様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　２ 年　 ６ 月 ２２ 日現在

機関番号：１５５０１
研究種目：基盤研究(C)（一般）
研究期間：2016～2019
課題番号：１６Ｋ０９１３２
研究課題名（和文）Changes in tactile perception, peripheral circulation and blood biomarkers induced by controlled vibration exposure in elderly Japanese

研究課題名（英文）Changes in tactile perception, peripheral circulation and blood biomarkers induced by controlled vibration exposure in elderly Japanese

研究代表者
Hossain Mahbub（HOSSAIN, Mahbub）

山口大学・大学院医学系研究科・講師

研究者番号：８０５３５３３６

交付決定額（研究期間全体）：（直接経費）　3,700,000円

研究成果の概要（和文）：実験で明らかにされた対応する対照値と比較して、WBVへの曝露は、特に15 Hzと20 Hzの曝露周波数で、母趾と踵での振動触覚知覚閾値の大幅な増加を引き起こした。しかし、振動触覚のこのような増加は、参加した高齢者の身体バランスと機能的可動性に有意な変化を引き起こさなかった。一方、WBVへの曝露は、すべての振動曝露条件下（15Hz、20 Hz、25 Hz）で末梢皮膚血流の有意な増加を引き起こし、最大増加は、25 Hzの曝露条件下であった。そのようなWBVでの心拍変動の要素に大きな変化を引き起こさず、末梢皮膚温度を低下させなかった。

研究成果の学術的意義や社会的意義
The current findings should be useful in: (1) inducing improvements in peripheral circulation among the elderly; (2) consideration of vibration parameters for improvements in body balance; 3) establishing the strategies for safe and effective use of whole-body vibration for therapeutic purposes.

研究成果の概要（英文）：According to the findings of our systematic review, we selected relatively lower magnitudes of acute whole-body vibration (WBV) exposure for investigation in the experimental study. As revealed in the experimental study, compared to the corresponding control values, exposure to WBV caused a significant increase in vibrotactile perception thresholds at the hallux and heel, especially at exposure frequencies of 15 Hz and 20 Hz. However, such increases in vibrotactile perception did not cause any significant change in body balance and functional mobility of elderly subjects participating in this study. On the other hand, exposure to WBV caused a significant increase in peripheral skin blood flow under all vibration exposure conditions (15Hz, 20 Hz, and 25 Hz); the increase was greater under the 25 Hz exposure condition. However, such exposure to WBV did not cause any significant change in the components of heart rate variability and did not decrease peripheral skin temperature.

研究分野：衛生学・公衆衛生学

キーワード：Whole-body vibration　Vibrotactile perception　Body balance　Skin blood flow　Skin temperature　Heart rate variability　Elderly

1. Background

Among the elderly, aging-related impairments in body balance and associated falls are a major public health concern as being the fifth leading cause of death and leading causes of fractures, serious soft tissue injuries, head trauma or other trauma-related morbidity and hospital admissions among them [1]. On the other hand, impairments in peripheral circulation are very common among the elderly and can cause delayed wound healing or impaired healing of soft tissue injuries, chronic wounds or ulcers, and pose increased risk for morbidity, loss of independence and reduced quality of life [2]. Without any preventive measures against these health disorders among the elderly, the related health care costs will continue to rise with the continued ageing of the world's population.

There is an urgent need to address the above-mentioned health issues among the elderly. A non-invasive intervention modality would be extremely beneficial to the elderly population which has the potential to induce improvements in both body balance and peripheral circulation. In this regard, a simple intervention using whole body vibration (WBV) device has been proposed as a safe, easy-to-use and suitable intervention modality, especially for the elderly who may be passive or physically weak, with limited mobility or physical disability, and unable to perform conventional active or high impact or strenuous physical exercise, or with contraindications to aerobic exercise [3,4].

As shown in the literature, exposure to WBV can cause stimulations of the plantar cutaneous mechanoreceptors with improvements in the latter and changes in body balance. Furthermore, such intervention with WBV has shown the potential to positively influence human peripheral circulation and improve sympathovagal balance. But a number of difficulties exist regarding the application of WBV for the mentioned purposes [4]. Firstly, for intervention with WBV, useful or optimum vibration parameters like frequency, amplitude and acceleration have not yet been established. Secondly, despite the existence of a large number of relevant studies, the findings seem inconsistent and inconclusive. For example, among older individuals, a number of studies observed WBV-induced improvements in body balance and lower limb peripheral circulation. On the other hand, other studies could not reveal such beneficial effects from exposure to WBV on body balance or peripheral circulation. Thirdly, widely variable study protocols among the investigators complicate the interpretation of the available study results. Fourthly, a number of those studies exposed human subjects to relatively high magnitudes of WBV which frequently exceeded the safe exposure limits recommended by the standards ISO 2631-1 [5] and EU Directive 2002/44/EU [6] for the purpose. Lastly, to our knowledge, no study has been conducted investigating the concomitant effects of exposure to WBV on tactile perception, body balance, peripheral circulation, and autonomic nervous activity among the elderly, with special consideration of WBV exposure values as recommended by the relevant international standards. All these make the application of WBV into practices extremely difficult.

2. Purpose of research

Considering the above-mentioned issues and controversies, the purposes of the current study were to examine the acute effects of intervention with exposure to WBV of different suitable frequencies on: a) vibrotactile perception threshold (VPT), balance and functional mobility, b) peripheral circulation, and c) heart rate variability (HRV) – among the elderly, with the vibration intensities defined according to the recommendations of the existing relevant standards, ISO 2631-1 (1997) and EU Directive 2002/44/EU (2002).

3. Materials and Methods

(1) At first, we conducted a systematic review to identify the safe and effective vibration parameters that can be used in our experimental study, in light of the recommended limits for such exposure. For this, we investigated the effects of controlled WBV intervention on peripheral circulation and ascertained the specific patterns of responses in the latter induced by acute and long-term exposure to WBV of different frequencies and magnitudes.

(2) We conducted a single-group, single blinded (participants) repeated measures study among the elderly subjects (aged 65 years and over). The protocol was approved by the relevant institutional review board of Yamaguchi University School of Medicine. A total of 30 subjects (males 15, females 15) were able to complete all the experimental sessions. All subjects provided written informed consent before participation.

Upon arrival for each experimental session, the subjects underwent acclimatization for a period of 15 min in the first experiment room with a room temperature maintained at around 24°C, while seated comfortably on a height-adjustable chair. Then the balance and mobility tests were conducted with regular footwear and socks. The following balance and mobility tests were performed in line with standard protocols: a) Static balance – one leg stance (OLS) test with eyes open and closed; b) Dynamic balance – parallel walk (PW) test and timed up and go (TUG) test; c) Mobility and functional lower limb muscle strength – 30 s chair stand (CS-30) test [4]. The measurements and counts were performed by a trained assistant. One min (2 min after the CS-30 test) of rest was allowed between tests with a rest period of approximately 30 s (2 min for the CS-30 test) between trials within a session when the participants were allowed to sit on a chair.

At the end of balance tests, the subjects moved to the next temperature-controlled (air temperature, 25.0±0.5°C) experiment room where they seated comfortably on a height-adjustable chair with the trouser rolled up to a level between the knees and heels, and the socks taken off. To measure skin temperature (ST) of the left foot, the sensor of the thermistor (SZL-64, Technol seven, Japan) was attached to the dorsal surface of the middle of left foot with adhesive tape. Then while seated, they underwent acclimatization for a period of 15 min, with the feet positioned on a wooden floor and both hands, on respective thighs. At the end of acclimatization period, 5-min measurements of HRV data were permoed using a portable battery-operated heart rate device (CheckMyHeart, DailyCare BioMedical, Inc., Taiwan) connected via electrode cables with self-adhesive disposable Ag/AgCl circular surface electrodes placed on the ventral side of subject's forearms. Following this, the baseline measurements of VPT were recorded. VPT (expressed in m/s^2) were measured at three locations: plantar aspect of the hallux, the base of the little toe, and the heel of the right leg, by using a commercially available vibrotactile perception meter (VPM, HVLab, University of Southampton, UK). Following this, the participants were asked to stand in complete upright posture, on the side-alternating vibration device. After ensuring a stable leg skin blood flow (SBF), the baseline value was recorded from the dorsal region of right foot, twice at an interval of 1 min, by a non-contact method using the Laser Speckle Flowgraphy system (LSFG-ANW, Softcare Co., LTD., Fukuoka, Japan.

After baseline SBF measurements, the subjects were instructed to stand with knees bent to an angle of about 30°, and position their feet on the platform parallel to each other, at a distance of 10.5 cm from the center of the platform. Then all the subjects underwent an intervention consisting of any of the following 4 exposure conditions: 1) WBV at 15 Hz, 2) WBV at 20 Hz, 3) WBV at 25 Hz, and 4) control condition (0 Hz). The peak-to-peak displacement of the vibrating platform was 4 mm. The unweighted and frequency-weighted peak accelerations were 17.75 m/s^2 and 9.64 m/s^2 rms, 31.56 m/s^2; and 14.19 m/s^2 rms, and 49.30 m/s^2 and 17.89 m/s^2 rms at 15 Hz, 20 Hz, and 25 Hz, respectively; the corresponding eight-hour energy-equivalent frequency-weighted acceleration or A(8) values were 0.76 m/s^2 rms, 1.12 m/s^2 rms, and 1.41 m/s^2 rms, respectively. WBV was produced using a commercially available side-alternating vibration device (Galileo 900, Novotec Medical GmbH, Pforzheim, Germany).

The 5-min intervention protocol consisted of three bouts of 1 min exposure separated by an interval of 1 min between the bouts. Just after the cessation of each bout of exposure, the subjects were asked to stand up quickly but smoothly and the measurements of SBF and ST were carried out. The subjects maintained the upright posture during the 2 interval periods of 1 min each between the bouts. The measurements of HRV were conducted during the 5-min intervention period.

After the completion of intervention, the participants maintained the upright position for further 1 min which was followed by the measurement of after-exposure SBF and ST. Following this, the subjects were seated again on the chair and measurements of VPT were conducted. Then the subjects moved to the other previous experimental room to undergo the balance tests after which the experimental session ended.

(3) Data processing and statistical analyses

For scanning of SBF, a circular region on the dorsum immediately proximal to the metatarsophalangeal joints and between the edges of the right foot was chosen (260-310 pixels, depending on the size of the foot) and the captured images were analyzed. The values of SBF and ST measured twice before intervention were averaged for each of the 4 exposure conditions and considered as the baseline values for the corresponding conditions. Also, for the balance and mobility tests, the results were calculated as the average of two trials. For HRV, the data for 3 min during 3 bouts of exposure were extracted and the following components (in milliseconds squared) were calculated for the detrended values of regular R-R interval data using the fast-Fourier-transformation (FFT): 1) high-frequency power (HF, 0.15 to 0.40 Hz), 2) low-frequency power (LF, 0.04 to 0.15 Hz), and 3) LF/HF (the ratio of low-to high-frequency power). The values of HF and LF were normalized as follows: (1) normalized HF or HFnu = HF ÷ (total power - VLF); and (2) normalized LF or LFnu = LF ÷ (total power - VLF), where VLF indicates very low frequency power (between 0.003 to 0.04 Hz) of HRV. Statistical analyses were performed by applying repeated measures ANOVA with Bonferroni adjustments for multiple comparisons, after logarithmic transformation of the collected data. The results have been reported in the original scale as geometric mean and corresponding 95% CI, after back transformation. All statistical tests were considered as two-tailed, and the significance level was set at $P<0.05$. The software package SPSS version 22 for Windows (SPSS Inc., Chicago, IL, USA) was used to perform the statistical analyses.

4. Results

(1) Results of the systematic review:

Overall, acute exposure to WBV of relatively lower frequency (especially between 20 Hz - 30 Hz) resulted in a consistent improvement in peripheral circulation. However, the long-term responses in peripheral circulation from chronic exposure to WBV did not show any particular pattern. Therefore, relatively lower magnitudes of acute exposure toWBV were selected for this experimental study, considering the human exposure limits recommended by the relevant international standards.

(2) Results of the experimental study:

The values of VPT obtained before and after intervention under 4 exposure conditions have been presented in Figure 1. Comparison between the before-intervention values at three test locations did not reveal any significant differences between the exposure conditions. After intervention, compared to the control value at the hallux, VPT increased significantly under 25 Hz vibration exposure condition only (P<0.01). Compared to the control value at the heel, the increase in VPT was significant under 15 Hz (P<0.05) and 20 Hz (P<0.005) exposure conditions, and the increase was notable under the 25 Hz condition (P=0.063). At the little finger, the after-intervention values of VPT under vibration conditions did not differ significantly from the control value.

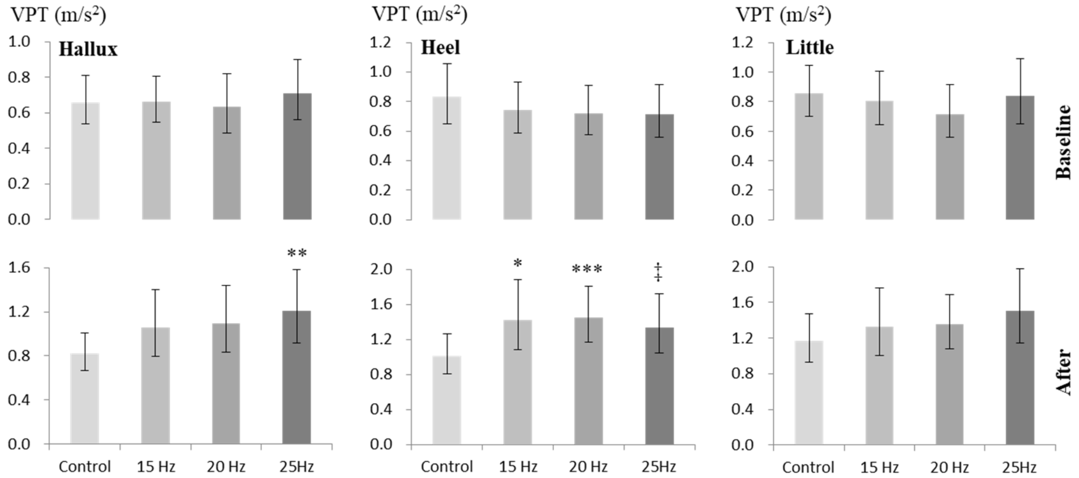

Figure 1. VPT (m/s^2) at the hallux, heel and little finger at baseline (upper panel) and after intervention (lower panel) under 4 different exposure conditions. Values are presented as geometric mean and 95% CI (shown as error bars). Levels of differences from the corresponding control values by repeated measures ANOVA with adjustments for multiple comparisons by Bonferroni corrections: ***P<0.005, **P<0.01, *P<0.05; ‡P=0.06.

Table 1 represents the effects of the intervention under 4 exposure conditions on the balance and mobility tests. Before intervention, the values for any of the tests did not differ significantly from the corresponding control values. Also, after intervention, no statistically significant improvements in those tests could be revealed as no significant difference from the corresponding control values was observed.

Table 1. The results of balance and mobility tests obtained before and after intervention under different exposure conditions. Values are shown as geometric mean (95% CI) (n=30)

Test	**Before/after**	**Control**	**15 Hz**	**20 Hz**	**25 Hz**
OLS, eyes	Before	25.1 (18.7-33.6)	28.8 (21.5-38.6)	27 (20.3-36.0)	26.1 (19.1-35.6)
open (s)	After	29.6 (23.5-37.4)	26.8 (19.2-37.4)	29 (22.9-36.6)	26.8 (19.4-37.1)
OLS, eyes	Before	3.7 (2.9-4.8)	3.3 (2.6-4.2)	4.0 (3.2-4.9)	3.4 (2.7-4.1)
closed (s)	After	3.7 (2.8-4.7)	3.6 (2.8-4.7)	4.3 (3.4-5.5)	3.8 (3.1-4.6)
PW	Before	4.6 (4.3-4.9)	4.5 (4.3-4.8)	4.7 (4.3-5.0)	4.5 (4.3-4.8)
(s)	After	4.6 (4.3-4.9)	4.5 (4.3-4.8)	4.4 (4.2-4.7)	4.4 (4.2-4.7)
TUG	Before	6.4 (6.1-6.7)	6.4 (6.0-6.7)	6.3 (6.0-6.7)	6.2 (5.9-6.6)
(s)	After	6.4 (6.1-6.8)	6.4 (6.0-6.7)	6.3 (6.0-6.6)	6.2 (5.9-6.6)
CS-30	Before	18.1 (16.4-19.9)	18.7 (17.1-20.5)	18.9 (17.0-21.1)	19.1 (17.4-21.0)
(repetitions)	After	18.6 (16.9-20.5)	19.1 (17.2-21.0)	19.1 (17.2-21.3)	20.0 (18.2-22.0)

The values of SBF obtained before, during (3 time points) and after exposure under each of the four exposure conditions have been displayed in Figure 2. The baseline values of SBF under the exposure conditions of 15-, 20- and 25-Hz did not differ significantly from the control value. But during intervention, compared to the corresponding control condition, WBV was associated with a significant increase in SBF under all 3 vibration exposure conditions at all 3 time points (P<0.001). When the comparison was limited between vibration exposure conditions only, compared to the corresponding values under 15 Hz condition, the increase in SBF showed significantly higher values at first 2 time points under 20 Hz condition (P<0.05 to 0.005) and at all 3 time points under 25 Hz condition (P<0.005 to 0.001). When the comparison was made between the latter conditions during exposure, a significantly greater increase in SBF was observed under the 25 Hz exposure condition at second and third time points during intervention (P<0.05 to 0.01). After intervention, compared to the control condition, the significant increase in SBF disappeared under the 15 Hz condition, but remained significantly elevated under two other vibration exposure conditions (P<0.001). When the comparison was made with the 15 Hz condition, SBF showed a significantly higher value under the 25 Hz exposure condition only (P<0.005). But after intervention, no statistically significant difference in SBF was observed between 20 Hz and 25 Hz exposure conditions.

No significant difference in ST could be revealed when the values under four exposure conditions were compared before, during and after intervention (results not shown). Also, the values of different components of HRV (LFnu, HFnu or LF/HF) did not show any significant difference before and during intervention (results not shown).

(3) Summary of results and their implications:

① Acute exposure of elderly subjects to WBV of 15-, 20- and 25-Hz with the same peak-to-peak displacement of 4 mm induced an improvement in peripheral SBF without exerting any negative effects on the autonomic nervous activity in the elderly, and caused a decrease in plantar cutaneous sensation without producing any changes in body balance.

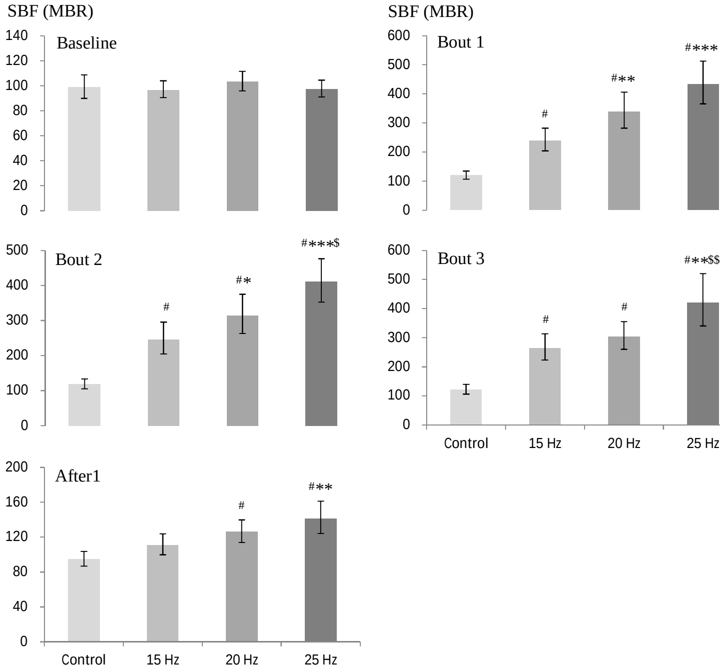

Figure 2. Comparison of SBF (MBR) between 4 exposure conditions at baseline (before), during (bouts 1, 2 and 3), and after exposure (n=30). Values are shown as geometric mean and 95% CI (shown as error bars). Levels of significant differences from the corresponding values by repeated measures ANOVA with adjustments for multiple comparisons by Bonferroni corrections: $^{\#}$P<0.001 versus control; ***P<0.001, **P <0.005 and *P<0.05 versus 15 Hz; $^{\$\$}$P<0.01 and $^{\$}$P<0.05 versus 20 Hz.

② For the purpose of increasing peripheral SBF, exposure to WBV of 20 Hz with a peak-to-peak displacement of 4 mm seems suitable as it generates a vibration magnitude that is within the recommended limit by ISO 2639-1 (1997) and EU Directive 2002/44/EU (2002).

③ The vibration magnitudes within the recommended limit and able to enhance peripheral SBF – might not be sufficient in inducing improvements in balance among the elderly.

④ The current findings should be useful in establishing the strategies for proper application of WBV and developing new guidelines by the relevant standards on safe and effective use of vibration-related parameters for the purpose of therapeutic exposure of human subjects to WBV in various pathological conditions.

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５．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計3件（うち招待講演　0件／うち国際学会　0件）

１．発表者名 Hossain Mahbub
２．発表標題 A review of exposure to whole-body vibration and associated changes in peripheral circulation
３．学会等名 第16回日本予防医学会学術総会，神戸
４．発表年 2018年

１．発表者名 Hossain Mahbub
２．発表標題 Therapeutic versus occupational exposure to whole-body vibration: a review in light of associated changes in peripheral circulation
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４．発表年 2018年

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２．発表標題 Therapeutic Exposure to Whole-Body Vibration and Changes in Peripheral Circulation: A Review
３．学会等名 第89回日本衛生学会学術総会,名古屋
４．発表年 2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
研究分担者	廣滋　恵一 (HIROSHIGE Keiichi) (20713225)	九州栄養福祉大学・リハビリテーション学部・准教授 (37122)	

６．研究組織（つづき）

	氏名 （研究者番号）	所属研究機関・部局・職 （機関番号）	備考
研究分担者	長谷　亮佑 (HASE Ryosuke) (30711262)	山口大学・大学院医学系研究科・講師 (15501)	