-WBV in an acute protocol with a short duration. Although the results in this study were below the minimum necessary to be considered as aerobic training to healthy adolescents, some children and adolescent population with lower capacity to practice exercise probably can benefit from a safe and tolerable protocol such as the WBV[20]. However, it is necessary new studies to explore that.

As for strengths, this is the first study to assess oxygen consumption in a dynamic squatting protocol associated with whole-body vibration. The analyses were made through an open circuit of spirometry, the gold standard.

The present study had some limitations, such as being an acute protocol with short duration applied in only one group, including boys and girls, without considering possible gender differences. The values of frequency and amplitude were fixed so that the found values could not be extrapolated to different protocols with different frequencies and amplitudes. However, the adequate sample size and the methodology design were the strongest points of the present study, such as maturation assessment. It is necessary to point out that 80% (86.6% of the boys and 70% of the girls) of the adolescents participating in the study reported being in the maturational stage V of the Tanner Scale, where development is in the adult stage avoiding being a confounding factor. The presented protocol could be used in a future training program to determine chronic effects in adolescents' cardiopulmonary and muscular system. Thus, further studies might address all these gaps.

In conclusion, squatting associated with WBV was considered a light-intensity exercise tolerated by healthy adolescents. This study provided valid results of the effectiveness of this training modality and could be used as a tool to define the energy consumption spent in this training modality, besides characterizing adolescents for such protocol bringing evidence that supports new studies in asymptomatic and symptomatic adolescents as well.

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Author contributions

Soares BA, Lacerda AC, Lage VKS, Camargos ACR, Mendonça VA, and Leite HR participated in the conception, design, data collection, interpretation, and analysis, interpretation of the results, and writing of the scientific article. Nonato LF and Corrêa FG participated in the conception, design, and data collection.

Competing interests

No financial, legal, or political competing interests with third parties (government, commercial, private foundation, etc.) were disclosed for any aspect of the submitted work (including but not limited to grants, data monitoring board, study design, manuscript preparation, statistical analysis, etc.).

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