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Chronic effects of whole-body vibration on jumping performance and body balance using different frequencies and amplitudes with identical acceleration load

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ABSTRACT

Previous studies on vibration training have all been based on protocols at different combinations of frequencies and amplitudes without controlling the loading intensity.
Objectives: This study investigated the effect of an 8-week vibration training program, under identical acceleration loads with various frequencies and amplitudes, on jumping performance, muscle activation and body balance.
Design: Fifty young adults were randomly assigned to an high-frequency (32 Hz, 1 mm, and 4 g), low-frequency (18 Hz, 3 mm, and 4 g), or a control group. The high-frequency and low-frequency groups underwent 60 s of squats exercise on the specific vibration platform three times a week, whereas the control group was trained without vibration.
Methods: A force platform was used to measure the center of pressure of a static single leg stance, and the heights and impulse of two consecutive countermovement jumps before and after intervention. The activation of the rectus femoris and biceps femoris were also measured synchronously by surface electromyography.
Results: The heights and impulse of both the first and second countermovement jumps were significantly increased and the area of center of pressure was significantly decreased after training in both the high-frequency and low-frequency groups ($P < .05$). Consequently, activation of the rectus femoris during the first countermovement jump was significantly lower than the pre-training value in the HF group but increased in the low-frequency group after training ($P < .05$).
Conclusions: An 8-week identical acceleration vibration training regimen with various frequencies and amplitudes can significantly improve jumping performance and body balance, but the specific neuromuscular adaptation is possibly induced by different training settings.

1. Introduction

Whole-body vibration (WBV) training has been reported to be an effective approach to relieve muscle tension,[1] lead to greater strength, and promote higher performance.[2,3] Hundreds of peer-reviewed papers have recently been published, and the number of ongoing studies on vibration training is still increasing, indicating that the optimal exercise modality remains unclear in the scientific community. Studies in recent years have concluded that vibration training can increase isometric and dynamic strength, as well as improve countermovement jump and bone density.[2] On the contrary, other studies demonstrated that vibration training could not effectively improve strength, countermovement jumps, or body balance.[2,4] Contradictory findings are possible because of the dissimilar vibration parameters, which primarily include frequency and amplitude. The interaction of frequency and amplitude determines the acceleration, which is the major loading parameter. Previous studies on vibration training have all been performed by following the protocols at different combinations of frequencies and amplitudes without controlling acceleration, which represents

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the loading intensity.[5] Any change in vibration frequency or amplitude alters the acceleration output from the vibration platform, which generates different training loads.

Incorrect vibration settings may lead to excessive acceleration transmitted to the human body, which can be harmful and increase the risk of injury.[2,3,6] The minimum acceleration used in previous vibration training studies that generated a positive training effect was 2.28 g,[7] where 1 g is the acceleration of gravity (1 g = 9.81 m/s^2). Therefore, load intensity for this study was set to 4 g. Moreover, some different mechanisms seem to supportively explain performance enhancement by vibration training. The findings of previous fundamental neuromuscular research indicated that when the muscles performed maximal voluntary contraction, the excitation frequency of the motor unit was nearly 30 Hz.[8] Consequently, stimulation vibration frequencies at 30–50 Hz could induce significant effects.[2] Such frequencies are the same as muscle spindle excitation frequencies, as well as the neural input frequencies at the maximal force generation state that can produce synchronized contraction effects.[9] Furthermore, greater spinal pathway or cortical reflex can be involved in the stretch-shortening cycle.[10] Thus, the higher-frequency set for this study was based on this premise. Consequently, the natural frequency of muscle tissues, ranging from 10 to 20 Hz, could induce a neural reflex.[11] We adopted the lower frequency within this range to induce muscle resonance and achieve a training effect.

Optimal vibration frequency for training has been analyzed in previous studies, but instead of controlling the load intensity, a wide variety of vibration accelerations were used in those studies.[12] To date, no vibration studies clearly indicated different combinations of frequencies and amplitudes with the same accelerations load. Therefore, this study investigated the effect of an 8-week vibration training program, under identical acceleration loads at varying frequencies and amplitudes, on jumping performance, muscle activation and body balance. We hypothesized that 8-week vibration training would result (i) in significant increases of jump height, vertical ground reaction impulse, and SSC ability, and (ii) in reduced area and speed of center of pressure (CoP). We also hypothesized that the HF vibration training would significantly reduce the rectus femoris and biceps femoris muscle activities.

2. Methods

We recruited 50 healthy young adults (age: 20.3 ± 1.1 y; height: 167.9 ± 10.1 cm; weight: 62.2 ± 11.2 kg), who were moderately trained and had neither lower-limb injuries nor bone and neural problems within 6 months prior to participating in the test. This study was approved by the Medical Research Ethics Committee of Taipei Medical University Hospital and all participants completed a statement of informed consent. Two participants could not meet the test requirements of movement; therefore, the total number of participants was 48 after excluding the unqualified two. All eligible participants were randomly divided into 3 groups: a high-frequency group (HF, 32 Hz, 1 mm, male 8, female 8, 20.6 ± 1.2 y, 167.3 ± 9.3 cm, 62.4 ± 8.9 kg), a low-frequency group (LF, 18 Hz, 3 mm, male 8, female 8, 19.3 ± 0.7 y, 168.7 ± 11.1 cm, 60.2 ± 14.1 kg), and a control group (CON, training without vibration, male 8, female 8, 19.7 ± 0.7 y, 166.8 ± 7.7 cm, 60.5 ± 12.9 kg). The loading intensity for both the HF and LF training conditions was set at 4 g.

Both types of vibration were vertical. The HF training used the Magtonic Zen Pro TVR-6900 (frequency: 20–50 Hz, amplitude: high 2–4 mm, low: 1–2 mm), and LF training involved using Magtonic Zen Pro TVR-4900 (frequency: 20–50 Hz, amplitude: 1.5 mm). However, to control the vibration accelerations, both machines were adjusted accordingly. The specification of vibration platform was specially tuned by the manufacturer and validated by the researcher. The amplitude and frequency were calibrated to 4 g by using the formula ($g = A(2\pi f)^2/9.81$).[5] Where g is the acceleration of vibration platform output, A is the amplitude and f is the frequency. Frequency and amplitude were adjusted and verified by the number of oscillations per second and peak-to-peak displacement by attaching an accelerometer at the center of the platform.

During the 8-week vibration training program, participants of HF and LF training were asked to perform squats on the vibration platform with vibration stimulation three times a week, whereas the CON group stood on the floor performing the same squats without vibration stimulation. The knee joint angles were confined within 90° and 150° (full knee extension = 180°), which could restrict the transmission of vibrations to the head when knees were semiflexed.[3] The knee angle during training was constantly monitored by a manual goniometer. A metronome was used to control the speed of squats at 2 s per squat and 60 s for a complete set. The training load was set gradually as follows: four sets in the first and second weeks; 5 sets in the third, fourth, and fifth weeks; and 6 sets in the sixth, seventh, and eighth weeks. There was a 2-min break between each set. This study consisted of a pre-test (conducted within 1 week prior to the 8-week training program) and a post-test (conducted within 1 week after the program).

Both pretest and posttest included the two consecutive countermovement jumps and a 30-s static single leg stance with the eyes closed balance test. Each test session was preceded by a 10-min warm-up that included aerobic exercises and stretching. For the two consecutive countermovement jumps, participants stood upright on the force platform (AMTI BP600900, Advanced Mechanical Technology Inc., USA) with hands on the waist while squatting rapidly and then jumping upward using their maximal efforts. Participants were asked to perform the second jump immediately which accompanied the feet touchdown of the first jump. The movement of the first jump involved pre-stretch of the first jump, whereas the second jump involved pre-stretch of the second jump. A successful trial was defined that the entire jump process had to be smooth, and landing on the force platform. In addition, the legs had to be fully extended when off the ground.

The vertical ground reaction impulse and jump height were measured using force platform. Jump height was calculated as the flight time (second). Jump height = $t \times g \times 8^{-1}$ (m), where g is the acceleration of gravity (9.81 m/s^2), and t is the flight time measured between take-off and landing. The intraclass correlation coefficients of test–retest measures of 1st and 2nd jump height as well as vertical ground reaction impulse were .981, .985, .993 and .983 which provided sufficient evidence of substantial reliability.

The skin where the electrodes were placed was shaved and cleaned with alcohol, and all of the electromyography equipment was connected to the same ground that was attached to the lateral femoral epicondyle. The electrode used in this study had two 1 cm diameter metal plates that were 3 cm apart. Surface electromyography (EMG, TSD150a, Biopac Systems Inc., USA) incorporated a high impedance (100 MΩ) and a differential amplifier (Common Mode Rejection Ratio = 95 dB; gain = 350). The activations of thigh muscle were acquired synchronously with the force platform from the rectus femoris (RF was the midpoint of the muscle belly from the anterior superior iliac spine to patella) and biceps femoris long head (BF was at the midpoint of the muscle belly on the centerline from the ischium to knee joint) on the dominant leg, and with a 1000 Hz sampling frequency. LabVIEW 8.5 (National Instruments, USA) software was applied to analyze the signals of the two consecutive countermovement jumps. A fourth-order Butterworth filter was used to filter and smooth the EMG raw data. Consequently, the EMG signals were first filtered using a band pass filter (10–500 Hz). The signals were then processed using full-wave rectification and were smoothed at a low frequency of 6 Hz to obtain a linear