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Original Article

Whole body vibration activates the tonic vibration reflex during voluntary contraction

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Abstract. [Purpose] The beneficial neuromuscular effects of whole-body vibration are explained by the tonic vibration or bone myoregulation reflex. Depending on factors that remain undefined, whole-body vibration may activate the tonic vibration or bone myoregulation reflex. We aimed to examine whether voluntary contraction facilitates activation of the tonic vibration reflex during whole-body vibration. [Participants and Methods] Eleven volunteers were included in this study. Local and whole-body vibrations were applied in a quiet standing (without voluntary contraction) and a semi-squatting (isometric soleus contraction) position. Local vibration was applied to the Achilles tendon. Surface electromyography was obtained from the soleus muscle. The cumulative average method was used to determine soleus reflex latency. [Results] In the quiet standing position, the bone myoregulation reflex latency was 39.9 ± 4.1 milliseconds and the tonic vibration reflex latency was 35.4 ± 3.6 milliseconds. Whole-body vibration application in the semi-squatting position activated the tonic vibration reflex in four participants and the bone myoregulation reflex in seven participants. Local vibration activated the tonic vibration reflex in both positions for all participants. [Conclusion] Simultaneous whole-body vibration application and voluntary contraction may activate the tonic vibration reflex. Determining the spinal mechanisms underlying the whole-body vibration exercises will enable their effective and efficient use in rehabilitation and sports.
Key words: Whole-body vibration, Muscle strength, Tonic vibration reflex

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INTRODUCTION

Whole-body vibration (WBV) training is gaining popularity as a modality for sports, exercise, and physical rehabilitation, due to its beneficial neuromuscular effects that increase muscle strength[1–9)]. The most commonly proposed mechanism for muscle-strengthening effects is the spinal segmental reflex. However, neuronal circuitry and receptors of the spinal reflex pathway have not been definitively defined. The neuromuscular effect of WBV can reportedly be explained by the tonic vibration reflex (TVR)[7–13)]. The TVR is a muscle spindle-based polysynaptic spinal reflex resulting from Ia afferent activation when 100–150 Hz vibrations are applied to the belly or tendon of a muscle[14)].

In contrast to vibration application to isolated muscles and tendons, WBV is performed at <50 Hz. Therefore, it is debatable whether TVR is elicited, particularly as both agonist and antagonist muscles in the lower extremities vibrate simultaneously[11)]. The WBV-induced properties (receptor, latency, recruitment, etc.) of the spinal reflex reportedly differ from

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those of TVR[4, 9, 15–21]. The latency of the WBV-induced muscular reflex (WBV-IMR) is reportedly longer than that of the TVR[9, 15–19]. The slow progressive recruitment of motor units is a prominent feature of TVR, and not of WBV-IMR[16]. Compared to the healthy group, the soleal TVR latency was longer in patients with spinal cord injuries; however, the WBV-IMR latency was the same between the two groups[18]. WBV also activates either TVR or WBV-IMR depending on the vibration amplitude[16, 17].

The TVR response elicited by the vibration of a single muscle or tendon may be enhanced by voluntary skeletal muscle activation[1, 22, 23]. We previously observed that when WBV was performed simultaneously with isometric quadriceps contractions, the eliciting reflex response latency was almost equal to that of the patellar tendon reflex. In our opinion, since both the patellar tendon reflex and TVR are muscle spindle-based reflexes, WBV can activate TVR if administered simultaneously with voluntary isometric contractions[9]. We aimed to demonstrate the effect of simultaneous voluntary contraction and WBV on the induced reflex response. We hypothesized that a combination of WBV and voluntary contractions can activate TVR and that WBV alone can activate bone myoregulation reflex (BMR). We hope the results of this study can provide more information on whether WBV can activate different reflexes under different conditions and form a scientific basis for the more efficient use of WBV exercises.

PARTICIPANTS AND METHODS

The participants comprised eleven young adult male medical staff members in the Istanbul Physical Therapy Rehabilitation Training and Research Hospital. The mean age of the participants who completed the study was 30.1 ± 2.8 years, and the mean height was 180.3 ± 5.9 cm. All participants gave written informed consent to the experimental procedures following the Declaration of Helsinki and were approved by the local ethics committee. (No: 125; 21.04.2021). The study protocol was registered at ClinicalTrials.gov (No: NCT05221541). WBV-IMR and TVR latency of the soleus muscle were measured in both quiet standing and semi-squatting positions (Fig. 1). WBV and Achilles tendon vibrations were applied in both positions in a random order while the participants were on the WBV platform. A five-minute rest was provided between WBV and tendon vibration.

WBV application was delivered using a Power Plate Pro5 device (Power Plate International, Amsterdam, Netherlands). First, a low-amplitude (1.2 millimeters (mm)) vibration of 30 Hertz (Hz) was applied for 30 seconds (s) to each participant for familiarization. After three minutes of rest, a high-amplitude (2.2 mm) WBV was applied in a random order in the quiet standing and semi-squatting positions. At each position, three different vibration frequencies (30, 35, and 40 Hz) were applied, each lasting for 30 s with 3-s rest interval in between. The participants rested for five minutes between the two WBV sets.

Local vibration was applied to the mid-point of the right Achilles tendon using a custom-made vibrator. The head of the tendon vibrator was in contact with the underlying skin. The tendon vibrations were applied by the same researcher (E.K.).

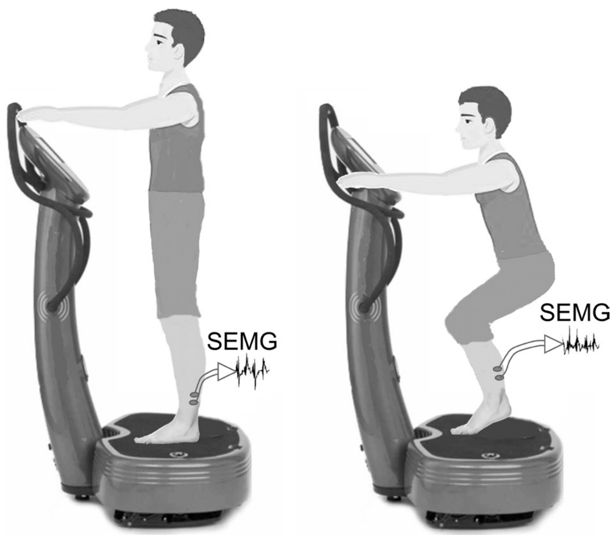

Fig. 1. Experimental setup. Participants were asked to hold the handles of the whole-body vibration (WBV) device. The participant's hips, knees, and ankles were placed in neutral position in quiet standing. In the semi-squatting position, the knee and hip were flexed to approximately 60° with the ankle in neutral. In the semi-squatting position, the participants contracted their soleus muscles voluntarily in order to maintain the ankle in neutral. In this position, their heel did not touch the vibration platform. Participants were barefooted, and no sponge or foam was placed between the vibration platform and their feet. SEMG: Surface electromyography.

TVR testing was performed in a random order in the quiet standing and semi-squatting positions. At each position, three different vibration frequencies (100, 135, and 150 Hz) were delivered, each lasting for 30 s with 3-s rest intervals. The participants rested for five minutes between the two TVR sets.

An electronic reflex hammer (Elcon, Germany) was used to determine the T-reflex latency. The T-reflex and TVR latencies are almost the same; both are spindle-based reflexes[19)]. Thus, we used the T-reflex latency to describe the TVR reflex.

Surface electromyography (SEMG) data recorded from the soleus and acceleration data were collected simultaneously using a data acquisition and analysis system (Power Lab® software, AD Instruments, Oxford, UK). Disposable self-adhesive bipolar Ag/AgCl (Covidien Kendall, Dublin, Ireland) surface electrodes were placed over the right soleus belly 4 cm apart[24)]. The skin overlying the muscle was shaved, light abrasion was applied, and the skin was cleaned with alcohol to reduce resistance.

To determine the TVR latency, a light piezoelectric accelerometer (LIS344ALH, ECOPACK®, Mansfield, TX, USA) was firmly fixed onto the skin overlying the right Achilles tendon using adhesive tape. To determine the WBV-IMR latency, an identical accelerometer was mounted firmly onto the WBV platform. Acceleration and SEMG signals were recorded at a sampling frequency of 20 kHz. The accelerometer recordings were filtered using a high-pass filter set at 5 Hz. SEMG data obtained during WBV were bandpass filtered at 80–500 Hz to reduce vibration-induced movement artifacts and then passed through a full-wave rectifier[25)]. Similarly, SEMG data obtained during tendon vibrations were bandpass filtered at 160–500 Hz and then passed through a full-wave rectifier. Thereafter, the WBV-IMR and TVR latencies were calculated using the cumulative average method[15)].

The cumulative average method is a unique mathematical instrument capable of determining the latency of reflexes induced by high sinusoidal stimulation of the neuromuscular system, such as WBV and tendon vibration stimulation[15)]. Spike-triggered averaging was performed using EMG spike peaks as triggers and the vibration records (acceleration data) as sources. The averaging process covered 75 milliseconds (ms) of vibration data preceding the trigger and 15 ms after the trigger. This process was performed separately for each vibration frequency. Subsequently, the average acceleration curves plotted for each vibration frequency were superimposed to obtain the cumulative average curve (Fig. 2a). The standard errors (SE) of the averaged acceleration data of the three vibration frequencies were calculated for each of the 1,500 bins in the averaging window from −75 to the trigger. The lowest point on the SE curve was determined to indicate the "effective stimulation time" point in the cumulative average acceleration curves (Fig. 2b). This averaging procedure was also performed to determine the onset of the EMG reflex response (Fig. 2c, 2d). The lowest SE on the cumulative EMG average was considered as the time point at which the vibration-induced reflex responses were the most synchronized, and hence, the onset of the reflex response. Reflex latency was calculated as the period between the effective stimulus application and the onset of the EMG spike[15)] (Fig. 2). All latencies were normalized to the body height of each participant and were expressed in milliseconds (ms).

BMR and TVR latencies measured in the quiet standing position were used as references to identify the WBV-induced reflex in the semi-squat position. The minimum significant difference (MSD) between TVR and BMR was calculated using the data obtained. To determine the MSD, the 95% confidence interval (CI) of the difference between the BMR and TVR latencies was calculated using the following formula: $MSD = \mu \mp 1.96 \times \mathrm{t(df)} \times \mathrm{SE}$ (μ: arithmetic mean, t(df): t value, df: degree of freedom, and SE: standard error). If the latency of the WBV-induced reflex in the semi-squat position was at least 1 MSD shorter than that of the BMR, the short-latency reflex (i.e., TVR) was considered activated. BMR latency is longer than the muscle spindle-based reflex (i.e., TVR, T-reflex) latency[9, 16–19)]. If the difference between the latencies of the WBV-induced reflex and BMR was within ± 1 MSD in the semi-squat position, it was accepted that the latency did not change and that BMR was activated in the semi-squat position.

The normal distribution of the data was assessed using the Shapiro–Wilk test. The arithmetic means and standard deviations (SDs) were calculated for each variable. Depending on the fit of the data to the normal distribution, the means of the two groups were compared using the Wilcoxon test or the paired t-test. Statistical significance was set at $p<0.05$. The software package used for data management was PASW Statistics for Windows, Version 18.0 (SPSS Inc., Armonk, NY, USA). The effect size (Cohen's *d*) was calculated using G*Power (version 3.1.9.4, Franz Faul, Universität Kiel, Dusseldorf, Germany). Effect sizes were categorized as follows: small effect=0.2, medium effect=0.5, and large effect=0.8[26)].

RESULTS

In the standing position, the soleus T-reflex and TVR latencies were 36.4 ± 2.8 ms and 35.4 ± 3.6 ms, respectively. Furthermore, the soleus BMR latency was 39.9 ± 4.1 ms, and the MSD was 2.84 ms. The soleus TVR latency was 35.1 ± 3.1 ms in the semi-squat position, which was not significantly different from that in the quiet standing position (p=0.395).

The WBV-induced soleus reflex latency was 37.2 ± 5.2 ms in the semi-squat position, which was significantly shorter than the BMR latency in the quiet standing position (p=0.044). Compared to that in the quiet standing position, the WBV-induced soleus reflex latency in the semi-squat position was <1 MSD in four (36.4%) participants and remained unchanged (within ± 1MSD) in seven (63.6%) participants.

Among the unaffected seven participants, the reflex latency was measured in the semi-squat position was similar that measured in the quiet standing position (Table 1).

Among the four affected participants, the reflex latency measured in the semi-squatting position was significantly shorter than that measured in the standing position (Table 1). The soleus reflex latencies in the semi-squat position did not differ from their TVR latencies measured in the semi-squat position (33.8 ± 3.3 ms) (p=0.715). Thus, WBV application in the semi-squat position activated TVR in four cases and BMR in seven cases.

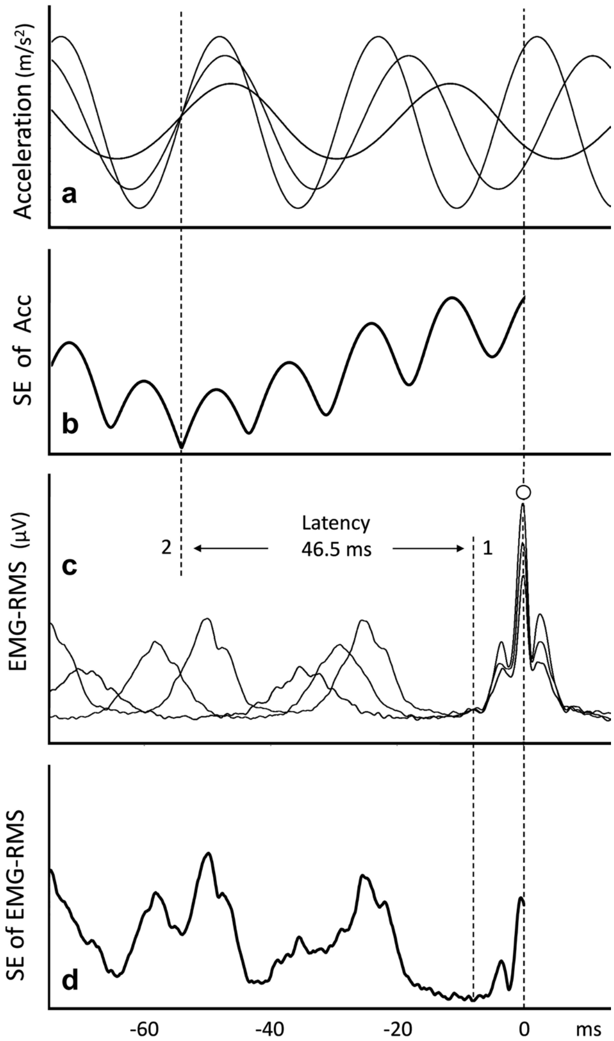

Fig. 2. Determination of reflex latency using the cumulative averaging method. (a) Three averaged acceleration sinusoidal curves, each representing different vibration frequencies. (b) SE curve of the three averaged acceleration sinusoidal data. (c) Three averaged EMG traces, each representing different vibration frequencies. (d) SE curve of the three averaged EMG data. The empty circle represents the spike peaks in the rectified EMG data, which were the trigger points. Line-1 represents the lowest value on the SE curve for the EMG data, indicating the onset point of the reflex in response to the vibration stimulus. Line-2 represents the lowest value on the SE curve for the acceleration data, indicating the effective stimulus time point. SE: standard error; Acc: acceleration; EMG: electromyography; RMS: root mean square.

Table 1. Whole-body vibration (WBV)-induced reflex response latency (ms) in the upright standing and semi-squatting positions

Training position	Unaffected group (n=7)	Affected group (n=4)
Standing upright	39.4 ± 4.8	40.8 ± 3.1
Semi-squating	39.2 ± 5.5	33.9 ± 2.8*

Data are presented as the mean ± standard deviation. *indicated statistical significance as compared to standing upright position; p<0.01 (Cohen’s d effect siz 3.69).

DISCUSSION

Two spinal reflex mechanisms have been proposed to explain the neuromuscular effects of WBV[4, 7–21]. The primary findings of the present study were that simultaneous WBV application and voluntary contraction activated TVR, whereas WBV application alone activated BMR in all participants.

In this study, the ankle joint was held in a neutral position, both in upright standing and semi-squatting positions. Thus, it was ensured that the soleus muscle length did not change with the position. In the semi-squatting position, participants were asked to isometrically contract their soleus muscles to keep the ankle joint neutral. Ogiso et al. showed that the soleus stretch reflex latency did not change at 0%, 35%, and 50% maximal isometric voluntary contraction levels when the ankle was in a neutral position[27]. Our findings were consistent with those of this study; we demonstrated that soleus TVR latency did not change with an isometric contraction.

The reason for a short reflex latency during WBV and isometric contraction, even though the TVR latency during isolated tendon vibration does not change needs to be determined. This may be explained by the predominance of different spinal reflexes when applying WBV in the semi-squatted position. In our opinion, WBV can activate both TVR and BMR; however, one reflex becomes more dominant because of various factors, such as the WBV amplitude, and frequency[16, 17]. We determined that muscle contraction can also be included among these factors. In four participants, the WBV application activated BMR in the quiet standing position and activated TVR in the semi-squatting position. This indicates that TVR becomes dominant during WBV owing to voluntary muscle activity.

According to Bishop, four factors affect the strength of a TVR: 1) the vibrator location, 2) the initial muscle length, 3) the vibratory stimulus parameter, and 4) the central nervous system excitability state[28]. In all cases, local vibration was applied to the mid-point of the Achilles tendon, while the ankle was in a neutral position. Thus, the vibrator location and muscle length were controlled for each trial. In addition, the local vibration frequencies were 100, 135, and 150 Hz in all the trials. However, to see the effect of voluntary contraction on reflex response within the scope of the present study, vibration was applied while standing upright and in a semi-squatting position. To maintain the ankle in neutral in the semi-squatted position, the participants were asked to perform isometric soleus contractions. Increased muscle activity facilitates spindle-based reflex responses[29, 30]. Hence, when WBV is applied in the semi-squatted position, TVR pathway activation is enhanced and becomes dominant due to the increased soleus motor neuron excitability and isometric contractions.

Muscle stretching and low-level contractions may enhance TVR[1, 22, 23, 31]. In contrast, voluntary movements may suppress TVR. Volitional suppression of the TVR may be mediated by descending pathways that alter transmission in the polysynaptic reflex arc[22, 31]. Burke reported that a strong contraction attenuates the percussion wave and suppresses the stimulus reaching the spindle endings[30]. The descending inhibition and/or attenuation of the percussion wave may explain why TVR was not activated in some participants during concurrent WBV application and isometric contractions.

No methods were available to measure the latency of the reflex response activated by high-frequency sinusoidal mechanical stimuli in previous vibration studies. In this study, the reflex latencies activated by low-frequency (30–40 Hz) and high-frequency (100–150 Hz) vibrations were measured using the cumulative average method. Additionally, accelerometer and EMG recordings were recorded at a sample rate of 20 kHz. This high sampling rate allowed latency measurements to be performed with a sensitivity of 0.05 ms.

In conclusion, the present study showed that WBV activates either TVR or BMR depending on voluntary contraction. Elucidating the neurophysiological mechanisms underlying the neuromuscular effects of WBV may make it possible to use WBV exercises more efficiently in the field of sports and rehabilitation. In this context, future longitudinal studies are needed to evaluate the effects of WBV-activated reflex pathways (TVR or BMR) on muscle strength enhancement.

This study had some limitations. Although the sample size was small, the effect size (Cohen's d) of the difference in WBV-induced reflex latency between the semi-squatting and standing positions was large. Another limitation of this study was that the intensity of isometric contractions was not determined. Future studies are needed to examine the effects of varying intensity isometric contractions on the WBV-induced reflex.

Conflict of interest

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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