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Acute Effects of Hand-arm Vibration Exercise on Peripheral Circulation in Young Healthy Subjects

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Abstract We sought to investigate the effect of low frequency hand-arm vibration, from using a vibrating dumbbell, on blood flow in ventral and dorsal skin of the upper extremity. After 5-min baseline measurements of blood flow (BF), the subjects gripped the handle of a dumbbell vertically for two exposure periods (without and with isometric handgrip condition for 5 min and 3 min, respectively) separated by a 5-min rest-period. This was followed by a 15-min recovery period. During both exposure periods, subjects were exposed to three randomized experimental conditions: i) vibration exposure at 15 Hz; ii) vibration exposure at 30 Hz; and iii) no vibration or control condition. Overall, under both 15 Hz and 30 Hz vibration conditions, BF increased significantly during both periods of exposure and exposure with isometric handgrip conditions; the increase in percentage BF was found to be significantly more with exposure to vibration combined with isometric handgrip than with exposure to vibration only. However, exposure to 30 Hz hand-arm vibration was associated with the appearance of vesicles in 50% subjects. These data suggest that low-frequency hand-arm vibration exercise at 15 Hz may be used as a non-invasive method in increasing peripheral skin circulation.

Key words: hand-arm vibration, exercise, peripheral circulation

Introduction

Occupational exposure to hand-arm (especially high frequency) or whole-body (especially low frequency) vibration may lead to the development of various health disorders. In contrast, controlled exposure to vibration may induce various beneficial effects on human body.¹ Such beneficial effects of vibration have been shown in both healthy (athletes) and diseased (e.g. multiple sclerosis, osteoporosis, Parkinson's etc) populations. Application of short-term low frequency vibration has been shown to induce improvements in peripheral circulation without altering heart rate or blood pressure,²⁻⁴ and may contribute to the treatment of diseases with

vascular spasms. Most of the previously published studies used a low vibration frequency ranging between 10 Hz and 30 Hz. The method of increasing peripheral circulation by applying vibration would be beneficial clinically to populations with ulcerations and impaired healing of the limbs and also in populations where aerobic exercise is contraindicated or not feasible.³ Furthermore, vibration may be a better method for increasing skin blood flow compared to other methods, which can lead to serious burns (hot packs) or medication side effects.⁴

A number of researchers have investigated the influence of vibration on peripheral skin circulation; but the results are conflicting.³⁻⁵ Furthermore, due to the anatomical differences

in glabrous and nonglabrous skin, there may be differences in circulatory responses to vibration exposure between these two regions.⁵ There is a dearth of research works investigating the simultaneous effects of low frequency hand-arm vibration on both ventral (glabrous) and dorsal (nonglabrous) skin circulation in the extremities.

Now-a-days, a number of commercial vibrating devices have been developed for exercise and physical therapy. For upper-body exercise, vibrating dumbbells are available which can be suspended and combined with weight stacks.⁶ The purpose of the current study was to investigate the effect of low frequency hand-arm vibration, from using a vibrating dumbbell, on blood flow in ventral (glabrous) and dorsal (nonglabrous) skin of the upper extremity.

Materials and Methods

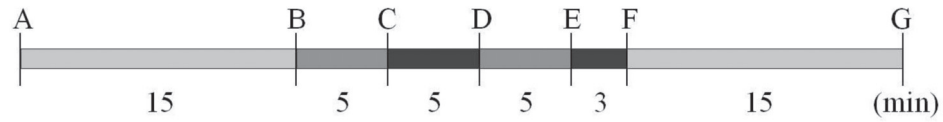
Six healthy nonsmoking normotensive male student volunteers participated in this study (age 22.3 ± 0.47 years, and BMI 21.7 ± 1.63 kg/m²). The subjects were without any vascular or neurological disease or on medication likely to influence vascular tone. After verbal explanation of the experimental procedure, written informed consent was obtained from all of them to participate in this study. The subjects refrained from eating and drinking tea or coffee for at least 2 h before the beginning of the experiment and they put on light clothing in the laboratory. Approval of the institutional review board of Yamaguchi University School of Medicine was obtained for this study.

Experimental design

The protocol and experimental set-up of this experiment are shown schematically in Figures 1 and 2, respectively. Initially, all the subjects underwent acclimatization for a period of 20 min in the temperature-controlled experiment room, seated comfortably on a height adjustable chair. After 5 min from the beginning of adaptation, measurement of nondominant (all left) arm blood pressure (NABP) was taken by an auscultatory technique (first measurement). After 15 min of adaptation period, the subjects positioned

their both hands approximately at heart level with palm down on a wooden table. Then sensors of the blood flow meter were fixed at two locations: to the ventral skin, 3 cm distal and 1 cm medial from the center of the elbow, and to the dorsal skin, 12 cm proximal from the center of the wrist joint of the dominant forearm. The sensors were fixed with adhesive tape without tape tension not to compress the tissue. After ensuring stable finger circulation for a period of 3 min, baseline values of blood flow (BF) were recorded at the ventral and dorsal skin for 5 min. Then the subject gripped the handle of the dumbbell, placed vertically on the wooden table (Fig. 2A), for 5 min. While the subject gripped the handle, his hand was exposed to vibration (exposure period). After vibration exposure the subject released the hands from the dumbbell and kept them on the table in a relaxed position for 5 min. Then the subject was asked to hold the vertical handle of the dumbbell with the dominant hand in an isometric handgrip condition (Fig. 2B), by the side of his body (angle at elbow joint approximately 90°) for 3 min. During this period, the subject was exposed to vibration of the same frequency as in the previous exposure period (hence, called exposure + handgrip period). Then he released the hand from the handle and kept his hand on the table for further 15 min (recovery period). At the beginning of recovery period, NABP was measured (second measurement) again. By the end of the recovery period, the third measurement of NABP was taken. Measurements of BF were continued to be recorded at 30-sec intervals during all these periods.

In the present experiment, the subjects were exposed to three experimental conditions: vibration at two frequencies of 15 Hz and 30 Hz, and control). The control experimental session was identical, but without exposure to vibration. Each of the three experimental conditions (control and vibration at two frequencies) was presented in a random order and performed on separate days for each of the subjects. The tests were conducted in a temperature-controlled experiment room with an ambient air temperature of around $28 \pm 1^\circ\text{C}$. Before gripping, the surface temperature of the handle was around $28 \pm 1^\circ\text{C}$.



- A: start
- A-B: acclimatization and measurement of BP
- B: setting sensors
- B-C: baseline measurements of BF (5 min)
- C-D: exposure (with or without vibration) for 5 min and measurement
- D-E: rest (5 min) and measurement
- E-F: exposure + isometric handgrip (3 min) and measurement
- F: cessation of vibration and measurements (also BP)
- F-G: recovery (15 min) and measurement
- G: measurement of BP

Fig. 1 The protocol of the experiment.

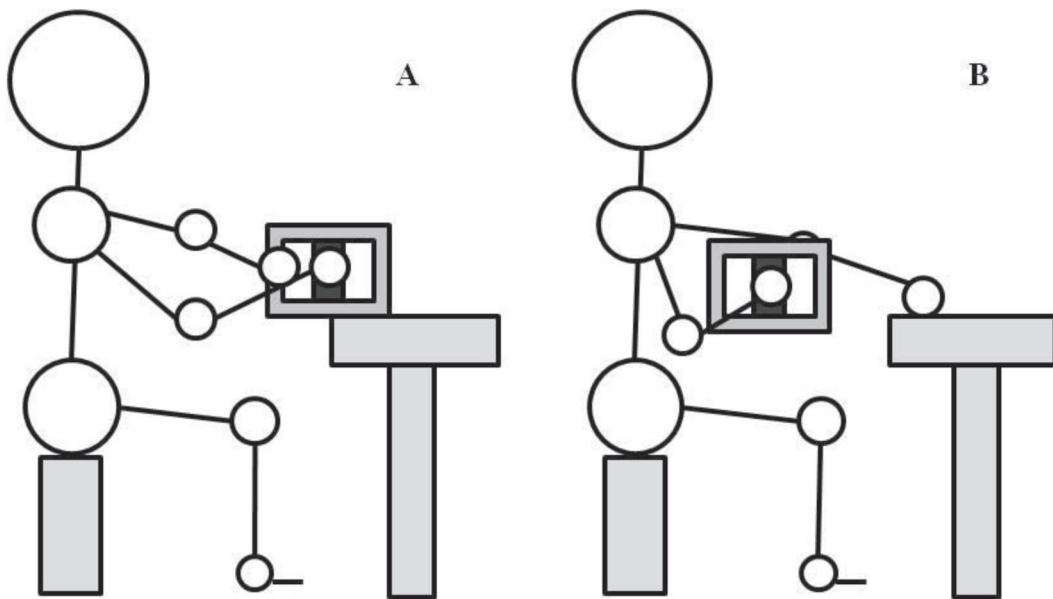


Fig. 2 Experimental set-up.

Equipments

A laser Doppler blood flowmeter (ALF21, Advance, Japan) was used to measure BF (ml/100 g/min). Room temperature was measured by using digital thermistors (D317, Takara, Japan). Vibration was delivered by a commercial handheld vibrating dumbbell (Galileo Up-X Dumbbell, Novotec Medical GmbH, Pforzheim, Germany), which can generate vibrations between 5 Hz and 30 Hz.

Statistical analysis

Percentage BF at each 30 sec during and after exposure was calculated against the corresponding mean baseline values (5-min data). Statistical analysis was performed with percent BF data using the average value of each period for each subject. Repeated measures ANOVA with Bonferroni correction for multiple comparisons was used to test the difference of responses between different exposure conditions during different periods (baseline, exposure, rest, exposure + isometric handgrip, and the 15 min of recovery divided into 3 equal periods). One subject's data for the dorsal side were not included in the analysis due to abnormally high baseline values at 30 Hz. SPSS statistical software version 16.0 was used for the analysis. Values are shown in text, tables and figures as mean with SE. Statistical significance was set at $P < 0.05$.

Results

The average values of baseline BF from both ventral and dorsal sides for each of the three exposure conditions are presented in Table 1. Data analysis including these values revealed that the values of BF under the conditions of 15 Hz and 30 Hz did not differ

significantly from the corresponding control value at both ventral and dorsal sides.

Percentage BF (calculated using corresponding baseline values) at every 30 sec under different exposure conditions in both the ventral and dorsal skin regions are shown in Figures 3 and 4, respectively. In general, during exposure and exposure + handgrip periods with vibration at 15 Hz and 30 Hz, BF showed an increasing pattern at both sides, which was not observed under the control condition.

Compared to the control condition in the ventral skin, the increase in percentage BF was significant during exposure and exposure + handgrip periods under both 15 Hz and 30 Hz ($P < 0.05 - 0.005$) exposure conditions except during exposure + handgrip period at 15 Hz which tended to be significant ($P = 0.063$) (Fig. 5). The increase in percentage BF in the ventral skin was found to be significantly more with exposure to vibration combined with isometric handgrip than with exposure to vibration only at 30 Hz ($P < 0.005$), and tended to be significant at 15 Hz ($P = 0.071$) (Fig. 5). On the other hand, compared to the control condition in the dorsal skin, percentage BF showed a significant increase during exposure and exposure + handgrip periods under both 15 Hz and 30 Hz ($P < 0.05 - 0.005$) exposure conditions except during exposure period at 30 Hz which tended to be significant ($P = 0.051$) (Fig. 6). In the dorsal skin, percentage BF increased significantly more with exposure to vibration combined with isometric handgrip than with exposure to vibration only at both 15 Hz and 30 Hz ($P < 0.05 - 0.005$) (Fig. 6). Repeated measures ANOVA showed that across different experimental conditions, the mean systolic or diastolic blood pressure did not differ signifi-

Table 1 Baseline BF (ml/100g/min) from both ventral and dorsal sides under three exposure conditions (N = 6)

	Control	15 Hz	30 Hz
Skin			
Ventral	3.46 ± 1.06	3.54 ± 1.41	3.92 ± 1.72
Dorsal [§]	3.21 ± 0.93	3.54 ± 0.42	3.73 ± 1.20

Values are shown as mean ± SD.

[§] Data for 5 subjects has been used for the dorsal skin.

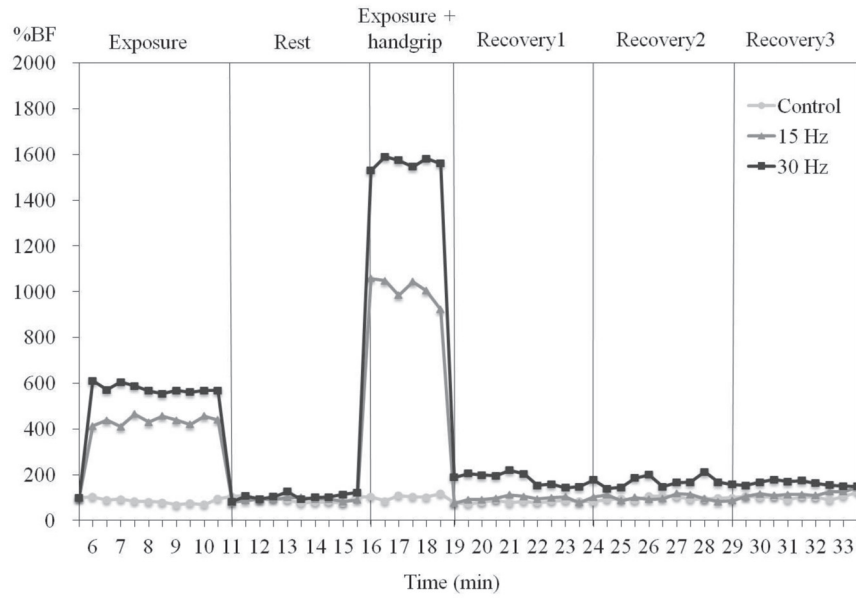


Fig. 3 Mean changes in ventral BF (ml/100 g/min) at each 30-sec interval under different exposure conditions. Data are shown for 6 subjects.

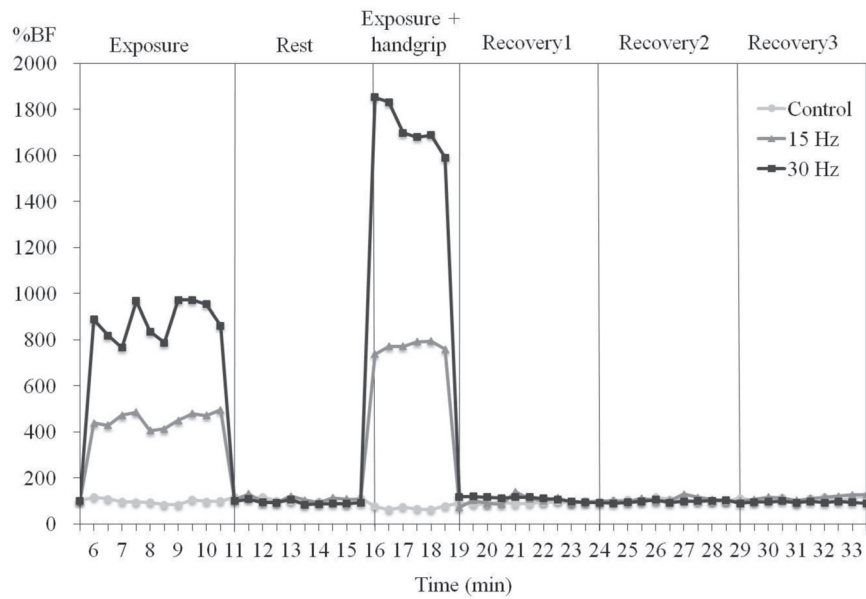


Fig. 4 Mean changes in dorsal BF (ml/100 g/min) at each 30-sec interval under different exposure conditions. Data are shown for 5 subjects.

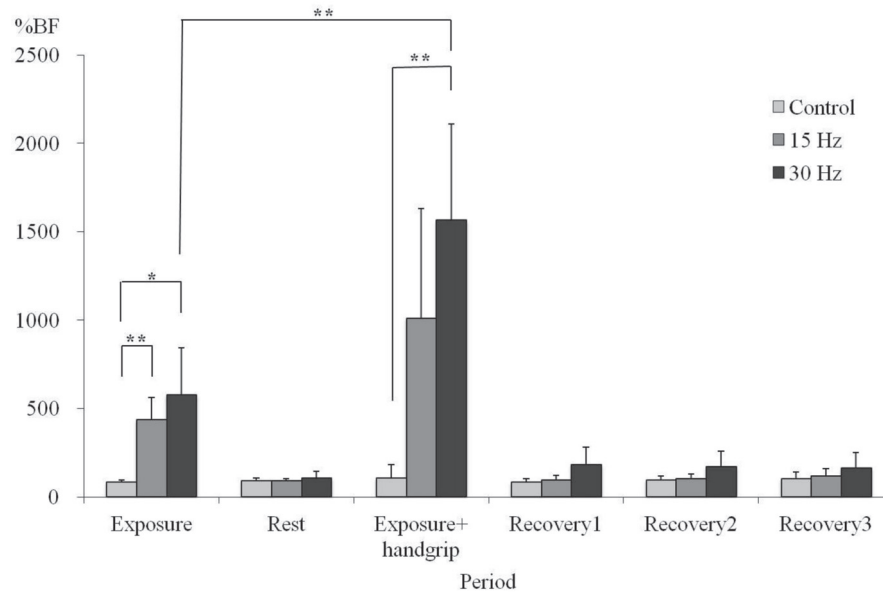


Fig. 5 Ventral %BF during different periods under 3 exposure conditions. Values are shown as mean + SE for 6 subjects. Significantly different from the corresponding control value or the value during exposure to vibration only: *P < 0.05 and **P < 0.005.

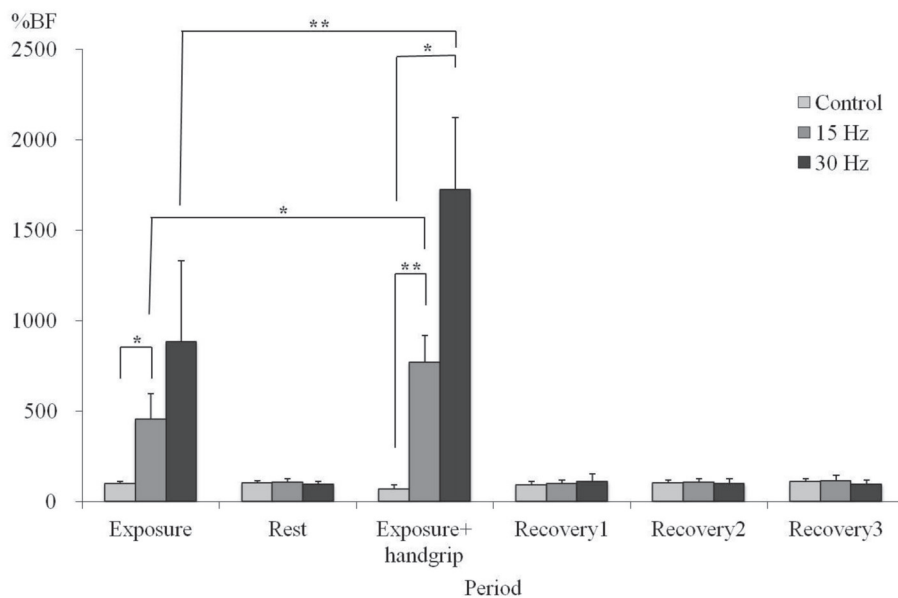


Fig. 6 Dorsal %BF during different periods under 3 exposure conditions. Values are shown as mean + SE for 6 subjects. Significantly different from the corresponding control value or the value during exposure to vibration only: *P < 0.05 and **P < 0.005.

cantly between different time points (results not shown).

Discussion

Application of vibration has been shown to be a method of increasing peripheral circulation; but there is a lack of consensus on optimal frequency, exposure pattern (continuous or intermittent) and duration of such exposure necessary for the desired increase in skin circulation. In the previous research works, the influence of vibration exposure on peripheral circulation has been investigated with vibration frequencies between 5 to 45 Hz and an exposure duration of 3 to 30 min. In this work, we investigated the influence of low frequency hand-arm vibration (15 Hz and 30 Hz with a frequency-weighted r.m.s. acceleration of 25.1 and 60.2 m/s² r.m.s., respectively), from using a vibrating dumbbell, on blood flow of the upper extremity in ventral (glabrous) and dorsal (nonglabrous) skin.

The previously published reports investigating the peripheral circulatory function with exposure of subjects to hand-arm vibration are conflicting. Several investigators identified that vibration produced vasodilatation and an increase in the skin circulation of the upper and lower extremities,^{3-5,7-9} while others exhibited a decrease in local circulation of the upper extremity from such exposure.¹⁰⁻¹³ The magnitude and frequency of vibration, and the type of vibration exposure (from a handle or plate) might have played roles in inducing different responses in peripheral circulation. Our study demonstrated an increase in peripheral skin circulation from exposure to low-frequency hand-arm vibration from grasping a vibrating dumbbell.

As shown in our investigation, significant increase in skin BF was observed at the ventral and dorsal skin under both 15 Hz and 30 Hz hand-arm vibration exposure conditions. The increase in peripheral skin BF was more with exposure to vibration combined with handgrip than with exposure to vibration only. However, the increased BF returned to the baseline shortly after the cessation of vibration. Such an increase in skin blood flow from exposure to vibration and rapid decrease during the post-vibration period is

consistent with the findings of other studies from acute exposure to short-duration hand-arm vibration from grasping a vibrating handle.^{5,14} Maloney-Hinds et al. also reported a rapid decrease in skin BF after passive vibration with 30 Hz. A longer duration of exposure or repeated exposure may be needed to maintain an increase in skin BF for a longer duration after the termination of exposure to vibration.

Vasodilatation during vibration exposure is thought to be caused by the inhibitory effect of vibration on adrenoceptors.¹⁵ In a study, Nakamura et al. theorized that a reduction in vasoconstrictor endothelin release caused by vibration exposure from vascular smooth muscle into the vessel cavity led to vasodilation, possibly attributable to a local axon reflex.⁹ It has been postulated that withdrawal in sympathetic nerve activity is possibly involved in a complex mechanism resulting in the elevation of peripheral vasodilation from low-frequency vibration exposure.^{16,17} Such observed response induced by exposure to hand-arm vibration is consistent with other research works.^{3,4} In this study, the increase in skin BF during exposure to vibration without or with handgrip condition was higher than that observed in the study of Maloney-Hinds et al. This may be explained by the fact that in the study of Maloney-Hinds et al., passive vibration was applied, whereas in this study, the vibrating dumbbell was actively held by the subjects.

Overall, exposure to both 15 Hz and 30 Hz frequencies of vibration could induce an increase in peripheral circulation in this study; exposure to vibration combined with handgrip induced more increase in skin BF than exposure to vibration only. However, exposure to 30 Hz hand-arm vibration was associated with the appearance of vesicles (Fig. 7) in 50% subjects. Besides, exposure to 30 Hz vibration was not comfortable to the subjects. Therefore, an exposure to a vibration frequency of 15 Hz may be used for the mentioned purpose.

In this experiment, we adopted a 3-min period for the exposure with isometric handgrip condition. In our preliminary experiments, we found it difficult to keep the dumbbell (with a weight of 2.6 kg) in ap-



Fig. 7 Vesicle on the palm after exposure to vibration at 30 Hz.

appropriate posture during a longer exposure period. Vibration exposure in this study did not induce any significant change in blood pressure, which indicates the physiological stability of the subjects with the current level of vibration magnitude.

There are several possible limitations to the findings of this study. The number of investigated subjects was relatively small and only two low frequencies of vibration were investigated. The nature of the generated vibration (sinusoidal or not) was also not identified. Therefore, the study results should be interpreted in the light of such limitations.

Conclusion

From the observed findings of this study, it can be concluded that exposure to low-frequency hand-arm vibration can induce an increase in peripheral blood flow. It has practical implication in wound healing among patients with peripheral circulatory disorders. Future studies are necessary to investigate and compare the peripheral circulatory responses to vibration in both ventral and dorsal skin, using larger samples of population including both patients with reduced peripheral circulation and healthy subjects.

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Conflict of Interest

The authors state no conflict of interest.

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