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Determining the Posture and Vibration Frequency that Maximize Pelvic Floor Muscle Activity During Whole-Body Vibration

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Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
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Literature Search F
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Background: The aim of this study was to investigate the electromyogram (EMG) response of pelvic floor muscle (PFM) to whole-body vibration (WBV) while using different body posture and vibration frequencies.

Material/Methods: Thirteen healthy adults (7 men, 6 women) voluntarily participated in this cross-sectional study in which EMG data from PFM were collected in a total of 12 trials for each subject (4 body postures, 3 vibration frequencies). Pelvic floor EMG activity was recorded using an anal probe. The rating of perceived exertion (RPE) was assessed with a modified Borg scale.

Results: We found that vibration frequency, body posture, and muscle stimulated had a significant effect on the EMG response. The PFM had high activation at 12 Hz and 26 Hz ($p<0.05$). PFM activation significantly increased with knee flexion ($p<0.05$). The RPE significantly increased with increased frequency ($p<0.05$).

Conclusions: The knee flexion angle of 40° at 12 Hz frequency can be readily promoted in improving muscle activation during WBV, and exercise would be performed effectively. Based on the results of the present investigation, sports trainers and physiotherapists may be able to optimize PFM training programs involving WBV.

MeSH Keywords: **Pelvic Floor • Vibration • Electromyography • Posture**

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Background

When the pelvic floor muscle (PFM) becomes weak, its ability to support the pelvic organs decreases and contraction of the anus, urethra, and vagina weakens. Thus, the pelvic organs and perineum are relaxed, which causes problems in the continence control system [1], causing diseases such as pelvic organ prolapse, stress incontinence, overactive bladder, overactive detrusor, micturition disorder, urinary tract infection, and fecal incontinence [2,3]. These diseases cause decreased quality of life due to emotional disorders such as depression or a sense of alienation by inducing psychological anxiety, shame, and tension and consequently limiting social activities as well as outings [4–6].

For the enhancement of PFM strength, biofeedback, electrical stimulation, PFM exercises, and vaginal cones were applied and their effects were verified [7–11]. There are 2 interruptive factors in PFM training. The first interruptive factor is the unnecessarily frequent use of accessory muscles around PFM for compensation in the training process [12,13]. The second interruptive factor is that the PFM is located in a deep part of the body and visual information is insufficient. Recognizing the PFM and controlling its activities is challenging for the brain because of the lack of tactile sense and proprioception information [14]. Therefore, PFM training needs to use methods that complement these interruptive factors.

Recently, whole-body vibration (WBV) was introduced as a muscle activation and peripheral circulation method in a clinical setting [15–18]. WBV causes a change in muscle length through vibration, and the excitement of muscle spindle recognizing this is transferred to the spinal cord through sensory nerves, and then causes muscle contraction by triggering the activity of α-motor neuron [14]. Based on such a mechanism, WBV has been reported as an effective training method for muscle enhancement [19].

In a previous study, WBV training was proven effective in the enhancement of muscle strength in patients with various diseases, such as chronic back pain [20], Parkinson's disease [21], multiple sclerosis [22], stroke [17], and cerebral palsy [23], and to improve the leg muscle strength of postmenopausal women [24] or the elderly [25].

The WBV method differs depending on the therapeutic purpose and its recipient [26]. Muscle activation varies with the frequency, amplitude, loading, posture, and vibration type of WBV. Thus, these determining factors need to be considered in WBV training. Augmented amplitude and loading increase muscle activation [17,27]. However, the relationship between muscle activation and frequency has not been clearly defined [28]. One study showed that augmented frequency increased muscle activation, whereas another study reported that muscle activation was increased by resonance when the resonance frequency was close to the natural frequency of muscle, regardless of the augmentation of frequency [29,30]. A study that compared posture changes proved that neuromuscular activation increased with flexing of the knee [31]. In the article that compared vibration types, side-alternation vibration caused greater muscle activation than synchronous vibration [32].

Most previous studies involved the leg muscle, and a recent study involved the frequency of WBV suitable for PFM. Lauper et al. [18] applied various frequencies to compare the effects of stochastic resonance vibration and sinusoidal vibration on muscle activation in healthy women and post-partum women by providing vertical vibration using 2 separate plates. They reported that stochastic resonance vibration caused greater muscle activation than sinusoidal vibration, and suggested 6~12 Hz as the most proper frequency. Muscle activation according to posture was not verified.

It is necessary to verify muscle change according to application method by analyzing the determining factors of vibration in order to perform exercise effectively during WBV. However, research about the determining factors of vibration was not sufficient in previous studies.

Therefore, this study aimed to verify the optimal frequency and posture by checking PFM activation and the rating of perceived exertion (RPE) change according to the changes in frequency and posture by applying WBV.

Material and Methods

Subjects

Thirteen healthy adults (7 men, 6 women) from Seoul, Republic of Korea, participated in this study. Subjects were free from conditions that would not allow intra-anal probe insertion, such as pregnancy and menstruation, perianal abscess, hemorrhoids, genitourinary prolapse, neurological or musculoskeletal disorders, acute inflammation, cardiovascular and pulmonary diseases, or any chronic disorders. Before the study, the principal investigator explained in detail all procedures to the subjects. All subjects were informed about the purpose of the study and about the possible risks and benefits of WBV, and they provided their written informed consent prior to participate in accordance with the ethical principles of the Declaration of Helsinki. All protocols and procedures were approved by the Institutional Review Board of Sahmyook University.

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Procedure

Electromyography (EMG) data from the PFM and RPE during WBV were collected over a total of 12 trials for each subject (4 knee flexion angles ×3 vibration frequencies). The 4 different vibration frequencies were 6 Hz, 12 Hz, 18 Hz, and 26 Hz. The 3 different postures were the knee flexion angles of 20°, 30°, and 40°. All vibration trials were performed on the same test day. The 12 trials were randomized.

This study used a WBV platform (Galileo® Advanced Plus, Novotec Medical GmbH, Germany) for PFM. Galileo features side-alternating vibration with frequency range of 5~30 Hz. The amplitude range is 0~5.2 mm and is determined by the position of a foot.

This study set 3 mm in the amplitude range of 2~5 mm generally used during WBV. The frequencies used were 6 Hz, 12 Hz, 18 Hz, and 26 Hz. These frequencies are the common sets used in WBV training. The posture was taken using 3 joint goniometers (Baseline® Plastic Goniometer, Hires, Germany) fixed at the knee joint as 20°, 30°, and 40° during measurement. A central line was marked with tape from the femur greater trochanter to the lateral malleolus of the lateral side of subjects' legs. After a fixed goniometer was set at the central line of a leg and fixed only at the thigh with a compression bandage, subjects were instructed to maintain the most accurate posture. The fingers of both hands were lightly placed on a handlebar in order to prevent falling during the experiment.

All subjects were educated about PFM contraction prior to the experiment in order to evaluate PFM activation according to vibration frequency and posture during WBV. Prior to measurement, an intra-anal probe was inserted and affixed with medical tape, and sufficient time was taken for adaptation to the probe. To verify if a probe was adequately inserted in the anus, we verified that a circle became smaller with contraction of the anus, and became larger with relaxation while looking at the circle on a computer screen. Measurement was conducted after subjects were educated about the contraction and relaxation of PFM 1 more time while maintaining probe insertion. The subjects were barefoot during WBV.

During WBV, the signals set in the EMG program for contraction and relaxations were used. The adaptation period of WBV was 15 s. It contracted for 5 s and relaxed for 10 s according to the signals, and this was repeated 3 times. One minute of sufficient resting time was set between each experiment to prevent the muscle fatigue of the participants.

Measurements

EMG (TELEMYO 24000 TG2, Noraxon Inc. USA) was used to measure the electronic signal of the muscles during the PFM activity. PFM activation was measured using an intra-anal probe (EMG A/STIM channel of the pathway, The Prometheus Group, USA). An intra-anal probe was inserted into the anus and attached to the muscle around the intra-anus, and a reference electrode and measuring electrode were placed in a certain interval in a probe electrode. Once it was verified that an intra-anal probe reached the inner wall of the anus after its insertion into the anus, it was affixed with medical tape, and the connecting line was attached to the posterior part of the femur.

The signals entered through an electrode were obtained through EMG and stored in a computer using software. For EMG signals, 80~250 Hz of band pass filter were used to remove noises, and then sampling was performed by calculating the root mean square value.

For RPE, the Borg scale, which consists of 6~20 points accounting for 10% of a healthy adult heart rate, is used to measure intensity during exercise. Because RPE integrates the muscles and joints used during exercise and cardiovascular, respiratory, and central nervous system function, it is used properly to verify exercise intensity. The measurement of RPE in this study was performed using the modified Borg scale. The modified Borg scale has a range of 0~10 points, with 0 representing rest and 10 representing extreme intensity. All subjects were told to mark the exercise intensity that they felt while riding WBV with their own fingers on the modified Borg scale prepared for each experiment.

Statistical analysis

Descriptive statistics were used for the general characteristics of the subjects. A two-way repeated measures analysis of variance (ANOVA) was used to explore PFM activation and RPE changes according to posture and vibration frequency. A one-way repeated measures ANOVA was used to explore muscle activation and RPE changes according to each variable, and a Bonferroni test was performed for post hoc analysis. SPSS version 19.0 for Windows was used to perform all analyses and p values <0.05 were regarded as significant.

Results

This study included 13 subjects. For general characteristics of the subjects, sex, age, height, weight, and body mass index were checked. The demographic general characteristics are shown in Table 1.

Figure 1 shows the mean and standard deviation of PFM maximal voluntary isometric contraction (MVIC%) according to each vibration frequency and posture. The analytical results of muscle activation according to the change in posture and frequency

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Table 1. General characteristics of subjects.

	Male (n = 7)	Female (n = 6)	Total
Age (year)	125.85±12.41	125.50±0.83	125.69±11.79
Height (cm)	178.00±14.50	164.50±3.44	171.76±12.22
Weight (kg)	173.42±12.56	154.00±3.84	164.46±13.66
BMI (kg/m²)	123.14±13.93	119.93±1.54	121.66±13.39

Values indicate mean standard deviation. BMI – body mass index.

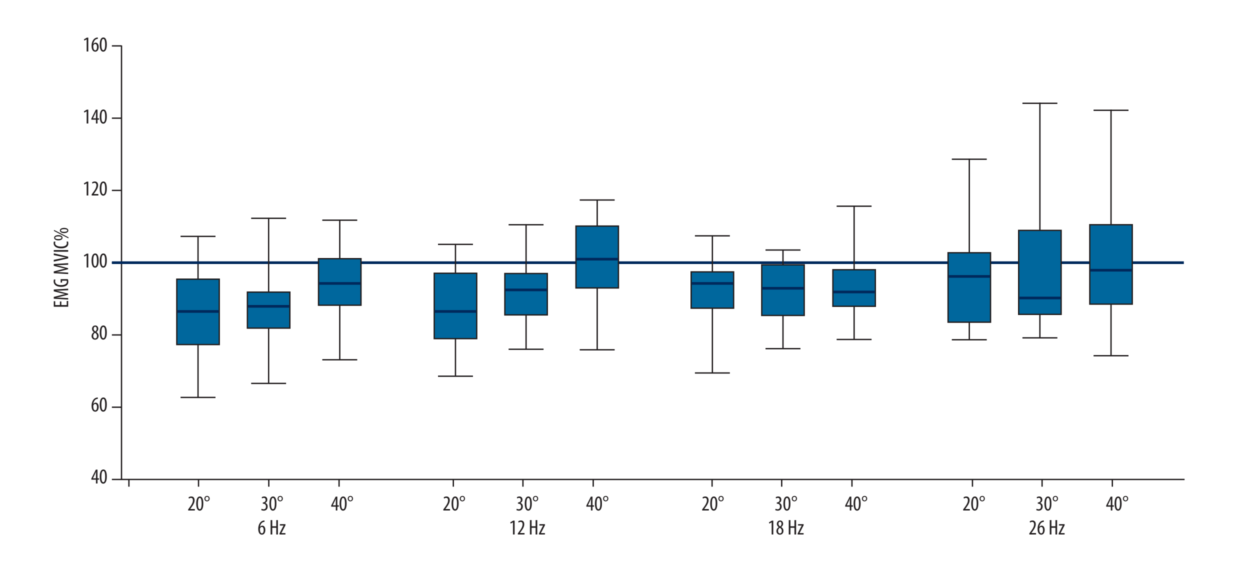

Figure 1. EMG data according to posture and frequency.

Table 2. EMG data according to posture (MVIC%).

	20° (A)	30° (B)	40° (C)	F(p)	Post-Hoc
Frequency	90.63±5.15	92.97±4.87	97.63±4.26	19.123 (0.000)	A|C, B|C

Values indicate mean ± standard deviation. Differences were determined using a one-way ANOVA followed by Bonferroni post-hoc analysis.

Table 3. EMG data according to frequency (MVIC%).

	6 Hz (A)	12 Hz (B)	18 Hz (C)	26 Hz (D)	F(p)	Post-Hoc
Posture	89.24±4.38	93.32±6.39	92.71±1.06	99.72±2.5	98.554 (0.000)	A|B|C|D

Values indicate mean ± standard deviation. Differences were determined using a one-way ANOVA followed by Bonferroni post-hoc analysis.

during WBV showed a significant difference for both posture and frequency. In comparing PFM activation for each posture, a significant difference was shown between 20° and 40° and between 30° and 40° (Table 2). In comparing PFM activation for each vibration frequency, all values showed a significant difference (Table 3). In addition, a significant difference was found in the interaction of posture and frequency (F=7.697, p=0.008).

In analyzing RPE depending on the change in posture and frequency during WBV, both posture and frequency showed a significant difference. In comparing RPE for each posture, a

Table 4. Modified Borg scale according to posture (points).

	20° (A)	30° (B)	40° (C)	F(p)	Post-Hoc
Frequency	5.08±2.65	4.50±2.58	4.25±2.17	18.738 (0.000)	A|B, A|C

Values indicate mean ± standard deviation. Differences were determined using a one-way ANOVA followed by Bonferroni post-hoc analysis.

Table 5. Modified Borg scale according to frequency (points).

	6 Hz (A)	12 Hz (B)	18 Hz (C)	26 Hz (D)	F(p)	Post-Hoc
Posture	1.74±0.19	3.85±0.41	5.23±0.55	7.62±0.66	31.823 (0.000)	A|B|C|D

Values indicate mean ± standard deviation. Differences were determined using a one-way ANOVA followed by Bonferroni post-hoc analysis.

significant difference was found between 20° and 40° and between 20° and 40° (Table 4). All values showed a significant difference in comparing RPE for each vibration frequency (Table 5). In addition, no significant difference was found in the interaction of posture and frequency.

Discussion

Muscle activation is affected by various factors during WBV. First, frequency is a general factor that affects muscle activation during WBV. In the present study, muscle activation at specific frequencies, such as 12 Hz and 26 Hz, was higher than at other frequencies. The study of Di Giminiani et al. [30] verified the change in muscle activation of the leg according to 9 frequencies within a range between 0 Hz and 55 Hz during WBV. As a result, the lateral vastus showed the highest muscle activation at 55 Hz, and higher frequencies showed greater muscle activation. The lateral gastrocnemius showed the highest muscle activation at 30 Hz, and the higher frequencies reduced muscle activation (i.e., each muscle had the highest activation at a different frequency). In this study, the highest activation was shown at 26 Hz and the second highest activation was at 12 Hz.

Two hypotheses can explain the increase in muscle activation at a specific frequency. The first is that muscle activation increases as frequency increases. Previous studies, such as the study of Ritzmann et al. [32] examining muscle activation of the leg and the study of Lauper et al. [18] investigating PFM activation, showed that muscle activation increased as frequency increased. However, another study showed a different result, depending on the muscle tested [30]. The lateral gastrocnemius showed the highest muscle activation at 30 Hz, and muscle activation decreased at frequencies >30 Hz. In this study, the highest activation was shown at 12 Hz and 26 Hz. Thus, the first hypothesis was not validated.

The second is that muscle activation increases as resonance occurs when vibration is transferred to muscle at a frequency similar to the natural frequency of each muscle [29]. In this study, it is postulated that 12 Hz and 26 Hz, at which muscle activation was high, are close to the resonance frequency. Therefore, the second hypothesis can be more persuasive. The pelvic floor consists of many muscles in 2 layers. Each muscle was postulated to have its own natural frequency; 12 Hz and 26 Hz was the resonance frequency closest to the natural frequency of specific PFM, thereby showing high activation.

The second factor affecting muscle activation during WBV is posture. In the study of Ritzmann et al. [32], muscle activation was measured at the knee flexion angles of 10°, 30°, and 60° to explore which postures increase muscle activation of the leg, and found that muscle activation of the leg increased with flexing of the knee. Similar to this, in other previous studies, muscle activation of the leg increased with flexing of the knee as a result of measuring muscle activation according to posture. It is reasonable that as the knee flexion angle increases, torque in the knee flexion increases and consequently increases activation of the quadriceps group [32]. However, because the target muscle of this study was the PFM and the pelvic floor is not related to knee flexion, it cannot be explained by flexion torque.

In the study of Harazin et al. [33], knee joint angles (0°, 45°, 70°) were compared to explore the posture in which vibration is transferred to the head during WBV. We found that the vibration transferred to the head was greatest at a complete extensive posture with 0° of the knee joint and decreased as the knee was flexed. Vibration was transferred to a lower part of the body as the knee was bent. Activation became greater as the knee angle became larger in this study, and posture was lower as the knee angle was larger and vibration was transferred closely to PFM.

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In this study, exercise intensity was verified according to frequency and posture using RPE during WBV. As a result, RPE increased as frequency increased, and RPE decreased with knee flexion. RPE is useful to verify exercise intensity, and adverse effects can be distinguished with a simple measuring tool. RPE was used in a variety of previous studies to verify exercise intensity and to apply proper exercise methods.

Sonza et al. [34] reported that the measured RPE was 10, corresponding to "extreme intensity" in the range of 21~25 Hz, when 12 different frequencies were applied during WBV. Similar to the previous study, the highest RPE in this study was 26 Hz.

Frequency of high intensity can cause adverse effects rather than exercise effects. A variety of previous studies reported that vibration transferred to the body caused adverse effects such as nausea and headache due to impaired vision, hearing loss, and strong stimuli to organs as vibration frequency increased [35–37]. In this study, RPE was highest at 22.67 at the frequency of 26 Hz, and some subjects complained of slight nausea and headache when WBV was applied at 26 Hz; they felt some pain at the knee joint and skin, had mild visual impairments, and had difficulty listening to the instructions of a computer program due to noises. Therefore, applying 26 Hz is considered clinically not feasible.

A previous study compared RPE according to posture and weight load during WBV. As a result, RPE was reported to be higher in a 90° squat (14.0) than in the posture (10.2) of standing upright during WBV and was highest in a 90° squat with loaded weight (17.1), indicating that RPE was higher with knee flexion [38].

However, RPE became lower with knee flexion in this study. This is contradictory to the results of a previous study reporting that higher RPE was shown in a 90° flexion posture rather than in a standing posture. Since the knee angle was bent to 40° in this study and the flexed posture of 90° was used in a previous study, this was due to the greater angle of the posture in the previous study rather than an opposite result. The study of Abercromby et al. [31] suggested that a posture with knee flexion >40° was an infrequently used clinical exercise method.

By integrating the results of this study, 12 Hz and 26 Hz were effective for PFM activation, a 40° posture was effective for PFM activation, and a high RPE of 26 Hz was difficult to apply clinically. Therefore, taking posture at 40° and 12 Hz, which is helpful for muscle contraction as the stable and proper exercise intensity, and performing PFM training would be a more effective and clinically applicable method.

This study had some limitations. First, it had a small sample size. In the future, it will be necessary to conduct a study with a larger sample size. Second, the WBV used in this study features a side-alternating vibration type, and the result of this study is limited to using side-alternating vibration. The optimal frequency and posture in a different type of vibration need to be verified through further studies. In addition, the effect of increasing muscle strength through PFM training using WBV needs to be verified in patients with pelvic disease.

Conclusions

The knee flexion angle of 40° at 12 Hz frequency can be readily promoted in improving muscle activation during WBV, and exercise would be performed effectively. Based on the results of the present investigation, physiotherapists may be able to optimize PFM training programs involving WBV.

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