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Acute Effects of Whole-Body Vibration on Quadriceps Isometric Muscular Endurance in Middle-Aged Adults: A Pilot Study

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Abstract: This study analysed the acute effects of whole-body vibration (WBV) on quadriceps isometric muscular endurance. Fifteen healthy middle-aged males performed an endurance isometric strength test after three different warm-up conditions: static half squat plus WBV (HSV), static half squat without WBV (HS), and control condition (CC). The endurance isometric strength test consisted of 10 maximal isometric contractions held for 4 s and interspersed by 2 s of rest between each repetition. Rate of Perceived Exertion (RPE) was assessed after warm-up (RPE_1) and at the end of the testing session (RPE_2). During each testing session, participant's heart rate (HR) was continuously recorded. For each trial, the mean force across the 10 repetitions and fatigue index were evaluated. Mean force was significantly higher ($p < 0.01$) in CC than in the other two conditions. Both RPE_1 and RPE_2 were significantly lower ($p < 0.01$) in CC than HSV and HS condition. Warm-up HR and the mean testing session HR were significantly lower in CC than the other two conditions ($p < 0.01$). No significant differences were observed in fatigue index between conditions ($p > 0.05$) or in HR during the endurance protocol. Performing half-squat with or without vibration stimuli does not increase isometric muscular endurance and does not influence fatigue index.

Keywords: muscular fitness; strength; adults; vibration; RPE

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1. Introduction

Resistance training plays a crucial role in achieving various health benefits and to preserve muscular fitness integrity across the lifespan [1]. Indeed, resistance training increases muscle strength, endurance, and power, attenuating the physiological decline in muscle function [1,2]. During the ageing process, the loss of muscular function is not uniform across muscles, showing more pronounced deterioration in the lower limbs (e.g., quadriceps muscles) compared to the upper ones [3]. Therefore, investigations on novel methodologies to increase lower limb strength assume a paramount importance to counteract functional limitations in daily activities [3]. Recently, whole-body vibration (WBV) has been introduced in health and fitness centres as an alternative exercise modality to improve health-related physical fitness components [4,5]. WBV training has been utilized for therapeutic [6] and performance-enhancing purposes [7]. The pioneer studies that used vibration as an alternative exercise intervention reported an improvement in maximal strength and power in both acute and chronic conditions [8,9]. Thereafter, WBV has been used as an alternative method to produce adaptive responses comparable to those observed following resistance training [10,11]. It was proposed that the frequency (15–50 Hz), the duration (5–10 min), and the amplitude (2–5 mm) of the vibration stimuli may all contribute to an improvement of muscular performance due to their effect on neuromuscular excitatory state that, along with the stimulation of specific areas of the brain, influences the force-generating capacity of muscles [10,12].

Despite the heterogeneity of the applied WBV protocols (frequency, time, and type of exercise) a consensus exists on the beneficial effects of WBV on muscle strength. Indeed, previous studies have reported an increase in muscle strength and power in different target populations after the exposure to WBV training [13–16]. However, this body of literature overlooked the effect of WBV on muscular endurance which can be defined as the ability of the muscles to sustain repeated contractions over time [17]. As muscular endurance is a critical component to carry out activities of daily living requiring repetitive work such as walking or climbing stairs, its evaluation becomes even more important when assessing physical functioning [17,18]. To the best of our knowledge, only one study analysed the effects of WBV on isometric endurance of calf muscles, indicating an improvement after the WBV training protocol [19]. However, Ritzmann and colleagues used a sustained isometric contraction protocol to verify the effects of a chronic exposure to WBV on endurance [19]. While this protocol ensures an accurate evaluation of muscle endurance, it seems to lack specificity for daily living activities or dynamic sport actions. Understanding whether WBV increases muscular endurance performance would be useful to exercise specialists involed in structuring an optimal training protocol. Therefore, the aim of this study was to investigate the acute effects of WBV on quadriceps muscle endurance in healthy middle-aged male using a cyclic isometric endurance protocol.

2. Materials and Methods

2.1. Study Design

The study adopted a randomized repeated-measure design. Participants attended the Physical Exercise and Sports Science laboratory four times at the University of "Magna Graecia", Catanzaro. All participants performed one pre-testing session and three testing sessions. During the pre-testing session, anthropometric variables and body composition were measured. Afterwards, participants underwent a preliminary exercise test to get acquainted with the experimental protocol. During the three testing sessions, each participant underwent an isometric leg extension protocol after three different warm-up conditions which were administered in a randomized order (www.random.org (accessed on 10 December 2022)): static half squat plus WBV (HSV), static half squat without WBV (HS), and control condition (CC). To avoid fatigue and muscle soreness, each condition was spaced 72 h apart. Participants performed the isometric leg extension protocol with their dominant leg. After a careful explanation of the test procedures, risks, and benefits, participants signed a written informed consent. All experimental procedures detailed in the following paragraphs comply with the Declaration of Helsinki. The study was approved by the regional ethical committee (Approval Number n. 122).

2.2. Participants

Fifteen healthy middle-aged males volunteered to participate in the study (mean ± standard deviation (SD): Age = 40.0 ± 5.3 years; BMI = 27.9 ± 4.0 kg/m^2). All participants underwent clinical examination to exclude any contraindications to physical activity. Participants were included in the study if they were 30–55 years old and were not engaged in regular resistance training. Exclusion criteria included: any contraindication to physical activity according to the physical activity readiness questionnaire (PAR-Q+) [20], the presence of cognitive impairments, and any present or past impairment affecting lower limbs functionality. Participants' characteristics involved in the study are shown in Table 1.

Table 1. Participants' characteristics. Data are presented as mean ± SD. BMI, Body Mass Index; SMM, Skeletal Muscle Mass; %FM, Percentage of Fat Mass; PAL, Physical Activity Level.

Participants' Characteristics	
Age (years)	40.0 ± 5.3
Height (m)	1.74 ± 0.06
Body Mass (kg)	83.8 ± 12.1
BMI (kg/m^2)	27.9 ± 4.0
SMM (kg)	33.5 ± 3.4
% FM (%)	28.2 ± 5.9
PAL (METs-min/week)	762.4 ± 631.9

2.3. Experimental Protocol

During the pre-testing session, body mass and height were measured using a scale and a Harpenden stadiometer to the nearest 0.1 kg and 0.1 cm, respectively. Body composition was measured by a bioelectrical impedance method (BIA ACCUNIQ 360, Daejeon, Republic of Korea) while participants wore minimal clothing. Moreover, physical activity levels were evaluated using the global physical activity questionnaire (G-PAQ) [21]. During the three testing sessions, the isometric leg extension protocol was performed after three different warm-up conditions. For each testing session, exercise intensity was evaluated using the Rate of Perceived Exertion (RPE) scale [22] and heart rate (HR). To evaluate the warm-up (HR_1), the isometric leg extension endurance protocol (HR_2), and the mean testing session (HR_{mean}) intensities, HR (beats × min) was continuously recorded using a HR monitor (Forerunner® 45, Garmin, Olathe, KS, USA).

For each condition, RPE was assessed after the warm-up (RPE_1) and at the end of the testing session (RPE_2). Each testing condition began with 7 min of cycling at 50 rpm on a cycling ergometer (Ergoselect, ergoline GmbH, Bitz, Germany) plus 3 min of stretching exercise. Then, all participants performed, in random order, half squat plus WBV (HSV), half squat without vibration (HS), and control condition (CC) condition. In the HSV condition, participants stood on a Pro Evolve vibrating platform (DKN, USA) in a static half squat position (90° of knee flexion) for 60 s. Flexion angle was measured using a goniometer and posture was visually controlled during each test session. Five consecutive bouts of 60 s of vibration stimuli interspersed with 60 s rest were administered [10,23] at a median vibration frequency of 30 Hz (g = 2.65 m/s^2, horizontal displacement = 0.527 mm, vertical amplitude = 3.9 mm). This vibration frequency has been shown to elicit the highest reflex response in *vastus lateralis* muscle during whole-body vibrations in half-squat position [23]. In the HS condition, participants performed the same exercise protocol as the HSV condition without being exposed to the vibration stimulus. In the control condition (CC), no exercise protocol after cycling was performed. After warming-up, participants performed the isometric leg extension endurance protocol on a modified leg extension machine (Nextline Leg extension; Visa Sport, Marcellinara, Italy). Knee extension force was recorded as previously described [24] using a load cell (MuscleLab™ 6000; MuscleLab, Porsgrunn, Norway). Briefly, participants were instructed to perform 10 isometric leg extensions pushing as forcefully as possible and to hold each contraction for 4 s, interspersed with 2 s rest between each repetition. All conditions ended with lower limb stretching exercises.

2.4. Data Analysis

The MuscleLab™ 6000 system was used to record isometric muscle strength. The load cell recorded the force output at 200 Hz using a single data interface and its dedicated software (MuscleLab v. 10.213.98.5188, MuscleLab™ 6000 Ergotest Innovation; MuscleLab, Porsgrunn, Norway). For each participant, the mean force across 10 repetitions was computed and used to assess endurance. A 25-newton threshold was set to avoid baseline noise. Moreover, the fatigue index was calculated as follows [18]: [(maximal force at 1st repetition−maximal force at 10th repetition)/maximal force at 1st repetition] × 100).

2.5. Statistical Analysis

The sample size was identified based on an a priori power analysis (effect size = 0.3; $1-\beta = 0.8$; $\alpha = 0.05$). Before further analysis, the normal distribution of the dependent variables was tested by applying the Shapiro-Wilk test. Thereafter, one-way ANOVA for repeated measures with condition as a repeated factor (HSV, HS, CC) was conducted to verify the effects of vibration stimuli on mean force and fatigue index. The assumption of sphericity for each ANOVA model was checked with the Mauchly's sphericity test. When significant differences were detected, a Bonferroni post hoc analysis was carried out. The level of significance was set at $p < 0.05$. Statistical analysis was implemented with IBM®SPSS statistics software version 23.0 (SPSS Inc., Chicago, IL, USA).

3. Results

All participants completed all testing sessions with no physical problems and no injuries were observed. A significant main effect of condition was observed on mean force across 10 repetitions ($F_{2,28} = 7.007$, $p = 0.003$, $\eta^2 = 0.334$, $1 - \beta = 0.898$). Post hoc analysis showed that mean force was significantly higher in CC (365.1 ± 64.9 N) than in HSV (301.9 ± 57.6 N, $p < 0.01$) and in HS (322.2 ± 66.9 N, $p < 0.01$) conditions. Mean force for each isometric contraction in the three conditions and mean force during test sessions for each condition are reported in Figure 1, panel A and B. No significant effect of condition was observed on fatigue index ($F_{2,28} = 0.003$, $p = 0.997$, $\eta^2 < 0.01$). Indeed, fatigue index was 28.1% in CC, 28.1% in HSV and 28.0% in HS conditions. A significant main effect of condition was observed on RPE_1 ($F_{2,28} = 114.169$, $p < 0.01$, $\eta^2 = 0.891$, $1-\beta = 1.0$), and on RPE_2 ($F_{2,28} = 14.779$, $p < 0.01$, $\eta^2 = 0.514$, $1 - \beta = 0.998$). Post hoc analysis showed that RPE_1 was significantly lower in CC (2.80 ± 1.01) than in HSV (7.80 ± 1.57, $p < 0.01$) and HS (7.40 ± 1.45, $p < 0.01$) conditions. Moreover, RPE_2 was significantly lower in CC (4.73 ± 1.62) than in HSV (6.83 ± 1.60, $p < 0.01$) and HS (6.47 ± 0.92, $p < 0.01$) conditions. A significant main effect of condition was observed on HR_1 ($F_{2,28} = 14.830$, $p < 0.01$, $\eta^2 = 0.514$, $1 - \beta = 0.998$) and HR_{mean} ($F_{2,28} = 12.645$, $p < 0.01$, $\eta^2 = 0.475$, $1-\beta = 0.993$). Post hoc analysis showed that HR_1 was significantly lower in CC (101.5 ± 14.7 bpm) than in HSV (121.7 ± 17.8 bpm, $p < 0.01$) and HS (118.9 ± 13.4 bpm, $p < 0.01$). Moreover, HR_{mean} was significantly lower in CC (98.9 ± 9.3 bpm) than HSV (105.5 ± 10.6 bpm, $p < 0.01$) and HS (107.1 ± 11.2 bpm, $p < 0.01$). No significant difference was found for HR_2.

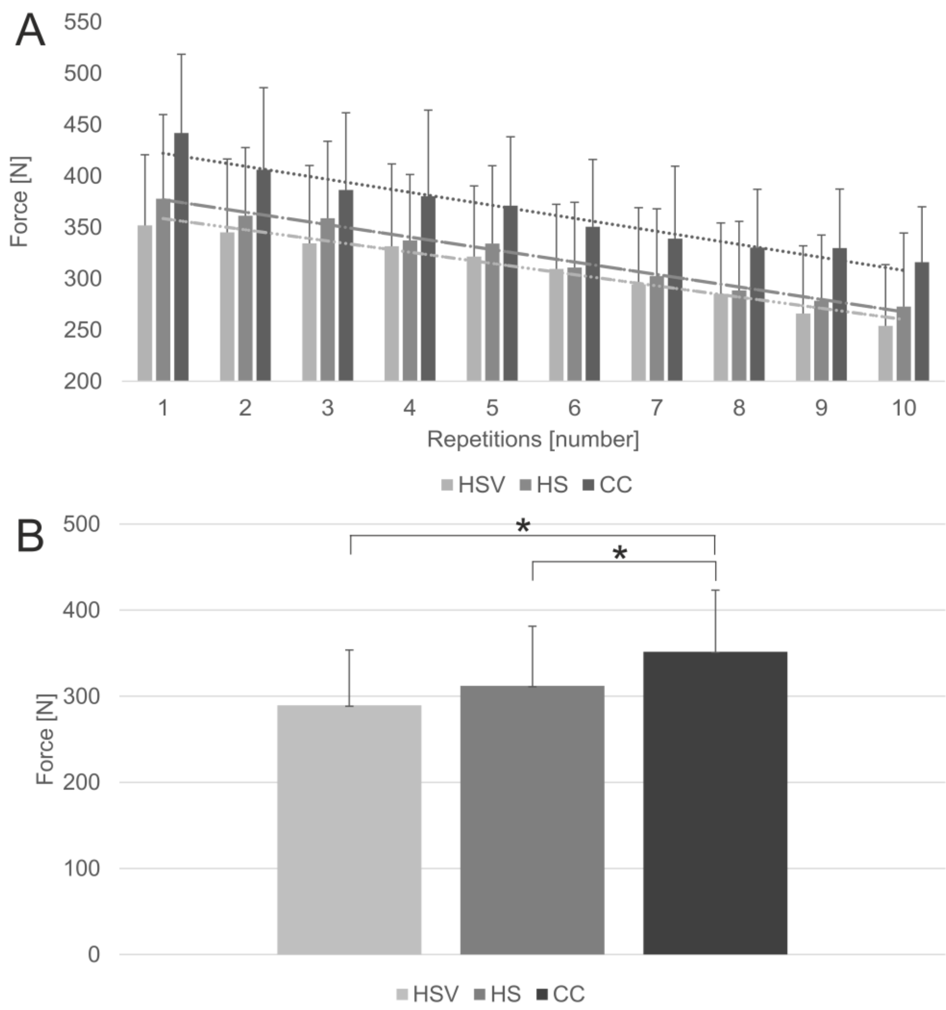

Figure 1. (**A**) Mean force for each isometric contraction in the three conditions. (**B**) Mean force across 10 repetitions for HSV, HS, and CC, respectively. Data are mean ± SD. * Denotes significant difference with $p < 0.05$. Acronyms: HSV, half-squat plus vibration; HS, half-squat without vibration.CC, control condition.

4. Discussion

This study investigated the effects of WBV on quadriceps isometric muscular endurance in healthy middle-aged males. Together with lower limb muscle strength and power, isometric muscular endurance is a health-related component involved in several daily activities [3]. Therefore, the evaluation of this muscular component becomes even more significant when assessing physical functioning [17,18] and the identification of new strategies to improve muscular endurance may be helpful for exercise specialist.

Our results revealed higher mean force production across 10 repetitions in CC compared to HSV and HS conditions. Vibration stimuli and static half-squat administered prior to the endurance test did not influence the fatigue index. The practice of half-squat both with and without vibration increased the subjective perception of exertion. Although participants produced the highest mean force when they perceived less exertion (CC condition), the fatigue index did not differ between conditions. Indeed, both isometric half-squat with and without vibration were perceived as more physically demanding. This result may support the non-significant differences in mean force production between HSV and HS conditions.

Vertical WBV elicits a tonic reflex contraction affecting skeletal muscle fibres length and speed, leading to an improvement of muscular strength [10]. However, we did not find improvements in the mean force after WBV stimuli. It is conceivable that, during an isometric contraction in which no net change in muscle length occurs, the effects of WBV may be concealed. Indeed, although not focused on a muscular endurance task, previous studies have also reported no improvements in isometric maximal force production after an acute WBV session at 30 Hz (amplitude range: 2–8 mm) [25–27]. On the contrary, WBV seems to influence fast and powerful force production (e.g., countermovement jump) [9,26,28] which leads us to infer a greater influence of vibration on the elastic and neuronal components of muscles. Additionally, our results showed no differences in the mean force between HSV and HS. Although muscular activity was not analysed in the present investigation, a previous study showed that, despite the increased muscle activation with WBV at different frequencies (25–45 Hz), this was not superior to a conventional squat exercise performed without vibration [29]. Our results are in line with those of Marín and colleagues in which no differences between HSV and HS conditions were observed in terms of mean force production [29]. Therefore, based on our findings, half-squat exercise with or without vibration stimuli did not induce an improvement of mean force during a muscular endurance task.

Our results are in contrast with the study of Ritzamann et al. which revealed an improvement after WBV at 25 Hz (amplitude: 4 mm) while performing an isometric whole-body holding task [19]. However, this study did not evaluate the muscular strength, but only the time that participants could maintain the correct body posture. Moreover, that study was conducted after 4 weeks of WBV training and was focused on young well-trained individuals [19].

Regarding the fatigue index, we did not observe any differences between conditions. In skeletal muscles, if administered during active postures, WBV elicits a tonic reflex contraction in the agonist muscles and a relaxation of their antagonists [30]. The tonic vibration reflex may occur during direct vibratory musculo-tendinous stimulations that excite muscle spindles and enhance activation of primary endings of the muscle spindle (Ia afferent), which excite alpha motor neurons, causing contraction of the muscle [31]. Therefore, we hypothesized that greater muscular coordination might decrease fatigue index after a vibration stimulus. However, our results do not support this hypothesis since vibration stimuli had no beneficial effects on the muscular fatigue index. As endurance force-generation is affected by several factors (e.g., age, training status, type of fibres, motor unit recruitment) it is very difficult to investigate the potential effects of WBV. The effects of WBV may have been concealed by the type of training protocol proposed in the current study and the type of contraction considered (isometric). Therefore, the use of a combination of different WBV exposure frequencies and exercise protocols may produce different results. It is possible that performing a static rather than a dynamic exercise protocol may mask the effects of WBV on force production [12,32]. Any potential effect of acute WBV application is likely to be related also to the training status of the individual as well as the activity used before the isometric endurance task.

Regarding RPE results, we obtained the lowest values (after warm-up and after testing session) in CC, and found no significant differences between half-squat with and half-squat without vibration stimuli. Thus, WBV did not increase the physical demand of the task. Our results are in contrast with those reported by Marín et al. which showed lower RPE values after WBV protocol at 30-Hz in young adults [33]. Authors stated that 30 Hz might result in decreased fatigue in trunk muscles during WBV exposure [33]. Although we used the same vibration frequency, the differences between our results and those reported by Marin and colleagues [33] may be related to differences in age of study populations (young vs. middle-aged adult) and muscle contractions performed (20 s of dynamic quarter-squats vs. 60 s isometric half-squat) on the WBV platform. The results of RPE at the end of the testing session suggest that the testing session was more physically demanding in half-squat with or without vibration stimuli than CC. Therefore, according to our previous results, CC condition led to the best muscular endurance performance and lower perception of exertion compared to the other two conditions. HR results are in line with RPE results. Indeed, the mean HR during the whole session was lower in CC than the other two conditions, and no differences were found between HSV and HS. However, only warm-up HR was lower in CC than in HSV and HS without no differences in HR during the isometric endurance protocol. Therefore, we might assume that vibration stimuli do not negatively influence HR responses during an endurance protocol.

We are aware of some limitations of the present study. First, we did not analyse muscle activity using electromyography (EMG) or heart rate variability, which could have contributed to the explanation of our findings. Exercise intensity was only objectively measured by using a HR monitor. Second, we investigated muscle strength responses during an isometric exercise and only in middle-aged males. Thus, our results cannot be generalized to all strength-exercise modalities or to other age and gender groups. However, we used an isometric muscle contraction as this experimental setup reduces several potential confounding factors (e.g., differences in technical execution). Finally, the low sample size (15 participants) may be a limiting factor.

Future studies should include the assessment of muscle activation (i.e., EMG) to look for an effect of the frequency components and to deepen our understanding of the responses of human body to the exposure to vibration training. Moreover, further investigations are needed using different type of contractions and exercise protocols to determine the optimal WBV protocol in healthy middle-aged adults.

5. Conclusions

Based on our findings, the use of WBV as a strategy to improve quadriceps isometric muscle endurance was not superior compared to a no-vibration condition in terms of mean force produced, RPE and HR in healthy middle-aged males. Future studies should investigate shorter vibration protocols during warm-up session performed before an endurance exercise task.

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