

Original Article

Acute effects of unilateral whole body vibration training on single leg vertical jump height and symmetry in healthy men

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Abstract. [Purpose] The aim of the present study was to investigate the acute effects of unilateral whole body vibration training on height and symmetry of the single leg vertical jump in healthy men. [Subjects] Thirty males with no history of lower limb dysfunction participated in this study. [Methods] The participants were randomly allocated to one of three groups: the unilateral vibratory stimulation group (n=10), bilateral vibratory stimulation group (n=10), and, no vibratory stimulation group (n=10). The subjects in the unilateral and bilateral stimulation groups participated in one session of whole body vibration training at 26 Hz for 3 min. The no vibratory stimulation group subjects underwent the same training for 3 min without whole body vibration. All participants performed the single leg vertical jump for each lower limb, to account for the strong and weak sides. The single leg vertical jump height and symmetry were measured before and after the intervention. [Results] The single leg vertical jump height of the weak lower limb significantly improved in the unilateral vibratory stimulation group, but not in the other groups. The single leg vertical jump height of the strong lower limb significantly improved in the bilateral vibratory stimulation group, but not in the other groups. The single leg vertical jump symmetry significantly improved in the unilateral vibratory stimulation group, but not in the other groups. [Conclusion] Therefore, the present study found that the effects of whole body vibration training were different depending on the type of application. To improve the single leg vertical jump height in the weak lower limbs as well as limb symmetry, unilateral vibratory stimulation might be more desirable.

Key words: Single leg vertical jump, Symmetry, Whole body vibration

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INTRODUCTION

Lower limb asymmetry is highly related to damage of the lower limbs that causes changes in lower limb function during daily or sports activities^{1, 2)}. Lower limb asymmetry causes changes in the movement of the ankle, knee, and hip joints and in the combined proprioceptive sensation and neuromuscular control required for change of direction³⁾. Therefore, the different movement pattern of the non-affected or affected side could change the mechanism of alternating movements such as walking, running, jumping, and landing and damage the lower limb during such movements. Asymmetry after this damage exacerbates the condition, resulting in even greater damage^{4, 5)}.

Diagnostic tests to measure lower limb asymmetry are necessary. Diagnostic tests can help identify healthy people

who are at risk of lower limb damage²⁾. Moreover, diagnostic tests serve as a criterion for rehabilitation of damage and are helpful in determining the appropriate time for a person to return to the community⁶⁾. A study by Fitzgerald et al.⁷⁾ suggested that the functional performance test could predict the possibility of knee damage and serve as a tool to assess postoperative improvement in patients. The functional performance test includes a single leg hop for distance, single leg triple hop for distance, single leg internal/external jump, and single leg vertical jump (SLVJ), all of which have been widely used both clinically and academically⁸⁾. The SLVJ, in particular, is one of the most common tests of functional performance and has been used to evaluate lower limb performance by applying similar stimulations as those experienced during daily or sporting activities; moreover, the SLVJ has a reported test-retest reliability of 0.88–0.97⁹⁾. As an officially certified assessment tool, the SLVJ comprehensively measures flexibility, balance, power, and neuromuscular control and provides objective measurements based on subject performance¹⁰⁾.

The SLVJ can be used to assess the functional performance ability of both lower limbs, and the results can be represented using the limb symmetry index (LSI). The LSI is the ratio of the jump height of the measured lower limb to

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the jump height of the contralateral lower limb. For classification of normal and abnormal limb symmetry, O'Donnell et al.¹¹⁾ suggested that an LSI $\geq 90\%$ should be considered in the normal range. Therefore, functional ability as measured by the SLVJ is abnormal, and asymmetry exists, if there is $> 10\%$ difference between the two lower limbs.

To restore symmetry, a significant goal can be to improve the functional ability of the weaker side of the asymmetric lower limbs. Elements related to functional ability include muscle strength, power, lower extremity joint stability, endurance, muscle flexibility, balance, proprioception, speed, and agility.

Diverse methods including muscular strengthening exercise, endurance training, balance training, perturbation training, and agility training have been used to improve the functional ability of a weaker lower limb. However, these exercises and training methods only improve specific elements of lower limb functional ability at a time. In this sense, a number of elements need to be trained to achieve sufficient capacity of the lower limb.

Over the most recent decade, WBV has emerged as a new training method that involves diverse elements by improving bone density, blood circulation, muscular strength, endurance, proprioception, and balancing ability¹²⁻¹⁴⁾. WBV applies fast repeated, alternating concentric–eccentric stimulations while the subject is in a static standing posture; the external vibration affects the muscles and nervous system¹⁵⁾. Other existing training methods with stronger stimulation are more likely to harm the subjects, but WBV is associated with only a low risk of such harm¹⁶⁾.

Several studies have investigated the potential of whole body vibration (WBV) to improve subsequent performance. Traditionally, bilateral vibratory stimulation transmitted through both lower limbs has been provided to enhance muscular activity and functional performance. However, training using bilateral vibratory stimulation may not be proper in the case of subjects showing a severe difference between both lower limbs. The amount of vibratory stimulation accepted by each lower limb may differ while supporting body weight against gravity and the magnitude of the effect depends on the condition of each limb. Therefore, training using unilateral vibratory stimulation can be a way to improve the functional ability of a weak lower limb and the symmetry of functional ability between both lower limbs. But it is not well understood whether unilateral vibratory stimulation will cause improvement in the performance of a trained lower limb and the other limb, and no studies have examined the effect of unilateral vibratory stimulation compared with bilateral vibratory stimulation in the same position.

Thus, in recognition of this, the present study aimed to differentiate the weaker and strong lower limbs and identify the effect of unilateral WBV training on the SLVJ height as well as limb symmetry.

SUBJECTS AND METHODS

Thirty-five physically active men volunteered to participate. The subjects were volunteers recruited from a university in Seoul, South Korea. All subjects were classified as recreationally active, which was operationally defined as

Table 1. Subject characteristics (N=30)

	UVSG	BVSG	NVS
	(n=10)	(n=10)	(n=10)
Age (years)	21.1 \pm 2.4	20.9 \pm 1.5	21.2 \pm 2.3
Height (cm)	175.9 \pm 5.8	175.3 \pm 4.6	174.7 \pm 4.4
Weight (kg)	65.6 \pm 7.6	67.8 \pm 6.2	65.4 \pm 7.6

Values are expressed as the mean \pm standard deviation.

UVSG: unilateral vibratory stimulation group; BVSG: bilateral vibratory stimulation group; NVSG: no vibratory stimulation group

participation in regular structured exercise training or competition. None of the subjects were exposed to WBV training before participation in this study¹⁷⁾. The subjects were excluded if they had pain, recent or possible thrombosis, severe headache, vestibular disorder, advanced arthritis, lower limb implant, lumbar disc disorder, medication that could interfere with the study, a recent sprain, a recent fracture, a gall bladder or kidney stone, or a malignancy¹⁸⁾.

The subjects were fully informed about the possible risk and discomfort that might result from the investigations. The protocol was approved by the Institutional Review Board and Ethics Committee of Sahmyook University, South Korea. Five subjects were excluded because of knee joint pain (n = 3), recent sprain (n = 1), or lumbar disc disorder (n = 1). After interviews for exclusion, thirty subjects were randomly assigned into one of three groups, namely the unilateral vibratory stimulation group (UVSG, n=10), bilateral vibratory stimulation group (BVSG, n=10), and no vibratory stimulation group (NVSG, n = 10). Random Allocation Software (version 1.0) was used to minimize selection bias¹⁹⁾ (Table 1).

During the course of the study, participants were not permitted to undertake any power or strength training and were also instructed to avoid any vigorous activity 24 hours prior to the intervention²⁰⁾. The vibratory stimulation was conducted by the following method. Based on the findings of Cochrane and Stannard²¹⁾, each participant was familiarized with the vibration platform. In the study by Cochrane and Stannard, vibratory stimulation was provided for 5 min; however, in the present study, the subjects could not maintain the squat posture for more than 3 minutes because of calf muscle spasm.

The Galileo 2000 (Novotec, Pforzheim, Germany) was used for bilateral WBV training, and a researcher provided a full explanation of the study purpose and methods, as well as the proper exercise posture, to the subjects. The isometric squat posture was conducted as described in the following paragraphs. Based on the methods of Cochrane and Stannard²¹⁾, the exercise posture was corrected, and the subject stood on a foothold while barefoot and maintained a specific distance from the rotation axis. The subject crossed his arms, and a researcher supported the subject's waist to prevent falling. The vibratory stimulation was conducted as described in the following sentences. The vibratory stimulation was administered once at a vibration frequency of 26 Hz for 3 min. The amplitude of the vibration foothold was fixed at 3 mm. The proper exercise posture included maintenance of

Table 2. Differences between the strong and weak lower limbs (N=30)

		UVSG	BVSG	NVSG
		(n=10)	(n=10)	(n=10)
SLVJ height (cm)	WLL	17.8 ± 1.7	17.9 ± 1.5	17.7 ± 1.5
	SLL	21.7 ± 1.7	21.4 ± 1.7	21.7 ± 1.5
	SLL-WLL	3.9 ± 0.2*	3.6 ± 0.8*	4.0 ± 0.2*

Values were expressed as the mean ± standard deviation. *There is a significant difference between the SLL and WLL

SLVJ: symmetry of single leg vertical jump; UVS: unilateral vibratory stimulation group; BVSG: bilateral vibratory stimulation group; NVSG: no vibratory stimulation group; WLL: weak lower limb; SLL: strong lower limb

the knee and hip joint angles at 140 degrees and 90 degrees, respectively. Both feet were placed on the vibratory plate to transfer vibratory stimulation through both the lower limbs. For unilateral WBV training of the lower limb on the weak side, all the conditions were the same as those for the isometric squat exercise with bilateral vibratory stimulation. The foot of the strong side was placed on a foothold at the same height as the vibration plate, and the foot of the weak side was placed on the vibration plate so that the vibratory stimulation was transferred only through the weak lower limb. Training without WBV was performed by the same method as bilateral WBV training except for vibratory stimulation. Both feet were placed on the vibratory plate; however, vibratory stimulation was not provided.

The SLVJ test was performed before and after the intervention. It was performed three times for each lower limb. No attempt was made to randomize the order in which the lower limbs were tested. Prior to the experimental procedure, assessors were trained regarding their behavior and to be aware of the problems that could occur. The SLVJ test was used to assess the lower-limb performance capacity. For the SLVJ, it was recommended that the subjects stand on one leg and be unsupported at take off. The subjects then jumped as quickly and as high as possible and landed on the same extremity. The subjects kept their hands on the pelvis and were informed that they could swing their arms freely or use a selected countermovement without stepping prior to jumping. The tests were performed with an OptoGait system (OptoGait, Microgate Srl, Bolzano, Italy), which measured the flying time. An OptoGait with high-density photoelectric cells that allows for quantification of spatiotemporal gait parameters on basically all flat surfaces has recently been introduced. The OptoGait system is composed of transmitting and receiving bars that are placed parallel to each other. When a subject passes between the transmitting bar and receiving bar, the system detects any interruption in light signal due to the presence of feet within the recording area and automatically calculates spatiotemporal parameters. It has been shown to have high concurrent validity and test-retest reliability²²). Ground contact and flight time during a jump or series of jumps were measured. The flight time was used to estimate the height of the body's center of gravity during the vertical jump. The average value of three measurements was used as the test record. The flight time (T_f) and acceleration due to gravity (g) were used to calculate the vertical rise (h) of the center of gravity of the body.

$$h(\text{cm}) = \frac{T_f^2}{8} \times g$$

The LSI was quantified and used to compare the involved and uninvolved limbs. Performance in the weak limb (h_1) and performance in the strong limb (h_2) were used to calculate for LSI. Thus, physical performance in the weak limb was expressed as a percentage of the physical performance in the strong limb.

$$\text{LSI}(\%) = \frac{h_1}{h_2} \times 100$$

All statistical analyses were performed using the IBM SPSS Statistics version 19.0 statistical software (IBM Corp., Armonk, NY, USA). Results are presented as the mean ± standard deviation. Prior to training, the Shapiro-Wilk test was used to check if the distribution of all parameters was normal. When data were normally distributed, one-way analysis of variance (ANOVA) was used to assess differences in continuous variables among groups. The paired t-test was used to assess differences in continuous variables within groups before and after interventions for each group. Differences in categorical variables were analyzed using the χ^2 test. P-values less than 0.05 were considered statistically significant.

RESULTS

The SLVJ heights of the strong lower limb and weak lower limb were significantly different in the UVSG, BVSG, and NVSG ($p < 0.05$) (Table 2).

The SLVJ height of the weak lower limb showed significant improvement in the NVSG, BVSG, and NVSG ($p < 0.05$). The SLVJ height of the weak lower limb showed significant improvement in both the UVSG and BVSG compared with the NVSG ($p < 0.05$). In addition, significant improvement was observed in the UVSG compared with the BVSG ($p < 0.05$). The SLVJ height of the strong lower limb showed significant improvement in the NVSG, BVSG, and NVSG ($p < 0.05$). The SLVJ height of the strong lower limb showed a significant improvement for the BVSG compared with the UVSG and NVSG (Table 3).

SLVJ symmetry showed significant improvement in the UVSG and BVSG ($p < 0.05$), but not in the NVSG. SLVJ symmetry showed significant improvement in both the

Table 3. Changes in single leg vertical jump height (N=30)

		UVSG (A)	BVSG (B)	NVSG (C)	Post hoc
		(n=10)	(n=10)	(n=10)	
WLL (cm)	Pre	17.8 ± 1.7	17.8 ± 1.5	17.7 ± 1.5	
	Post	21.5 ± 1.7	20.2 ± 1.7	18.03 ± 1.5	
	Post-Pre	3.7 ± 0.5*	2.3 ± 0.7*	0.35 ± 0.2*	A B C
SLL (cm)	Pre	21.7 ± 1.7	21.42 ± 1.7	21.68 ± 1.5	
	Post	23.0 ± 1.8	23.70 ± 1.9	22.11 ± 1.6	
	Post-Pre	1.2 ± 0.6*	2.27 ± 0.5*	0.42 ± 0.3*	B A, C

Values were expressed as mean ± standard deviation. *There is a significant difference between the pre- and post-intervention values

UVSG: unilateral vibratory stimulation group; BVSG: bilateral vibratory stimulation group; NVSG: no vibratory stimulation group; WLL: weak lower limb; SLL: strong lower limb

Table 4. Changes in symmetry (N=30)

		UVSG (A)	BVSG (B)	NVSG (C)	Post hoc
		(n=10)	(n=10)	(n=10)	
LSI (%)	Pre	81.9±1.6	83.4±3.5	81.5±1.5	
	Post	93.8±1.2	85.1±2.7	81.5±1.7	
	Post-Pre	11.9±1.9*	1.7±2.5*	-0.0±1.3	A B C

Values were expressed as the mean ± standard deviation. *There is a significant difference between the pre- and post-intervention values

LSI: limb symmetry index; UVSG: unilateral vibratory stimulation group; BVSG: bilateral vibratory stimulation group; NVSG: no vibratory stimulation group

UVSG and BVSG compared with the NVSG ($p < 0.05$). In addition, significant improvement was observed in the UVSG compared with the BVSG ($p < 0.05$) (Table 4).

DISCUSSION

This study verified the effects of unilateral WBV training in healthy men. One session of an isometric squat exercise and unilateral vibratory stimulation applied only to the weak side improved SLVJ height and symmetry.

A variety of functional performance tests have been described, including single leg hop tests for distance or time, hop and stop tests, and vertical jump tests⁷. In particular, the SLVJ is typically used to assess elements of lower limb function and the ability of the lower limb to perform challenging tasks. Previous studies have described the relationships between hop test measurements and physical impairments, such as muscle weakness, passive joint laxity, and knee joint proprioception deficits²³. The SLVJ height is a meaningful indication of functional performance capacity²⁴.

The SLVJ height in both the UVSG and BVSG showed a considerably larger increase than that in the NVSG. With an increase of 21% in SLVJ height in the weak lower limb, the UVSG showed a considerably larger increase than the BVSG, which had an increase of 12%. Although the present study resulted in only small improvements in the average SLVJ height after the WBV training, the improvement was obvious. Torvinen et al.¹⁶ demonstrated an improvement in isometric knee joint extension torque after one 4-min WBV session. Pellegrini et al.²⁵ also showed enhanced foot joint

planter flexion torque. This improved lower limb extension torque is likely because WBV constantly expands muscular capacity²⁵.

The WBV stimulates the Ia afferent tendency of muscle spindles, and continued stimulation of the stretch reflex mechanism activates motor neurons, increasing the sensitivity of primary ending. Moreover, more muscles are recruited via the muscle spindles and neuron bundles²⁶. Small type I muscles are first recruited under the muscle recruitment principle, followed by large type II muscles thereafter, and the more large type II muscles are recruited, the better the improvements in movements and muscle strength¹⁰. These all imply that brief WBV has a significant effect on muscle recruitment required for the SLVJ.

As mentioned above, the neuron work and muscle enhancement elicited by both concentric and eccentric contractions with the WBV also follows the process of the SLVJ. Each joint of the lower limbs is flexed for instant extension for a jump, and the stretch-shortening cycle of extended muscles activates the spinal reflex for a burst of concentric contraction, in which the stretch receptors are activated in the eccentric loading phase²¹. This mechanism increases the SLVJ height such that it is higher than that of the squat jump.

Therefore, the concentric and eccentric muscle contractions induced by WBV activates the stretch reflex mechanism and increases the muscular recruitment required for jumping, and the effect of the stretch-shortening cycle elicited by the eccentric contraction during the SLVJ further increases the jump height. Of course, the NVSG also showed the effect of the stretch-shortening cycle, but it did not improve,

seemingly because there was no stretch reflex mechanism, as this group did not receive WBV.

In contrast, based on the results of the present study, vibratory stimulation in the BVSG was transmitted though both lower limbs, not only the weak lower limb. Therefore, a certain amount of vibration was divided between the legs, and the vibratory stimulation transmitted to the weak lower limb in the BVSG might have been less than that in the UVSG. This meant that the stretch reflex mechanism and muscular recruitment were not sufficiently experienced in the weak lower limb in the BVSG compared with the UVSG.

With an SLVJ height increase of 5% in the strong lower limb, the UVSG showed a considerably larger increase than the NVSG but not a considerably larger increase than the BVSG, which showed an increase of 10%. With unilateral vibratory stimulation, the strong side failed to experience the stretch-reflex mechanism, as in the case of no vibratory stimulation. Nevertheless, increased jump height was observed in the UVSG.

The aforementioned effects of improved lower limb extension torque of the non-stimulated lower limb could be caused by supporting the body weight against external sway without losing balance. In addition, the cross-training effect documented in a previous study also enhances muscle strength in the untrained lower limb compared with unilateral resistance training²⁷). The gain in muscle strength through the cross transfer of resistance training could be caused by modifications in neural control. Neural modifications could be elicited from the cortical areas responsible for excitatory responses of the appropriate cortex area during voluntary contraction²⁸). The characteristics of the cross-training effect indicated that it was likely to occur even though the untrained lower limb did not participate directly in the interventions²⁹).

Therefore, improved lower limb extension torque as a result of supporting body weight against external sway in addition to the cross-training effect during unilateral WBV training led to enhanced function of the non-stimulated lower limb during performance of the SLVJ.

With an increase in symmetry of 14%, the UVSG showed a considerably larger increase than the other groups. Unilateral vibratory stimulation increases the stability of the lumbosacral area and activates the muscles of the lower limb, improving SLVJ performance compared with the pre-intervention performance. Accordingly, the ability of the weak lower limb improves more than that of the strong lower limb, which did not receive vibratory stimulation. Therefore, this increases the symmetry of the functional performance of both lower limbs. Bilateral vibratory stimulation improves the capacity of not only the weak lower limb but also the strong lower limb at the same time. Therefore, the symmetry of the BVSG did not improve compared with that of the UVSG.

In this sense, for enhanced symmetry between the lower limbs, unilateral vibratory stimulation applied to only the weak lower limb could be a good approach.

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