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Effect of whole body vibration on lactate level recovery and heart rate recovery in rest after intense exercise

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Abstract.
OBJECTIVE: In this paper, we investigated the recovery of the lactate level, muscular fatigue, and heart rate recovery (HRR) with respect to whole body vibration (WBV) during the rest stage after a gait exercise.
METHODS: A total of 24 healthy subjects with no medical history of exercise injury participated. The participants were divided into a training group with vibration during rest and a control group with the same conditions but without vibration. The subjects performed a gait exercise with a slope of 15% and velocity of 4 km/h to consume 450 kcal in 30 min. Then, they rested on a vibrating chair or on a chair without vibrations for 30 min. The vibration protocol consists of a frequency of 10 Hz and amplitude of 5 mm. To estimate the recovery effect, we measured the lactate levels in blood, spectral edge frequency (SEF) of MVIC, and HRR before, immediately after exercise, and after rest.
RESULTS: The results showed that the lactate level in the training group decreased more (93.8%) than in the control group (32.8%). Also, HRR showed a similar trend with a recovery of 88.39% in the training group but 64.72% in the control group. We considered that whole-body vibrations during rest would help remove lactic acid by improving the level of lactic acid oxidation with stimulated blood vessels in the muscles and by helping to maintain blood flow. Also, WBV would lead to compensation to actively decrease the fast excess post-exercise oxygen consumption from blood circulation.
CONCLUSIONS: We suggest that whole-body vibrations during rest can provide fast, efficient fatigue recovery as a cool down exercise for women, the elderly, and patients without other activity after intense exercise.

Keywords: Fatigue, lactate level in blood, heart rate recovery, whole body vibration, healthcare

1. Introduction

Recently, there has been research and development of various exercise methods and machines as a result of interest in exercise for people of all ages to improve their health [1]. Whole body vibration has entered the limelight as a new exercise method in sports training and rehabilitation during the last

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decade [2,3]. Whole body vibration (WBV) provides harmless vibrations to the whole body including stimulated muscles [4,5]. Research on WBV has focused in the areas of sports and medical science. The effects of WBV include increased muscular strength, power, and jumping performance with muscular ability in untrained and elderly individuals, and in young trained subjects [6]. Other studies tested the effects of WBV on flexibility and they found positive effects [7,8]. Also, Park reported that WBV could change metabolic and physiological variables according to vibration frequency [9].

Positive effects of WBV have also been reported in rehabilitation, as well exercise effects. Also, there has been research in rehabilitation and treating elderly persons' diseases and preventing falls using WBV; positive effects on muscle strength, living ability, gait, and postural balance were reported [10,11]. Moreover, it was reported that WBV was helpful in osteoporosis, improving muscle strength and proprioception [12].

According to these effects, foundational studies on WBV have examined parameters such as frequency, amplitude, and duration [13]. WBV effects were accelerated by frequency and amplitude and stimulated human body exercise load [14,15]. A few studies reported significant effects of frequency or amplitude on muscle function [16,17]. Moreover, it was recently reported that WBV could provide a more efficient warm-up method to improve range of motion, compared with 'traditional' exercise methods, such as stretching [18–20].

To our knowledge, the WBV studies reported to date concern the effects on muscle function, flexibility, postural balance, and warm-up. There has been no study estimating the recovery effect, such as cool-down. Thus, this study was to investigate the recovery effect in terms of lactate level, medial frequency of muscular activity, and HRR according to WBV during rest after a gait exercise. We suggest that WBV could be an appropriate part of exercise cool-down.

2. Methods

2.1. Subjects

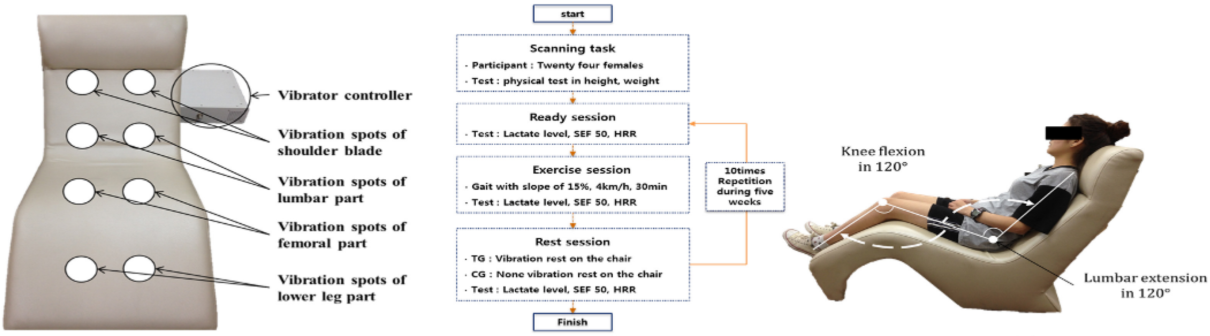
For this study, we recruited 24 healthy female subjects with no medical history related to the musculoskeletal system from exercise injury. They were divided into two groups, consisting of a training group and a control group. We provided the vibration during rest after a gait exercise in the training group (TG) and without vibration during rest in the control group (CG). Written informed consent conforming to the Declaration of Helsinki (1964) was obtained from all volunteers. After checking that no subject had any problem with WBV, we also checked for similar body weights, heights, life habits, and exercise habits.

2.2. Chair-type vibrator

All vibration and control protocols were performed on a developed vibrator. This platform produces up-to-down alternating vertical sinusoidal vibration in the chair using sonic waves. The vibrator could provide vibration with frequency from 10 to 50 Hz as 10 units, amplitude from 1 to 5 mm as 1 unit and duration time from 1 to 30 min as 1 unit. The locations of the vibration sources were eight spots: the shoulder blades, lumbar area, femoral area, and lower legs, left and right in Fig. 1(a).

2.3. Experimental procedure

We determined all subjects' ages, heights, and weights. They were divided into a training group with



(a) (b) (c)

Fig. 1. (a) Vibrations provided were up-to-down alternating vertical sinusoidal vibration in the chair using sonic waves and vibration spots, (b) Experimental procedure per session according to whole body vibration (WBV), (c) Vibration posture with angles of knee flexion and lumbar extension during the rest session in the chair-type vibrator.

WBV and a control group without vibration. The experimental procedure progressed in sequence: ready, exercise, and rest. In the ready session, we measured the lactate level in blood, spectral edge frequency (SEF) of maximal voluntary isometric contraction (MVIC), and heart rate recovery (HRR). In the exercise session, the subject exercised gait on a slope of 15%, a velocity of 4 km/h and a time of 30 min with no restriction. In the rest session, the training group rested on the vibrating chair with vibration but control group rested on it with no vibration during 30 min. After rest, we measured the lactate level and HRR to assess the recovery effect. We recommended all subjects to adopt the same posture during rest to minimize errors and all sessions were repeated 10 times over 5 weeks. The experimental environment was maintained with a constant room temperature at 20°C and humidity at 50% during all session in Fig. 1(b).

2.4. *Experimental protocol*

WBV and a control group without vibration. The experimental procedure progressed in sequence WBV loading was applied at a frequency of 10 Hz and amplitude of 5 mm. During all protocols, the subjects lay down on the chair with their lumbar region extended at 120° and knees flexed at 90° in the platform, as shown in Fig. 1(c). The subjects were asked to keep the same posture.

Measurements were performed of the three parameters: lactate level in blood, SEF of MVIC, and HRR test. First, to observe recovery from fatigue, we measured the lactate level in blood using an Accutrend plus (Cobas, Ltd., USA). We disinfected the surface of skin first using alcohol and then drew blood. The test for lactate levels was performed before exercise, immediately after exercise, and after rest for 30 min. Second, we measured SEF of MVIC in iliocostalis lumborum, rectus abdominis, rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius using a Delsys Bagnoli-8 EMG system.

Specifically, we measured and analyzed SEF 50. The spectral edge frequency is a measure used in signal processing. The SEF 50 is the frequency below which 50% of the total power of a given signal in located. Measuring postures were flying, crunch, toe-up, heel-up, and squat. In the flying posture, the subject raised her waist maximally for the iliocostalis lumborum, but kept her lower limbs on the floor. The crunch posture is a common abdominal exercise and primarily works the rectus abdominis muscle. The subject was face up on the floor with knees bent and curling the shoulders towards the pelvis, and the hands can be beside the neck. In the toe-up, the subject placed her toes with bearing weight on the heel. In the heel-up, the subject placed her heels with bearing weight on the toes. The squat was initiated

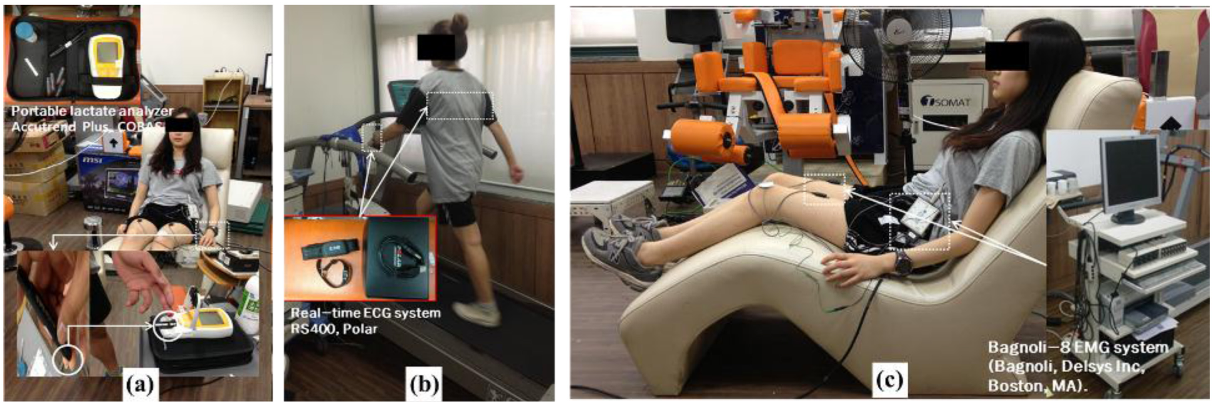


Fig. 2. Measurement performed in all sessions (a): measurement of blood lactate levels using a portable lactate analyzer, (b): measurement of HRR using a real-time ECG system, (c): measurement of SEF 50 for muscular activity using a real-time EMG system (Bagnoli, Delsys Inc., Boston, MA).

by moving the hips back and bending the knees and hips to lower the torso and accompanying weight, then returning to the upright position.

To observe the stabilizing body function, we tested the HRR parameter using a portable heart rate system (Polar RS400, POLAR, Ltd., USA) every 10 min. The heart rate system was located at the center of chest and subjects wore a watch for checking the heart rate. We checked and recorded the variation in heart rate during all sessions every 10 min. All sessions – test, exercise, and rest – were repeated 10 times, 2 days per week for 5 weeks (Fig. 2).

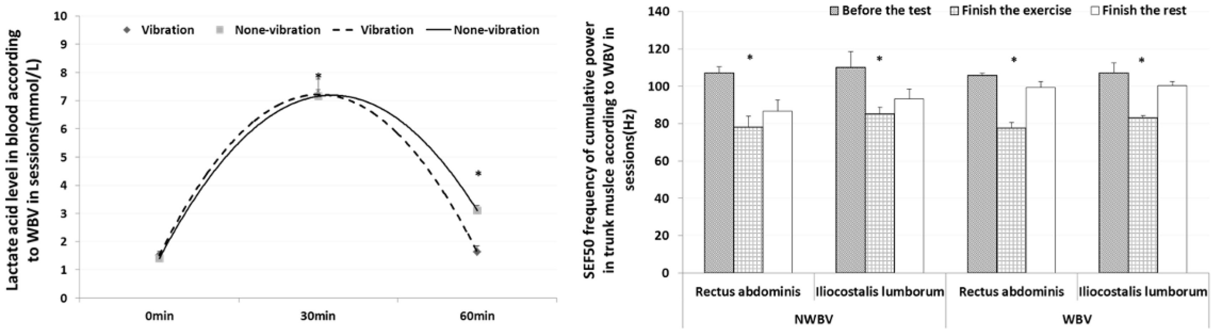
2.5. Statistical analysis

To observe recovery after fatigue, we measured lactate levels and HRR according to WBV use during rest. Statistical analyses were conducted using the SPSS software (ver. 18.0 for Windows; SPSS Inc., Chicago, IL, USA). Means and standard deviations (SD) were calculated for all variables. For each, the systematic change among the three trials was tested using a paired Student's t-test, and quantified from within-group differences. *Post hoc* Tukey tests, modified for repeated measures, were used to determine where significant differences occurred. Statistical significance was set at $^{*}p \leqslant 0.05$.

3. Results

3.1. Changes in blood lactate levels according to WBV in the rest session between the training and control groups

The blood lactate level results showed that it decreased faster when providing WBV during rest in the training group than in the control group. Before exercise (ready session), the participants' lactate levels showed little few difference between groups at 0.11 ± 0.02 mmol/L. Immediately after exercise, the lactate level increased to 5.70 mmol/L (TG) and 5.76 mmol/L (CG) in both groups but with little difference between the groups. After the rest session, the lactate level in TG decreased from 7.21 ± 0.55 mmol/L (end of exercise) to 1.63 ± 0.21 mmol/L (end of rest), 77.45%, for the group provided with whole body vibration. However, the lactate level in the control group showed a smaller decrease, from 7.15 ± 0.73 mmol/L to 3.11 ± 0.51 mmol/L, 56.61%. Thus, there was a large difference in the reduction ratio, over 20%, between the groups according to WBV (Fig. 3a).



(a) (b)

Fig. 3. (a) Variation in blood lactate levels according to WBV between groups (mean ± SD, $^{*}p < 0.05$), (b) Results of SEF 50 frequency of cumulative power for observing muscle fatigue in trunk muscles according to WBV (mean ± SD, $^{*}p < 0.05$).

3.2. Changes in the SEF 50 of MVIC in muscles according to WBV in the rest session between the training and control groups

We measured and analyzed SEF 50 of MVIC in muscles. Specifically, we assessed trunk muscles with the iliocostalis lumborum and rectus abdominis, femoral muscles with the rectus femoris and biceps femoris, and lower leg muscles with the tibialis anterior and gastrocnemius. The result of the rectus abdominis showed that the medial frequency was reduced at 26.75% (ready session: 105.83 ± 1.21 Hz, after exercise: 77.52 ± 3.13 Hz) in TG. With WBV, the medial frequency recovered to 28.18% (rest session: 99.37 ± 3.15 Hz) and muscular activity was at 93.89% in contrast with the ready session, for a recovery ratio at 159.14%. However, the medial frequency also reduced at 27.09% (ready session: 107.20 ± 3.21 Hz, after exercise: 78.15 ± 5.84 Hz) in CG. The medial frequency in static rest recovered at 10.87% (rest session: 86.65 ± 6.15 Hz). This shows less recovery of muscular activity at 80.83% versus the ready session. The results of the iliocostalis lumborum muscle showed that the medial frequency reduced at 26.75% (ready session: 107.25 ± 5.25 Hz, after exercise: 83.15 ± 1.16 Hz) in TG and 22.71% (ready session: 110.25 ± 8.21 Hz, after exercise: 85.21 ± 3.54 Hz) in CG. After rest, the medial frequency recovered at 9.43% (rest session: 93.25 ± 5.21 Hz), including muscular activity at 84.58% (Fig. 3b).

The results for the rectus femoris showed that the medial frequency was reduced at 15.35% (ready session: 92.5 ± 3.54 Hz, after exercise: 78.3 ± 2.54 Hz) in TG. After the rest session, the medial frequency recovered at 15.58% by WBV (rest session: 90.5 ± 1.21 Hz) in TG. The muscular activity recovered at 97.83% versus the ready session with a higher recovery ratio at 290.01% than static rest in CG. The medial frequency also reduced at 14.69% (ready session: 93.9 ± 1.22 Hz, after exercise: 80.1 ± 5.01 Hz) in CG. The medial frequency during static rest recovered at 3.99% (rest session: 83.3 ± 5.13 Hz). That showed less recovery of muscular activity at 88.71% versus the ready session. The results of the biceps femoris muscle showed that the medial frequency decreased at 15.24% (ready session: 102.3 ± 3.75 Hz, after exercise: 86.7 ± 3.36 Hz) in TG and 22.71% (ready session: 100.8 ± 3.56 Hz, after exercise: 85.3 ± 3.69 Hz) in CG. After rest, the medial frequency recovered at 10.14% (rest session: 95.5 ± 3.01 Hz) including muscular activity at 93.35% but 88.71% with recovery at 3.99% (rest session 83.3 ± 5.13 Hz) (Fig. 4a).

The result of the tibialis anterior showed that the medial frequency reduced at 14.04% (ready session: 96.10 ± 1.15 Hz, after exercise: 82.60 ± 3.21 Hz) in TG. After the rest session with WBV, the medial frequency recovered faster at 10.04% (rest session: 90.90 ± 2.54 Hz) than static rest in CG and the

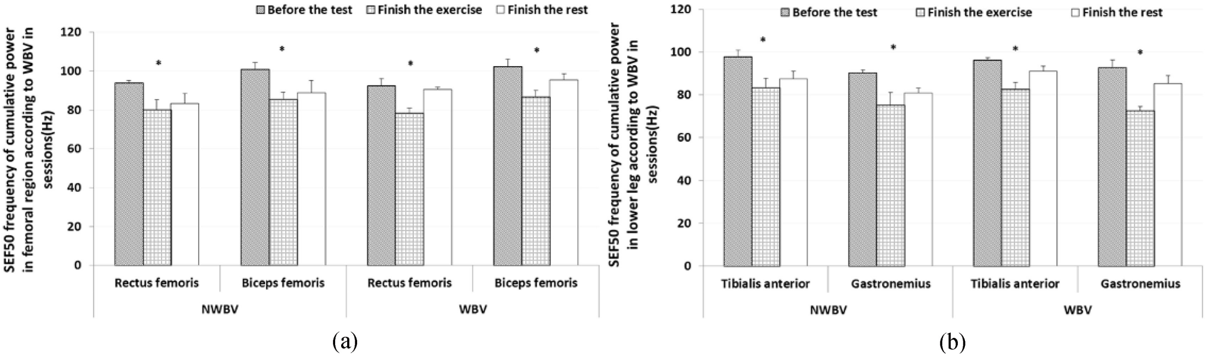


Fig. 4. Results of SEF 50 frequency of cumulative power for observing muscle fatigue according to WBV (mean ± SD, $^*p <$ 0.05) : (a) Femoral muscles, (b) Lower leg muscles.

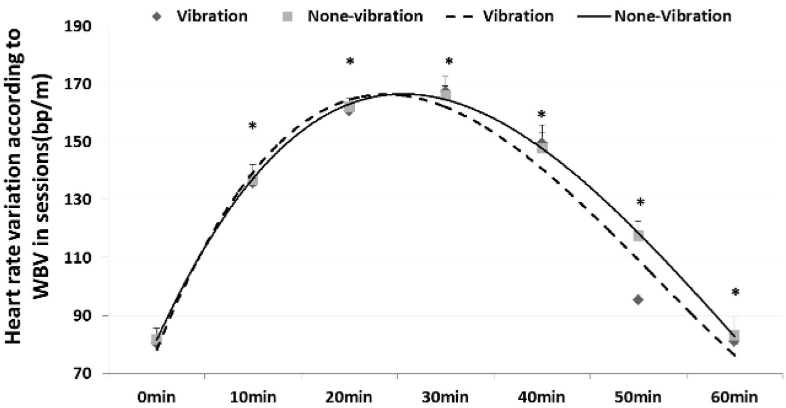


Fig. 5. Variation in heart rate according to WBV during rest after exercise between groups (mean ± SD, $^*p < 0.05$).

muscular activity was 94.58% compared with the ready session including a higher recovery ratio at 92.07%. However, the medial frequency in CG was reduced at 14.84% (ready session: 97.65 ± 3.15 Hz, after exercise: 83.15 ± 4.54 Hz) in CG. The medial frequency after static rest recovered at 5.23% (rest session: 87.50 ± 3.56 Hz). This showed a lower recovery ratio of muscular activity at 89.60% in CG. The results for the gastrocnemius showed that the medial frequency decreased at 21.79% (ready session: 92.7 ± 3.55 Hz, after exercise: 72.50 ± 2.16 Hz) in TG and 16.89% (ready session: 90.15 ± 1.54 Hz, after exercise: 75.01 ± 6.21 Hz) in CG. After rest, the medial frequency recovered at 17.51% (rest session 85.20 ± 3.87 Hz) including muscular activity at 91.90% in TG but 89.73% with recovery at 7.86% (rest session 80.90 ± 2.21 Hz) (Fig. 4b).

3.3. Changes in HRR according to WBV in the rest session between the training and control groups

The HRR results showed that it recovered faster by providing WBV in TG than static rest in CG. In the ready session, there was little difference in HRR at 2.25 ± 0.75 bp/min with 2.63% between the groups. During the exercise session, the HR of both groups increased to 108.33% (TG: 167.5 ± 5.13 bp/min, CG: 166.2 ± 3.13 bp/min) with little difference at 2.55–3.73% between groups (Fig. 5). There was little difference between groups in the first 10 min of the rest session. However, the results of HR showed different trends at 20 min. In TG, HR decreased quickly to 95.4 $\pm$ 2.01 bp/min with 43.04% in contrast to 117.5 $\pm$ 5.21 bp/min with 29.30% in CG.

4. Discussion

Previous studies on WBV focused mostly on improvement in body condition, such as muscle strength, postural balance, flexibility, and coordination ability. The whole-body vibration could improve peripheral blood flow [21], pressure wave reflection [22], and leg arterial stiffness [23]. The whole body vibration caused a reflex neuromuscular stimulation [24] and, increased venous return as result of an active muscle pump [25]. However, most of studies only reported exercise effects without examining recovery effects. In this research, we investigated the recovery effect in terms of lactate level, medial frequency of muscular activity, and HRR according to WBV during rest after a gait exercise. The main findings were that WBV in rest after exercise significantly decreased fatigue in the human body, as evidenced by blood lactate levels, muscular fatigues, and heart rate changes. Furthermore, the results demonstrated that rest, applying to WBV after exercise, could elicit cool down effects of different kinds in these parameters.

We demonstrated that WBV in rest after exercise could improve the recovery in terms of lactate level, muscular fatigue, and HRR function. In the case of HRR, the provision of WBV at 10 Hz in a supine position significantly decreased fatigue in the human body by 13.74%, in contrast to a previous study using WBV at 25 Hz [26]. We provided a supine condition as the rest posture to investigate HRR variation in contrast to seated or standing conditions in previous studies [27,28]. However, a higher heart rate within 5 min of active recovery following supramaximal and submaximal cycling exercise was likely attributable to the stimulatory influence of central commands [29]. Our research provided WBV during the rest session for active recovery using reflex neuromuscular reactions. We suggest that WBV frequency did not strongly affect the extent of HRR function but it maybe affect exposal posture. We thought that the faster reduction ratio of heart rate during rest session with WBV was due to increased venous return from active muscle pumps. During the rest session for recovery, parasympathetic reactivation occurred rapidly in the first minute of recovery and heart rate decreased gradually as parasympathetic tone was reactivated and sympathetic tone declinedc from exercise levels [30].

The results of lactate levels and SEF 50 supported that our hypothesis, like the HRR results. WBV during rest after exercise could provide a significantly faster recovery effect than routine rest. WBV may activate more efficient exercise recovery with continuous stimulus of blood vessels in the muscle. This stimulus could increase the use of lactate as energy for the heart and the activated muscles and cause the faster distribution of the lactate into liver. In this research, immediately after exercise (30 min), the results of lactate levels between groups showed little difference with an increase of 2.5 times each, but in the recovery session (60 min), the lactate level results in TG showed that WBV caused a faster recovery, by approximately three-fold, including a recovery ratio from fatigue at 92.71% in contrast with the reduction of 45.07% in CG. After exercise, WBV can provide positive effects; WBV stimulus reduced lactate levels quickly by increasing lactic acid oxidation levels by maintaining blood flow into muscles.

Our study supported two hypotheses that have been postulated to explain the possible physiological basis for the recovery effect of WBV in terms of changes in blood lactate levels, muscular fatigue, and HRR. The first has been linked to the WBV during the rest session after exercise, which may reduce muscle fatigue and stabilize the heart rate effectively. The second hypothesis is based on the irrelevancy of WBV to any positive effect in cool down function after exercise for providing faster reduction of lactate and improving HRR function. Future studies should examine more detailed vibration protocols in terms of frequency, amplitude, and exposure time to normalize the recovery effect of WBV with exercise intensity.

5. Conclusion

We estimated the recovery effect in terms of blood lactate levels, medial frequency of muscular activity, and HRR according to WBV during rest after gait exercise in young females. We suggest that WBV could be appropriate for exercise cool-down. The experimental results, which were consistent with the study hypothesis, showed that the WBV rest method could be used to successfully assess the efficient recovery effects on blood lactate, muscular fatigue, and HRR function. Moreover, the significantly improved recovery function observed in the young participants suggested that they could benefit more from this WBV rest method as part of cool down after exercise and that a recovery protocol could be developed for women, patients, and athletes.

Acknowledgments

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Conflict of interest

None to report.

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