J Occup Health 2007; 49: 165–171

Journal of Occupational Health

Assessing the Influence of Antivibration Glove on Digital Vascular Responses to Acute Hand-arm Vibration

Md H. MAHBUB, Kenjiro YOKOYAMA, Md S. LASKAR, Masaiwa INOUE, Yukio TAKAHASHI, Shinji YAMAMOTO and Noriaki HARADA

Department of Hygiene, Yamaguchi University School of Medicine, Japan

Abstract: Assessing the Influence of Antivibration Glove on Digital Vascular Responses to Acute Hand-arm Vibration: Md H. MAHBUB, *et al.* Department of Hygiene, Yamaguchi University School of Medicine—This study was designed to assess the influence of an antivibration glove on digital vascular responses in healthy subjects exposed to short-term grasping of a vibrating handle. To measure finger blood flow (FBF) and finger skin temperature (FST) once at the end of every min, a blood flowmeter sensor was attached to the dorsum and a thermistor sensor was attached to the medial surface of the subject's middle phalanx of the third finger of the right hand. After 5 min of baseline measurements without or with an antivibration glove meeting ISO standard 10819, worn on the right hand, subjects gripped a vibrating handle with the same hand for a period of 5 min. Vibration was generated at two frequencies of 31.5 Hz and 250 Hz with a frequency weighted rms acceleration of 5.5 m/s^2. FBF and FST continued to be recorded for a further 5 min after release of the vibrating handle. Statistical analysis showed no significant change after vibration exposure in either FST or FBF at 250 Hz, compared to baseline (control) measurements while using the antivibration glove. At 31.5 Hz, FBF data exhibited a significant difference between before and after grasping of vibrating handle, which was less under the condition of wearing the antivibration glove than under the condition of bare hand. The results provide evidence that the antivibration glove considerably influenced finger vascular changes in healthy subjects induced by vibration exposure, especially against high frequency vibration. Further studies are required to assess finger vascular responses to hand-transmitted vibration with antivibration gloves of different manufacturers.
(J Occup Health 2007; 49: 165–171)

Key words: Finger vascular response, Influence, Vibration, Antivibration glove

Hand-arm vibration syndrome (HAVS), a chronic progressive disease of occupational origin, occurs after prolonged use of vibrating hand-held powered tools[1–3]. It results from the transfer of mechanical vibrations from the equipment to the hand and arm during vibration-intensive work. To prevent HAVS, reduction of the vibration energy from a tool transmitted to the arm and hand is thought of as an effective approach[4, 5]. Over the recent years, steady improvements have been made in the design of effective antivibration gloves for use while operating hand-held vibrating tools. According to the International Standard ISO 10819[6] an antivibration glove must have an ISO weighted average transmissibility of less than 1.0 in the medium frequency range (i.e. $\overline{TR}_M<1.0$), and less than 0.6 in the high frequency range (i.e. $\overline{TR}_H<0.6$). The antivibration gloves with lower vibration transmissibilities are considered more effective. The standardized test method, established by ISO, has been used by different researchers to evaluate vibration isolation properties of antivibration gloves[7–10].

Vibration-induced white finger (VWF), which is the most common and the best known digital vascular component of HAVS, usually starts at the fingers or fingertips[5, 11]. Therefore, the fingers are very vulnerable to hand-transmitted vibration injury. Vibration from various tools is transmitted to the hand through both the palm and fingers; but the measurement of the vibration transmissibility of an antivibration glove is performed at the palm, as specified in ISO 10819, not at the fingers. In several previous studies it has been established that exposure to vibration can significantly affect digital vascular responses in subjects exposed to hand-arm vibration[12–15]. In order to design a better antivibration glove, it is important to understand the role of it on digital circulatory changes induced by vibration. However, few reports have investigated digital vascular responses to

Received Oct 18, 2006; Accepted Jan 29, 2007
Correspondence to: N. Harada, Department of Hygiene, Yamaguchi University School of Medicine, 1–1–1, Minami-Kogushi, Ube, Yamaguchi 755-8505, Japan (e-mail: harada@yamaguchi-u.ac.jp)

vibration while wearing an antivibration glove. The effectiveness of an antivibration glove is specific to the spectrum of vibration[7, 16]. In ISO 10819 (1996), the standard defines the test procedure including the measurement of the vibration transmissibilities of a glove for medium and high frequencies. The more effective antivibration gloves are those which can damp and attenuate vibration frequencies of all spectra. The aim of this study was to evaluate the influence of an antivibration glove by measuring changes in both finger blood flow (FBF) and finger skin temperature (FST) induced by acute exposure to hand-transmitted vibration of two input frequencies representing medium and high frequency spectra.

Subjects and Methods

For this study six healthy nonsmoking male medical students (mean age ± SD, 24.4 ± 1.8 yr; mean BMI ± SD, 20.9 ± 1.6 kg/m^2) were recruited. Each of them attended four experimental sessions. The sizes of the gloves were 8 and 9[17]. None of the subjects had known vascular or neurological disease or was on medication likely to influence vascular tone. The test procedure of the present study was explained to each of the subjects prior to the experiment and written informed consent was obtained from all of them to participate in this study. The subjects were instructed to refrain from eating and drinking tea or coffee for at least 2 h before the beginning of the experimental sessions and to put on light clothing in the laboratory. Approval of the institutional review board of Yamaguchi University School of Medicine was obtained for this study.

In this study, vibration was produced at two frequencies of 31.5 Hz and 250 Hz, with a frequency weighted rms acceleration of 5.5 m/s^2. Most vibrating powered tools typically generate dominant vibration within the frequency range of 25 to 250 Hz[18], and the effect of vibration on the human body depends on factors including the frequency of vibration[7, 16]. In the research work by Furuta *et al.*[19] marked changes in FBF were demonstrated at frequencies of 31.5–63 Hz and 250–500Hz. In a recent study including three vibration frequencies of 16 Hz, 31.5 Hz and 63 Hz, autonomic nervous activity was found to be enhanced by vibration at 31.5 Hz[20]. Mountcastle *et al.*[21] found an optimal frequency of 30–40 Hz, to which cutaneous movement detectors like Meissner's corpuscles were sensitive. In the case of Pacinian corpuscles this frequency was near 200 Hz[21–23]. Lundstrom[24] found that Pacinian corpuscles were easily activated at 250 Hz and Meissner's corpuscles at 30 Hz. In consideration of these reports, frequencies of 31.5 Hz and 250 Hz representing medium and high frequencies as mentioned in ISO 10819 (1996), respectively, were used in the present experiment. At each frequency, measurements were made both with and without use of the antivibration glove (bare hand). To protect the subjects from the noise of vibration ear plugs were used.

The investigation was conducted using a commercially available antivibration glove (containing shock absorbent molded-in Gelfom padding in the palm and finger areas with nitrile coating) with $\overline{TR}_M$=0.90 and $\overline{TR}_H$=0.52, which meets the requirements of an antivibration glove as defined by ISO 10819. A hole was made on the back of gloves corresponding to the dorsal part of the mid-phalanx of the middle finger, to set the sensor for measuring FBF. The same glove of size 8 was worn by four subjects and a glove of size 9 was worn by the other two. The sequence of the four experimental conditions was presented in a random order for each test subject, and measurements for each of the four experimental conditions were performed on separate days for each of the subjects. All the tests were conducted in a temperature controlled experiment room with an air temperature of 21 ± 1°C. The surface temperature of the vibrating handle was maintained at 21 ± 0.5°C.

A duralumin cylindrical vertical handle (length 15 cm, diameter 4.0 cm) was mounted on the vibrating plate of an electromagnetic shaker (MES652, Akashi, Japan), which was connected to a computer-controlled power amplifier (S · DA, Akashi, Japan). A pick up was rigidly fitted to the handle, and the vibration level of this handle was continuously monitored with a vibration meter (VM-20A, Rion, Japan) to ensure a controlled vibration exposure. To display grip force a strain gauge was fixed on the handle and was connected to a strain indicator (CDV-700A, Kyowa, Japan). To maintain a constant temperature on the surface of the handle it had a columnar space in the middle, through which water of the desired temperature flowed from a water circulation control device (UA-100G, Tokyo Rikakikai, Japan), To measure FBF, a blood flowmeter (TGA-2, Biomedical science, Japan) with a sensor based on the thermal diffusion method was used. FST and handle temperature were measured by using digital thermistors (High accurate data logger K730, Technol seven, Japan).

Upon arrival, all the subjects underwent acclimatization in the temperature-controlled experiment room and sat comfortably on a height adjustable chair without physiological or psychological stress. They positioned their hands approximately at heart level, palm down on a wooden table. After 30 min of acclimatization, the thermistor sensor was attached to the medial surface and the blood flowmeter sensor was attached to the dorsum of the subject's middle phalanx of the third finger of the right hand with adhesive tape without tape tension so as not to compress the tissue. The antivibration glove was put on, according to experimental order, before setting the latter sensor. After ensuring stable FBF and FST for a 3 min period, baseline (pre-exposure) values were recorded for 5 min. Then the subjects were asked to grip

Table 1. Average FBF (ml/100 g/min) at every min in the exposed finger under conditions of without (bare hand) and with antivibration glove

Time (min)		31.5 Hz				250 Hz			
		Bare hand		With glove		Bare hand		With glove	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Before	1	37.5	2.9	36.2	3.1	41.2	3.0	37.7	2.6
	2	39.8	3.5	38.2	2.3	41.0	2.6	35.8	1.4
	3	40.2	3.2	36.2	2.2	40.3	2.3	37.7	2.3
	4	38.7	3.0	35.0	2.5	41.3	2.4	39.5	3.7
	5	39.2	3.5	33.3	2.5	40.8	2.6	39.0	2.8
After	1	58.2	8.9	49.2	4.2	51.3	4.3	47.2	4.5
	2	57.0	4.9	44.3	5.1	51.3	2.3	42.8	4.5
	3	52.8	3.0	39.8	3.8	50.5	2.3	37.0	3.0
	4	47.3	2.6	40.0	4.0	49.3	2.3	33.8	3.2
	5	47.5	3.1	38.0	3.4	48.3	2.4	34.2	2.5

Data obtained before and after vibration exposure at 31.5 Hz and 250 Hz are presented. Values are shown as mean and SE.

Table 2. Average FST (°C) at every min in the exposed finger under conditions of without (bare hand) and with antivibration glove

Time (min)		31.5 Hz				250 Hz			
		Bare hand		With glove		Bare hand		With glove	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Before	1	32.2	0.4	32.7	0.5	30.9	0.7	31.9	0.8
	2	32.0	0.4	32.7	0.5	30.8	0.7	31.8	0.8
	3	32.1	0.5	32.9	0.5	30.7	0.7	31.6	0.8
	4	32.0	0.5	32.9	0.5	30.8	0.8	31.7	0.7
	5	31.9	0.4	32.9	0.5	31.0	0.8	31.6	0.7
After	1	28.4	0.3	32.0	0.5	27.6	0.5	31.4	0.6
	2	29.1	0.6	32.4	0.5	28.4	0.7	32.0	0.6
	3	29.4	0.7	32.6	0.4	29.0	0.9	32.0	0.6
	4	29.4	0.8	32.5	0.4	29.1	0.9	31.9	0.6
	5	29.3	0.8	32.4	0.4	29.2	1.0	31.7	0.6

Data obtained before and after vibration exposure at 31.5 Hz and 250 Hz are presented. Values are shown as mean and SE.

the vertical handle with the right hand for 5 min under a grasping force of 20 ± 5 N. While the subjects gripped the handle, their hands were exposed to sinusoidal vibration. After vibration exposure the subjects released their hands from the handle and kept them on the table in a relaxed position for a further 5 min. Measurements were continued to be recorded during this time. FBF and FST were recorded at the end of every minute.

Statistical analysis

As the hand posture was different during grasping of the vibrating handle, only the data obtained before and after vibration exposure were used for the analysis. Statistical analysis was performed with SPSS statistical software version 11.5, by applying repeated measures analysis of variance (ANOVA) with Bonferroni correction for multiple comparisons and Student's paired *t*-test, where appropriate. A two-sided p-value less than 0.05 was considered statistically significant.

Results

Ambient room temperature and temperature of the vibratory handle did not differ significantly across different experimental sessions. The measurements of FBF and FST at each time point before and after vibration exposure are presented in Tables 1 and 2. For FBF the baseline values were lower in the gloved hand than in the bare (ungloved) hand at both 31.5 Hz and 250 Hz. But FST recordings showed baseline values at both frequencies which were higher under the gloved condition

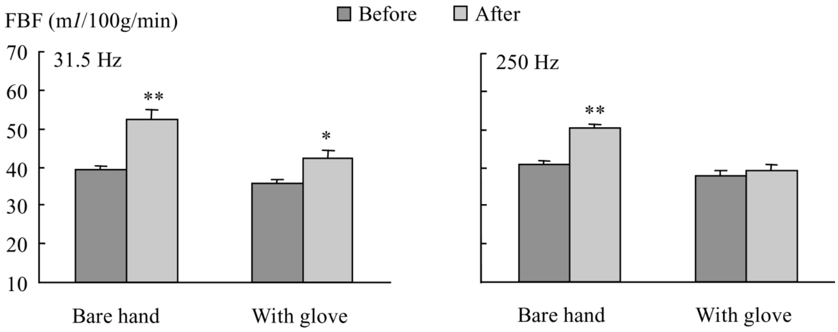

Fig. 1. Mean FBF (m*l*/100 g/min) in the exposed finger before and after vibration exposure at 31.5 Hz and 250 Hz measured under conditions of without (bare hand) and with antivibration glove. Values are mean+SE for 6 subjects. Significantly different from before (control) values: *$p<0.05$ and **$p<0.001$.

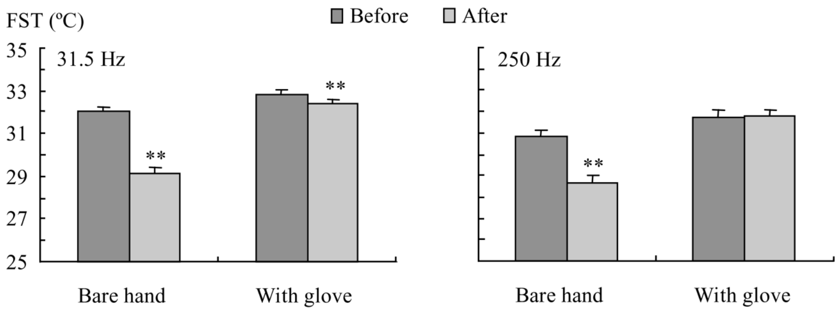

Fig. 2. Mean FST (°C) in the exposed finger before and after vibration exposure at 31.5 Hz and 250 Hz measured under conditions of without (bare hand) and with antivibration glove. Values are mean+SE for 6 subjects. Significantly different from before (control) values: **$p<0.001$.

than under the ungloved (bare hand) condition. Data analysis by repeated measure ANOVA with only the baseline measurements (before exposure to vibration) including both frequencies, with and without the antivibration glove, revealed that there was no significant difference among the values of FBF except between the conditions of 31.5 Hz with the glove and 250 Hz without the glove ($p<0.001$). For FST the baseline values were significantly different among all conditions ($p<0.001$) except between the conditions of 31.5 Hz without the glove and 250 Hz with the glove (results not shown). As the baseline values for FBF and FST differed significantly among the different conditions, further analysis was limited to the conditions of with or without antivibration glove separately at each frequency.

Responses of both FBF and FST to grasping of the vibrating handle were of different patterns under both the gloved and ungloved conditions. A pattern of increase, compared to the baseline values, was revealed in case of FBF in all conditions after vibration exposure (recovery period). But FST data showed a decreasing pattern following exposure to vibration.

At 31.5 Hz the increase in FBF during the 5 min recovery period, compared to the baseline control values, was highly significant ($p<0.001$) under the ungloved condition (Fig. 1); under the gloved condition it was less significant ($p<0.05$). At 250 Hz this increase was also highly significant under the ungloved condition ($p<0.001$), while under the gloved condition the difference in FBF before and after grasping the vibrating handle was not significant.

FST data show that the decrease after vibration exposure was equally significant at 31.5 Hz under both the gloved and ungloved conditions ($p<0.001$), as shown in Fig. 2. At 250 Hz, however, similar to the findings for FBF, there was no statistically significant difference between FST values before and after vibration under the gloved condition, whereas the difference was highly significant under the ungloved condition ($p<0.001$).

Discussion

Over the recent years, the need for protective measures to reduce vibration energy transmitted to the arm and hand, in particular, the wearing of antivibration gloves with adequate damping characteristics, has become very apparent. As a result, there has been an increased commercial interest by different manufacturers in marketing a variety of antivibration gloves, including full-fingered and half-fingered gloves. Many of these antivibration gloves may be ineffective at reducing the magnitude of vibration. According to the ISO 10819[6], an antivibration glove must be a full-fingered glove and the fingers of the glove must have the same properties (materials and thickness) as the part of the glove covering the palm of the hand.

The purpose of this study was not to analyze the effectiveness of an antivibration glove by comparing it with an ordinary glove, but rather to evaluate the influence of an antivibration glove fulfilling the criteria of ISO 10819, on digital circulation, by quantifying the changes in FBF and FST.

Though there are some limitations regarding the uses of input vibrations of medium and high frequency ranges and frequency weighted acceleration as addressed by different researchers[10, 25], the frequencies of 31.5 Hz and 250 Hz corresponding to medium and high frequency spectra as specified in the current standard (ISO 10819) were used in this work with a frequency weighted acceleration of 5.5 m/s^2.

The palmar aspect of the glove came into contact with the surface of the vibrating handle while the subjects grasped it. Also the dorsal aspect of the gloves did not contain antivibration material. Therefore, the small window made in the back of the glove, as we believe, did not influence the protection from vibration exposure while grasping the vibrating handle.

The baseline values of FBF and FST differed significantly between the conditions of with and without the glove. This is likely due to the fact that resting digital circulation at different times is highly variable[26]. Moreover, compared to the corresponding condition of without the glove FBF showed lower and FST showed higher baseline values under the gloved condition. A number of factors could potentially contribute to such a difference. Microcirculation in the skin of the human hand is accomplished through the superficial capillary (nutritive) network and the deeper subpapillary (thermoregulatory) network[27, 28]. The blood flowmeter used in this study recorded FBF in the superficial vessels. The lower FBF, while the anti-vibration glove was worn, may have been a consequence of pressure from the weight of glove mainly on the superficial vessels of dorsal hand. On the other hand, FST measurements showed baseline values at both frequencies under the gloved condition higher than under the ungloved (bare) condition. This may have been due to the warming effect of the antivibration glove, as FST reflects mainly the volume of blood flow in deeply located vessels[29] playing roles in thermoregulation. Though our study design could not identify the warming effect of the glove, to minimize this effect the results were compared using the data before and after vibration exposure under each condition of with and without the antivibration glove, separately. Also, the warming effect of a conventional glove alone cannot protect the hand from vibration damages[30]. Thus, there is a need for the development of antivibration gloves.

Patterns of increased FBF and decreased FST were demonstrated following vibration under both conditions of with or without the antivibration glove, with respect to baseline values. In this study, FBF and FST were recorded from the dorsal and medial surfaces of the right middle finger, respectively. It has been established that the reflex control of circulation in the dorsal skin of human fingers is mediated by a noradrenergic vasoconstrictor system and an active vasodilator system, whereas vasculature in the glabrous skin is mediated only by a noradrenergic vasoconstrictor system[31–33]. There is a possibility that short-duration vibration acted as a stimulator to this vasodilator system in the superficial vessels of the dorsal skin. On the other hand, vessels of the medial aspect of the finger near to the glabrous skin of the hand, lacking any vasodilator system, may have responded in a different way than the vessels of the nonglabrous side. Increases in FBF and decreases in FST arising from exposure to hand-arm vibration have also been observed in previous studies[12, 15, 34, 35].

The results of the present study demonstrate that the antivibration glove influenced the finger vascular response to acute hand-arm vibration. Both FBF and FST data showed that the antivibration glove could prevent changes in finger circulation induced by acute exposure to vibration at the frequency of 250 Hz; but at 31.5 Hz the antivibration glove was effective to a limited extent at preventing changes in FBF. This finding also supports the notion that the same antivibration glove may not be effective or equally effective against vibration at different frequencies. It was noted in a recent research work that ISO 10819 gloves provide most of their vibration attenuation at frequencies above 200 Hz[36]. According to the manufacturer's description, the glove used in this study can reduce the frequency weighted vibration by 10% in the medium frequency range and about 50% in the high frequency range. Vibration transmissibility indicating protective efficacy of the antivibration glove used in this study is measured only at the palm according to ISO standard 10819. On the other hand, in the current study we investigated vibration-induced circulatory changes in the finger to examine the influence of an antivibration glove on them. It can be hypothesized that if an antivibration glove utilizes the same material in the palm and fingers, the influence of it on vibration transmission to the human hand induced by exposure to hand-arm vibration may be similar in both the palmar and digital regions.

Responses in finger circulation to acute hand-arm vibration were considerably influenced by the antivibration glove. The findings of the present study suggest that wearing an antivibration glove may provide protection against finger circulatory changes caused by exposure to hand-arm vibration. Measurement of finger vascular responses, especially FBF, may be a useful measure for assessing the influence of an antivibration glove on reducing vibration effects. Such knowledge may be helpful in the selection of a suitable or proper antivibration glove for a particular vibratory tool.

In conclusion, finger circulatory changes in healthy subjects induced by vibration exposure were diminished by an antivibration glove indicating beneficial effect of the antivibration glove. Future studies assessing changes in finger circulation induced by hand-arm vibration using gloves with different antivibration materials are required to further expand the observations of this study.

References

1) Friden J: Vibration damage to the hand: clinical presentation, prognosis and length and severity of vibration required. J Hand Surg 26, 471–474 (2001)
2) Greenstein D, Kent PJ, Wilkinson D and Kester RC: Raynaud's phenomenon of occupational origin. J Hand Surg 16, 370–377 (1991)
3) Noel B: Pathophysiology and classification of the vibration white finger. Int Arch Occup Environ Health 73, 150–155 (2000)
4) Griffin MJ. Handbook of Human Vibration. London: Academic Press, 1990.
5) Pelmear PL, Wasserman DE. Hand-Arm Vibration: A Comprehensive Guide for Occupational Health Professionals. Beverly Farms, MA: OEM Press, 1998.
6) ISO 10819. Mechanical vibration and shock—hand-arm vibration—method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand. International Organization for Standardization, Geneva, 1996.
7) Griffin MJ: Evaluating the effectiveness of gloves in reducing hazards of hand-transmitted vibration. Occup Environ Med 55, 340–348 (1998)
8) Xiao J, Zheng F. Measurement and evaluation of attenuation effectiveness of antivibration gloves. In: Lundstrom R, Lindmark A, eds. Proceedings of the 8th International Conference on Hand-arm Vibration. Umeå: Arbetslivsinstitutet, 1998: 323–327.
9) Reynolds D, Stein JK. Evaluation of the test procedures for the testing of antivibration gloves per ISO Standard 10819. In: Lundstrom R, Lindmark A, eds. Proceedings of the 8th International Conference on Hand-arm Vibration. Umeå: Arbetslivsinstitutet, 1998: 309–322.
10) Reynold DD and Wolf E: Evaluation of antivibration glove test protocols associated with the revision of ISO 10819. Ind Health 43, 556–565 (2005)
11) Taylor W and Pelmear PL. Vibration white finger in industry. London: Academic Press, 1975.
12) Bovenzi M, Griffin MJ and Ruffell CM: Vascular responses to acute vibration in the fingers of normal subjects. Cent Eur J Public Health 3, 15–18 (1995)
13) Bovenzi M, Welsh AL and Griffin MJ: Acute effects of continuous and intermittent vibration on finger circulation. Int Arch Occup Environ Health 77, 255–263 (2004)
14) Egan CE, Espie BH, McGrann S, McKenna KM and Allen JA: Acute effects of vibration on peripheral blood flow in healthy subjects. Occup Environ Med 53, 663–669 (1996)
15) Nakamura H, Ariizumi M, Okazawa T, Nagase H, Yoshida M and Okada A: Involvement of endothelin in peripheral circulatory change induced by hand-arm vibration. Cent Eur J Public Health 3, 27–30 (1995)
16) Rakheja S, Dong RG, Welcome DE and Schopper AW: Estimation of tool-specific isolation performance of anti-vibration gloves. Int J Ind Ergon 30, 71–87 (2002)
17) EN 420. General requirements for gloves. Brussels: European Committee for Standardization, 1994.
18) Griffin MJ: Measurement, evaluation, and assessment of occupational exposures to hand-transmitted vibration. Occup Environ Med 54, 73–89 (1997)
19) Furuta M, Sakakibara H, Miyao M, Kondo T and Yamada S: Effect of vibration frequency on finger blood flow. Int Arch Occup Environ Health 63, 221–224 (1991)
20) Ando H and Noguchi R: Dependence of palmar sweating response and central nervous system activity on the frequency of whole-body vibration. Scand J Work Environ Health 29, 216–219 (2003)
21) Mountcastle VB, Talbot WH and Kornhuber HH: Neural basis of sense of flutter-vibration. Science 155, 597–600 (1967)
22) Sato M: Response of Pacinian corpuscles to sinusoidal vibration. J Physiol 159, 391–409 (1961)
23) Talbot WH, Darin-Smith I, Kornhuber HH and Mountcastle VB: The sense of flutter-vibration: comparison of the human capacity with response patterns of mechanoreceptive afferents from the monkey hand. J Neurophysiol 31, 301–334 (1968)
24) Lundstrom RJ: Responses of mechanoreceptive afferent units in the glaborous skin of the human hand to vibration. Scand J Work Environ Health 12, 413–416 (1986)
25) Dong RG, Welcome DE and Wu JZ: Frequency weightings based on biodynamics of fingers-hand-arm system. Ind Health 43, 516–526 (2005)
26) Lau CS, Khan F, Brown R, McCallum P and Belch JJ: Digital blood flow response to body warming, cooling and rewarming in patients with Raynaud's phenomenon. Angiology 46, 1–10 (1995)
27) Coffman JD: Effects of endothelium-derived nitric oxide on skin and digital blood flow in humans. Am J Physiol 267, H2087–H2090 (1994)
28) Fagrell B. Peripheral vascular disease. In: Shepherd AP, Oberg PA, eds. Laser-doppler blood flowmetry. Boston: Kluwer Academic, 1990: 201–213.
29) Mirbod SM, Yoshida H, Jamali M, Miyashita K, Takada

H, Inaba R and Iwata H: Finger skin temperature and laser-doppler finger blood flow in subjects exposed to hand-arm vibration. Ind Health 36, 171–178 (1998)

30) Rens G, Dubrulle P and Malchaire J: Efficiency of conventional gloves against vibration. Ann Occup Hyg 31, 249–254 (1987)

31) Crandall CG, Musick J, Hatch JP, Kellogg DL Jr and Johnson JM: Cutaneous vascular and sudomotor responses to isometric exercise in humans. J Appl Physiol 79, 1946–1950 (1995)

32) Greenfield ADM. The circulation through the skin. In: Handbook of physiology. Circulation. Washington DC: Am Physiol Soc, 1963: 1325–1351.

33) Johnson JM, Pergola PE, Liao FK, Kellogg DL Jr and Crandall CG: Skin of the dorsal aspect of human hands and fingers possesses an active vasodilator system. J Appl Physiol 78, 948–954 (1995)

34) Azuma T, Ohhashi T and Sakaguchi M: An approach to the pathogenesis of "white finger" induced by vibratory stimulation: acute but sustained changes in vascular responsiveness of canine hindlimb to noradrenaline. Cardiovasc Res 14, 725–730 (1980)

35) Mahbub MH, Inoue M, Yokoyama K, Laskar MS, Ohnari H, Suizu K, Inagaki J, Takahashi Y and Harada N: Assessment of room temperature influence on finger blood flow response induced by short-term grasping of vibrating handle. Int Arch Occup Environ Health 79, 22–26 (2006)

36) Jetzer T, Haydon P and Reynolds D: Effective intervention with ergonomics, antivibration gloves, and medical surveillance to minimize hand-arm vibration hazards in the workplace. J Occup Environ Med 45, 1312–1317 (2003)