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Original Article

Whole-body vibration enhances effectiveness of "locomotion training" evaluated in healthy young adult women

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Abstract. [Purpose] Locomotion training is recommended as a countermeasure against locomotive syndrome. Recently, whole-body vibration has been clinically applied in rehabilitation medicine. Therefore, we aimed to investigate the preliminary effectiveness of whole-body vibration on locomotion training. [Participants and Methods] Overall, 28 healthy adult females were randomly assigned to either a locomotion training group using a whole-body vibration device (whole-body vibration group, n=14) or training on the flat floor (non-whole-body vibration group: n=14). Participants conducted two sets of locomotion training twice a day and three times a week for 12 weeks. [Results] A significant difference was observed in the group factor for all outcome measures and in the before and after the training factor for Timed Up and Go test. After the training, knee muscle strength, dynamic balance, and mobility function in the whole-body vibration group were significantly improved compared with the non-whole-body vibration group. In the whole-body vibration group, the Timed Up and Go time after the training was significantly shorter compared with that before training. [Conclusion] The results suggest that locomotion training with whole-body vibration can improve the physical functions in healthy adult females and locomotion training using whole-body vibration might enhance the effectiveness of locomotion training.

Key words: Whole-body vibration, Locomotion training, Mobility

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INTRODUCTION

Japan is a super-aging society, so reforming the consciousness of citizens in regard to nursing care and health maintenance and promotion has become an increasingly important issue, and new concepts need to be created. Therefore, in 2007, the Japan Orthopedic Society proposed the concept of locomotive syndrome (LOCOMO)[1)], a state in which the ability to move

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has deteriorated because of musculoskeletal system disorders. As the risk of requiring additional nursing care increases with decreases in mobility function[2)], it is important both to devise LOCOMO countermeasures to help prevent conditions requiring long-term care and to extend healthy life spans. Locomotion training, including single-leg standing with eyes open and squatting[3, 4)], improved dietary habits, and increased daily activities are recommended as countermeasures against LOCOMO.

Whole-body vibration (WBV) was developed in the 1960s as a training program for astronauts, and it has recently been clinically applied to sports and rehabilitation medicine[5)]. WBV is a training method that increases exercise efficiency by transmitting loads based on Newton's second law (F=ma) to the musculoskeletal system in a precise and short time by adjusting the amplitude and frequency of vibrations. WBV devices include a vertical type that vibrates while the plate maintains a horizontal plane, and a rotating type in which the left and right sides of the plate alternate up and down. Although it is easy to assume various poses using the vertical type, vibration transmission to the head is increased. On the other hand, the rotating type involves a vibration stimulus similar to that of physiological walking, and there are reports that vibration transmission to the head is decreased and safer compared with the vertical type[6, 7)]. By adjusting the vibration stimulation condition in WBV, it is possible to obtain beneficial effects such as muscle strengthening, improved balance ability, improved flexibility, increased bone density, and positive effects on the nervous, circulatory, and hormone systems[8, 9)]. In addition, since WBV can reduce loads and enable more efficient training, it is also suitable for training in elderly people[10)].

Although locomotion training is usually carried out on a flat floor, it is speculated that combining WBV with locomotion training could enhance its effectiveness. However, to our knowledge, no studies have examined the effectiveness of a combination of locomotion training and WBV. Therefore, in the present study, as a preliminary study of a randomized controlled trial (RCT) for the elderly, we aimed to compare the effectiveness of locomotion training on a rotating-type WBV device and locomotion training on the flat floor in healthy adult women. We hypothesized that locomotion training combined with WBV would improve physical functions such as lower-limb muscular strength, balance ability, and mobility function more than locomotion training on the flat floor.

PARTICIPANTS AND METHODS

In total, 36 healthy women in their 20s were invited to participate in the study. The exclusion criteria were pregnancy, a musculoskeletal system disorder under treatment, disorders of the stroma, severe dizziness, acute thrombosis, circulatory system disease, spinal canal stenosis, acute inflammation, tumor, trauma, a history of artificial joint replacement surgery or pacemaker implantation, and stent graft or bypass surgery within the previous 6 months. After excluding eight women because of musculoskeletal system disorders under treatment (n=5) and pregnancy (n=3), 28 individuals who understood the purpose of the research and gave their consent to participate were included (Fig. 1). Prior to the training, the women were randomly assigned into a group performing locomotion training using WBV (WBV group: n=14) and a group performing locomotion training on the floor (non-WBV group: n=14) by a computer-generated random number table using JMP® pro version 14 (SAS Institute Inc., Cary, NC, USA). The sample size was calculated using G*Power[11)].

Locomotion training included single-leg standing with eyes open and squatting, described as follows.

(Single-leg standing with eyes open) The participant lifted one leg from the position where the foot was expanded to shoulder width and maintained the posture for 1.5 min on both the left and right sides.

(Squatting) The participant stood standing wide with the feet spread slightly wider than shoulder width and continued to

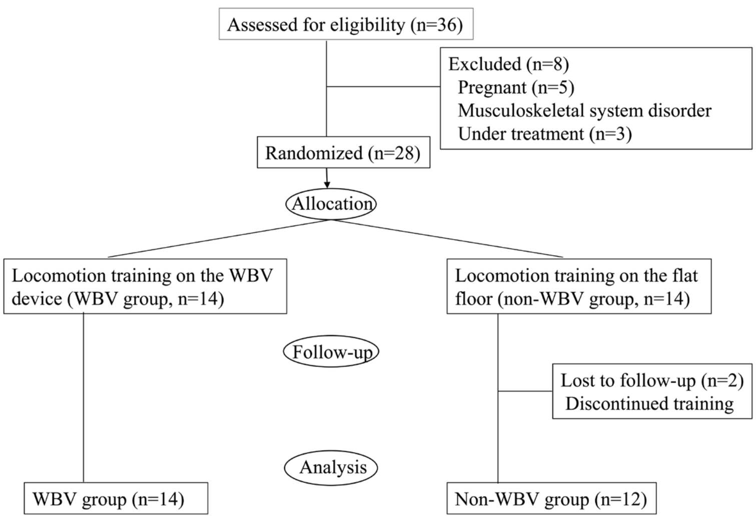

Fig. 1. Flowchart of the study sample.

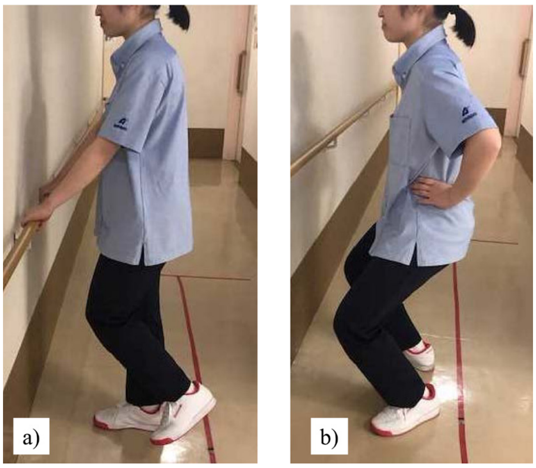

Fig. 2. Locomotion training on the flat floor.
a) Single-leg standing with eyes open.
Lifting one leg for 1.5 min on both the left and right sides.
b) Squatting.
Continuing to sink slowly for 3 min.

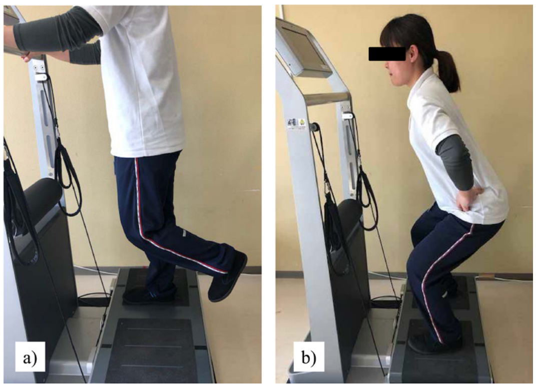

Fig. 3. Locomotion training on the whole-body vibration (WBV) device.
a) Single-leg standing with eyes open, b) Squatting.
In the WBV group, similar locomotion training was carried out on the WellenGang Excellence® rotating-type WBV device.

sink slowly for 3 min to pull the buttocks back.

WBV device: The WellenGang Excellence® rotating-type WBV device (WellenGang GmbH, Ötisheim, Germany) was used. In accordance with Von Stengel et al.[12, 13], the frequency was adjusted to 10 Hz and the amplitude to 4.5 mm.

In the non-WBV group, two sets of locomotion training were carried out voluntarily twice a day in the morning and evening on the flat floor (Fig. 2. a, b). In the WBV group, similar training was voluntarily performed on the WBV device (Fig. 3. a, b). The training was conducted three times a week for 12 weeks in a rehabilitation hospital. The following evaluations were made in another hospital before starting and after completing training by the physical therapists who belong to that hospital and were blinded as to the study, and the results were compared among the two groups and before and after training.

The original purpose of locomotion training is to maintain physical functions such as lower limb muscular strength, balance ability, and mobility function in elderly people. Therefore, knee extension and flexion strength, the functional reach test (FRT), Y-balance test (YBT), and Timed Up and Go (TUG) test were measured in this study. Measurements were conducted in a rehabilitation hospital by 10 physiotherapists from a university hospital.

Knee extension and flexion strength were measured using an isokinetic dynamometer (Biodex 4; Biodex Medical Systems, Shirley, NY, USA) that evaluates knee muscle strength and joint torque by maintaining the joint angular velocity at a constant speed. First, the reclining angle of the seat and the anterior-posterior position were adjusted, and then the body was fixed by tightening the waist and chest belt. Next, the center of the knee joint was aligned with the center axis of the dynamometer and the lever arm was adjusted, after which, the ankle joint was fixed. Next, the range of motion of the knee joint was set at about 20°, and the weight of the leg was measured when the thigh was relaxed. After warming up, right knee joint flexion and extension muscle strength were measured under a low-speed condition (60 deg/s).

The FRT evaluates dynamic balance ability toward the front of the standing posture. In the upright position, the upper limbs were set at 90° flexion of the shoulder joint, extension of the elbow joint, intermediate position of the wrist joint, and extended position of the fingers. Next, the upper extremities were extended forward to the maximum degree possible without moving the foot sole on the ground surface. The distance from the stationary position to the maximum forward position was measured five times, and the maximum value after the third time was adopted.

The YBT was used to evaluate dynamic balance. From the upright posture, the lower limbs reaching the front, back, back and outward directions returned to the upright posture, after which, the maximum leg reach distance in each direction was measured.

The TUG test was used to evaluate mobility function. The total time required to rise from a chair, walk 3 m, turn around, walk another 3 m, and sit in the chair was measured.

Continuous variables were expressed as the mean ± standard deviation (SD). For comparisons of the baseline characteristics between the two groups, an unpaired t-test was used, with $p<0.05$ regarded as significant. The measured values of knee extension and flexion strength, FRT, YBT, and the TUG test were confirmed by the Shapiro-Wilk test according to whether each variable followed the normal distribution. Regarding the intervention effects for each outcome measure, two-way analysis of variance (ANOVA) was performed to identify the interactions and to compare between the variables of group and time. When the main effect (Group, Time) was significant in two-way ANOVA and the interaction was not significant, the post-hoc test using the Tukey HSD method was performed on the factors with significant difference. Data analysis was performed using JMP® pro version 14 (SAS Institute Inc.) and p<0.05 was regarded as significant in all outcome measures.

This study was approved by the Epidemiological Research Ethics Review Committee of the Amano Rehabilitation hospital (No. 1001).

RESULTS

During the study period, two women in the non-WBV group were unable to continue their training because of family reasons; thus, 14 women in the WBV group and 12 in the non-WBV group completed 3 months of training. No obvious adverse events were noted during the training period in either group. Table 1 shows the baseline characteristics (age, height, weight, body mass index) of the 26 women who completed the training. No significant differences in baseline characteristics were observed between the two groups.

Table 2 shows the results of the outcome measures in the WBV and non-WBV groups before and after training and a comparison of the intervention effects. In the two-way ANOVA, no interactions were observed between any outcome measures.

A significant difference was found in the group factor (WBV vs. non-WBV) in all outcome measures, and in the post-hoc test, a significant difference was also found between WBV group and non-WBV in all outcome measures after the training (Knee extension strength, p=0.030; Knee flexion strength, p=0.022, FRT, p=0.015; YBT anterior, p=0.037; YBT posteromedial, p=0.003; YBT posterolateral, p=0.033; TUG, p=0.037, respectively). A significant difference was also observed in the TUG test for the factor of before and after training. In the post-hoc test, a significant difference was observed between before and after training in the TUG test of the WBV group (p=0.030).

DISCUSSION

To our knowledge, no studies have been conducted to evaluate the effectiveness of locomotion training using a WBV device. Therefore, this is the first report to show that whole-body vibration enhances effectiveness of "locomotion training". Originally, locomotion training was focused on the elderly; however, the present preliminary study was conducted to examine the feasibility and effectiveness of locomotion training combined with WBV in healthy adult women. Locomotion training is related to standing and walking function, and is performed voluntarily by the elderly as a home exercise because it is safe and simple, however, its exercise intensity is not high[14, 15]. Thus, it was thought that the training effect on healthy young adult males would be difficult to observe, even when used with WBV, so healthy young adult women were recruited to participate in this preliminary study.

In this study, a significant difference was found for the group factor in all outcome measures based on a two-way ANOVA

Table 1. Baseline characteristics of the participants in both groups (n=26)

	WBV group (n=14)	Non-WBV group (n=12)	p value
Age (years)	24.1 ± 2.2	24.2 ± 2.1	0.978
Height (cm)	160.6 ± 5.6	157.5 ± 7.4	0.277
Weight (kg)	54.7 ± 6.9	53.4 ± 7.9	0.673
BMI (kg/m^2)	21.3 ± 2.0	21.4 ± 2.1	0.554

WBV: whole-body vibration; BMI: body mass index. Data are the means ± SD.

Table 2. Results of the outcome measures in the whole-body vibration (WBV) and non-WBV groups before and after training and comparison of the intervention effects

	WBV group (n=14) (mean ± SD)		Non-WBV group (n=12) (mean ± SD)		Repeated-measures ANOVA (Time × Group)	Main effect (Time)	Main effect (Group)
	Pre	Post	Pre	Post	p	p	p
Knee muscle strength (Nm/kg)							
Extension	224.9 ± 24.3	226.4 ± 23.6†	208.1 ± 36.8	192.3 ± 30.9	0.309	0.397	0.004
Flexion	103.7 ± 11.4	102.5 ± 16.9†	93.7 ± 14.8	87.7 ± 17.1	0.588	0.422	0.007
FRT (cm)	39.1 ± 5.6	44.4 ± 5.1†	38.4 ± 5.7	37.4 ± 5.4	0.055	0.176	0.018
YBT (cm)							
Anterior	60.7 ± 7.0	60.8 ± 4.7†	57.1 ± 5.6	54.6 ± 3.7	0.412	0.464	0.003
Posteromedial	89.4 ± 7.3	93.9 ± 4.9†	83.3 ± 8.4	83.6 ± 6.0	0.297	0.227	<0.001
Posterolateral	89.5 ± 9.0	93.2 ± 4.6†	88.2 ± 8.5	84.9 ± 5.1	0.100	0.928	0.027
TUG (s)	5.3 ± 0.9	4.7 ± 0.5# †	5.6 ± 0.6	5.2 ± 0.5	0.507	0.022	0.048

FRT: functional reach test; YBT: Y-balance test; TUG: Timed Up and Go test; ANOVA: analysis of variance.
#p<0.05 vs. Pre-training, †p<0.05 vs. Non-WBV group.

and in the following post-hoc test in all outcome measures. In addition, a significant difference was also observed in the factor of before and after the training in the TUG test and in the following post-hoc test in the WBV group. However, in the present study, improvements before and after the training were only seen in TUG test, and although no significant differences were observed, some values after the training were decreased, especially in the non-WBV group. The suspected reasons underlying these results included the fact that the exercise intensity of locomotion training was low, even for young adult women.

Regarding the effects of locomotion training, Aoki et al. reported that locomotion training alone reduced falls and fractures among elderly people, as well as the number of elderly people requiring long-term care[17)]. In addition, Sakamoto et al. reported that single-leg standing reduced the risk of falls and fracture of the proximal femur in elderly people[18)]. Furthermore, Maruya et al.[19)] reported that locomotion training improved 10-m walking speed and knee extension muscle strength, and Young et al.[20)] reported that squatting improved lower-limb strength and balance ability in elderly people. These studies focused on elderly people, and found that improvements in physical functional could be obtained, however, since locomotion training has a low exercise intensity, it should be accompanied by other muscle strengthening, aerobic exercises in some elderly people.

In the present study, locomotion training using WBV improved physical function compared with locomotion training on the floor. Regarding the effects of WBV training on muscle strength, Cormie et al. reported that vertical jumping ability improved immediately after WBV training[21)]. In addition, some studies have reported the immediate effectiveness of WBV training[22, 23)]. A systematic review conducted by Rehn et al. on long-term muscle performance reported strong evidence that long-term WBV training improves lower-limb muscle performance in elderly women and individuals with no regular exercise habit[24)]. The involvement of the tonic vibration reflex, which is an unconscious muscle contraction, has been reported as a beneficial effect of WBV for muscle strength[25)]. As for balance ability, Moezy et al. reported that WBV training for 4 weeks after knee anterior cruciate ligament reconstruction surgery improved balance ability[26)]. In addition, Maeda et al. examined the effects of WBV training in healthy volunteers, and found that trunk flexion strength, dynamic balance ability, and physical performance was significantly improved in a WBV compared with a non-WBV group[27)]. Furthermore, a meta-analysis conducted by Rogan et al. found that WBV training might influence dynamic balance ability in elderly people[28)]. The reason why dynamic balance ability was improved in the present study was considered as follows. The fine vibration of the basal plane induced by WBV caused instability of the basal plane and activated the nerve-muscle function for maintaining a standing posture. In addition, Cochrane et al. showed the possibility of muscle relaxation by the Golgi tendon organ as a mechanism by which WBV training improves flexibility and balance ability[28)]. Although this was a preliminary study involving healthy young women, Bautmans et al. previously conducted an RCT on WBV training for 6 weeks in elderly people living in a nursing home, and reported that WBV training improved balance ability[29)]. Sitjà-Rabert et al.[30)] also conducted an RCT involving WBV training for 6 weeks in elderly people; however, they reported that physical function such as balance ability was not significantly different between WBV training and physical therapy conducted by physical therapists. Therefore, in the future, it will be necessary to verify the effectiveness of locomotion training using WBV on elderly people. In the present study, locomotion training using WBV also improved mobility function. Since muscle strength and balance ability are strongly related to mobility function, mobility function could be improved by the combined effect of locomotion training using WBV for muscle strength and balance function.

This study did have some limitations. First, we only recruited healthy young women in their 20s and their exercise habits were not considered; this remains a topic for a future study. Second, it was impossible to blind the groups in the present study. Third, the examiners and capabilities varied and could not be fixed. Fourth, the muscular strength of the trunk, hip joint, and ankle joint, which are important for maintaining balance, were not evaluated. Therefore, the muscle strength of the trunk, hip joint, and ankle joint should be evaluated in a future study. In addition, because the present study was conducted on young women, the frequency of falls and fractures and the rate of requiring nursing care were not considered. However, since combining WBV with locomotion training could improve physical function, and is expected to further reduce falls and fractures among elderly people, it will be necessary to examine these evaluations for elderly people in the future. If the physical function of elderly people could be improved, and the numbers of falls and fractures and elderly people who need nursing care could be further decreased by locomotion training using WBV, the clinical and social significance of such training would be substantial.

In conclusion, the results of the present study suggest that locomotion training using WBV could improve knee muscle strength, dynamic balance, and mobility function compared with locomotion training on the floor and locomotion training, especially with WBV, could improve mobility function. Therefore, locomotion training using WBV could enhance the effectiveness of locomotion training on the floor and might further reduce the incidence of falls and fractures while improving mobility function in elderly people compared with locomotion training on the flat floor. Thus, an RCT involving elderly people should be conducted in the near future.

Conflict of interest

There are no conflicts of interest.

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