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Measurements of Vibrotactile Perception Thresholds at the Fingertips in Poland

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Abstract: Objectives: The measurement of vibrotactile perception thresholds (VPTs) at fingertips in workers belongs in Poland among obligatory methods used to diagnose hand-arm vibration syndrome. The aim of the study was to compare vibrotactile perception threshold (VPT) values for healthy subjects using two different types of measuring equipment, i.e. a system designed according to the requirements of the ISO 13091-1 standard and a system that had so far been in use in Poland. Materials and Methods: 59 men and 22 women aged on average 40.4 years old participated in the study. The VPT measurements were carried out using a new pallesthesiometer P8 (EMSON-MAT, Poland), developed according to the ISO 13091-1 standard and a vibrotactile meter MCW 2K that had so far been used in Poland. Measurements were taken for the index, middle and ring fingers of both hands using the frequencies of 4, 25, 31.5, 63, 125, 250, 400 and 500 Hz for the ISO method and 63, 125, 250, 400 and 500 Hz for the Polish method. Results: The mean vibrotactile perception threshold values determined with the ISO 13091-1 method were significantly higher in comparison with the values obtained when the method used in Poland was employed. The differences between vibrotactile threshold levels were almost the same at the compared frequencies. Conclusions: The results of the VPT measurements obtained employing the standard method adopted in Poland may be used in further diagnostic examinations carried out with the ISO 13091-1 method only if an appropriate correction value is calculated in order to determine the difference in the VPT levels at a selected frequency.

Key words: Vibrotactile perception threshold, Reference values, Measuring equipment

Introduction

The evaluation of vibrotactile perception thresholds (VPTs) at fingers, so called pallesthesiometry, is one of the basic methods for early detection of peripheral neuropathies in the upper extremities in workers employed in harmful conditions, including those being exposed to chemical neurotoxic agents, vibration and mechanical shocks[1–3]. In Poland pallesthesiometry is indispensable for diagnostic and certification purposes of the vibration syndrome. It is also obligatory during the preliminary, periodic and final medical examinations of the workers exposed to vibration.

The vibrotactile perception thresholds at fingertips depend on many factors connected with the characteristics of vibration stimulus, such as: the diameter and the vibration frequency of the stimulating probe, the surround or lack of the surround around the probe, the contact force between the probe and the finger, the contact area and the psychophysical measurement procedure[4, 5]. Numerous studies have been carried out over the last twenty years concerning measurement methods and properties of mechanoreceptors located in the finger skin. The outcome of these studies has been instrumental in developing the international ISO 13091-1 standard for methods used to

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measure vibrotactile perception at fingertips. Following the new ISO standard it became necessary to test its usefulness for determining VPTs against older methods[6, 7].

The guidelines on measurement methods and interpretation of the VPT measurement results, which are currently in use in Poland, were developed in the early 1970s on the basis of the contemporary knowledge on finger mechanoreceptors. Polish vibrotactile meters were then designed according to these guidelines.

Nowadays, the Polish guidelines considerably vary from the measuring requirements contained in the ISO 13091-1 standard.

The aim of this study was to compare vibrotactile perception threshold values for healthy subjects using two different types of measuring equipment, i.e. a system designed according to the requirements of the ISO 13091-1 standard and a system that had so far been in use in Poland.

Materials and Methods

Subjects

Eighty one healthy individuals—59 men and 22 women—participated in the study as volunteers. All the subjects had no history of neuromuscular or vascular disorders and had not suffered from any serious injures of the upper extremities. The study groups included workers, nurses, laboratory technicians and researchers. Their physical characteristics and the mean finger skin temperature are given in Table 1. All the subjects were required to be fit and healthy during the measurement sessions.

Table 1. The characteristics of the subjects

Group	Mean value ± SD		
	Age (yr)	BMI (m/kg^2)	Finger skin temperature (°C)
Men (n=59)	42.9 ± 12.3	26.0 ± 3.4	29.9 ± 1.6
Women (n=22)	37.9 ± 9.7	24.4 ± 2.9	29.3 ± 2.5
Total (n=81)	40.4 ± 11.0	25.1 ± 3.3	29.6 ± 2.1

Measuring systems

1) The 1(MS2) measuring system—a P8 Pallesthesiometer

A new pallesthesiometer designated P8 (EMSON-MAT, Poland) was developed according to the ISO 13091-1 standard[7]. The measuring system consisted of a vibrometer unit, a subject response button, a set of vibrotactile meter working state indicators and the vibrometer software. In the vibrometer unit, a counterbalanced vibration exciter was used to drive a stimulating probe and a piezoelectric accelerometer to measure the acceleration magnitude. The stimulating probe was a flat-ended perspex cylinder, 5 mm in diameter. A subject kept his or her forearm and hand on the unit box resting the palm on a special support, which ensured the required contact between the fingertip and the probe. The center of the stimulating probe tip was located on the distal phalanx at a point midway between the center of the whorl and the fingernail. The probe was pressed by the subject's finger with a constant force of 0.1 N. The static force between the probe and the finger was monitored by the subjects themselves. Adopting the method for counterbalancing the weight of the stimulator, the subjects watched two small lamps placed at the panel of the vibrometer unit near the stimulating probe. Whenever the static force was too strong or too weak, one of the lamps lit up. The vibrometer unit was equipped with an acceleration monitoring system, which made it possible to carry out measurements even if the interference significantly exceeded the input vibration level. The acceptable noise-to-signal ratio was 20 dB; it was measured and displayed in the indicator of the vibrotactile meter working state[8]. The P8 vibrometer software was used with an IBM PC compatible computer. It controlled the course of the measuring procedure, displayed measurement data as well as computed and stored the results in the database.

The Von Bèkèsy algorithm was used to determine vibrotactile perception thresholds. In this method the vibration magnitude was increased until the subject was able to perceive it. Then the subject pressed the button held in the other hand. This caused a decrease in the vibration level until the subject no longer perceived a vibration stimulus. Releasing the button caused the vibration level to increase again. The direction of the continuous stimulus magnitude change was then reversed. The vibration magnitude was increased and decreased with a continuous stimulus at a constant rate of 2 dB/s (4 dB/s until the subject responded for the first time).

This procedure was repeated three times by an automatic test program to establish the threshold level at a selected vibration frequency. The VPT value was calculated from the arithmetic mean of the mean peak (ascending thresholds) and the mean trough (descending thresholds) for each frequency. The values of the levels were expressed in dB (re. 10^{-6} ms^{-2}). The vibrometer software monitored the measurement, rejecting the acceleration values that differed from the mean value by more than ± 2 dB. The measurements were continued until 3 ascending thresholds and 3 descending thresholds were obtained, each with acceleration values within ± 2 dB.

Table 2. Description of the two measuring systems

	Pallesthesiometer P8 MSI	Vibrotactile meter MCW MS2
Frequency, Hz	4; 25; 31.5; 63; 125; 250; 400; 500	63; 125; 250; 400; 500
Diameter probe, mm	5	10
Probe-surround gap, mm	No surround	3
Contact force, N	0,1	2
Stimulation	Automatic	Manual
Psychophysical algorithm	Von Békésy algorithm	Ascending threshold
Vibration parameter	Acceleration	Velocity
Vibrotactile threshold level	dB (re 10^{-6} ms^{-2})	dB (re $5 \cdot 10^{-8}$ ms^{-1})

2) The 2 (MS2) measuring system—a MCW 2K Vibrotactile meter

The second measuring system was built around an MCW 2K vibrotactile meter, manufactured in Poland since 1980. It consisted of a vibrometer unit, a counterbalanced vibrator and a perspex-tipped circular stimulating probe with a force indicator and a subject response button. The probe protruded through a circular hole 16 mm diameter in a rigid plate. The subject placed the pulp of his or her finger on the 10 mm diameter probe, approximately in the center of the whorl of the distal phalanx. The static force exerted by the finger on the probe was 2N. This force was monitored by the subjects who watched a mobile red line, which moved under a transparent plate near the stimulating probe. The force was correct if the red line was exactly under a white line painted on the surface of the transparent plate. The force exerted by the finger on the plate was not controlled. The subject rested the palm on the surface of the table, to which the equipment including the probe and the force indicator were attached. The subject was asked to press the response button held in the other hand as soon as the stimulus was perceived. The vibration magnitude was increased manually by the person conducting the examinations until the subject was able to detect vibration. The vibration magnitude level of the stimulating probe was read in dB (re. $5 \cdot 10^{-8}$ ms^{-1}) directly from the vibrotactile meter monitor.

The mean VPT value expressed as the velocity level was calculated from the arithmetic mean of three ascending thresholds and then recalculated into the acceleration level (in dB re.10^{-6} ms^{-2}).

The two measuring systems are compared in Table 2.

Procedure

Prior to the experiment, a pre-test was performed to familiarize the subjects with the vibration stimuli and the measurement procedure. The subjects performed the test once with each measuring system.

The VPT measurements were taken for the index, middle and ring fingers of both hands using first a P8 pallesthesiometer and then an MCW 2K vibrotactile meter. The VPTs were determined using the P8 meter at the frequencies of: 4, 25, 31.5, 63, 125, 250, 400 and 500 Hz. As compared to the ISO 13091-1 standard, the range of applied frequencies was widened and additional VPT measurements at 250, 400 and 500 Hz were performed. Only the higher frequencies were taken into consideration when the ISO method was compared with the method used in Poland. The VPT measurements using the MCW 2K meter were taken at the frequencies of: 63, 125, 250, 400 and 500 Hz, the lower frequencies being unavailable with the MCW 2K. The order of vibration stimuli ranged from the lowest to the highest frequency for each measuring system. The VPTs were determined successively at each stimulation frequency for three fingers of both hands. Duration of one session did not exceed 40 min.

The finger skin temperature of both hands was measured on the distal phalanx of all 6 digits before, during and after the VPT measurement, using non-contacted infrared thermometer. The subjects wore earmuffs to attenuate the sound generated by the meters at a frequency higher than 125 Hz.

Smoking was not allowed for at least 1 h prior to the VPT measurements. Room temperature was maintained within the 21–24°C range.

One motion parameter, i.e. vibration acceleration, commonly used in bibliography and recommended in the ISO 13091-1 standard, was adopted in this study in order to compare the VPT levels expressed in dB and obtained with the two measurement methods, which relied on different parameters of the oscillatory motion and different reference values.

Statistical analysis

The statistical analysis of vibrotactile perception thresholds was performed using the Statistical Package for Statistica 6, StatSoft Poland.

The t-test for paired data was employed to assess the significance of differences between the mean VPT values, determined using the MS1 and MS2 measuring system at five frequencies (63, 125, 250 400 and 500 Hz). The mean VPT value for a given frequency was calculated after six measurements for each individual and the number of subjects were taken into account. The force of dependence between VPT values obtained using the MS1 and MS2 measuring systems was determined on the basis of Pearson line correlation coefficients *r*. The statistical correlation significance was determined using a t-test.

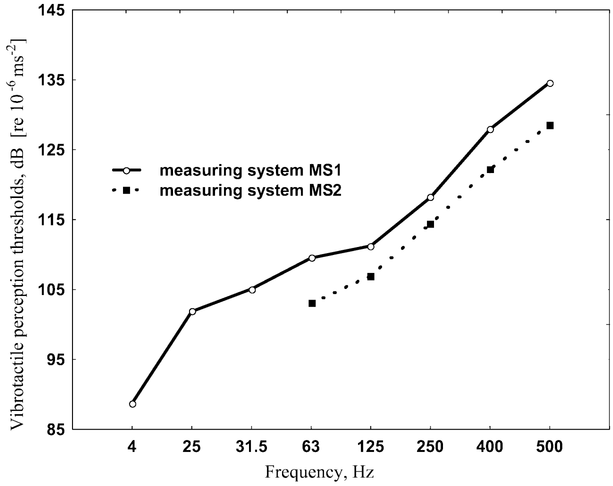

Fig. 1. Mean values of vibrotactile perception thresholds obtained with the measuring system MS1 and MS2.

Results

The comparison of mean VPT values obtained using the two measuring systems is shown in Fig. 1. The VPT levels measured with the MS1 system were significantly higher in comparison with the mean VPT values obtained using the MS2 system for all common frequencies (Table 3).

Table 4 shows correlation between VPT values obtained using the two measurement methods. In both cases statistical significance of correlation between the two measurement methods was observed.

Discussion

The psychophysical VPT measurements at fingers have for a long time been used in clinical, experimental and prophylactic studies as non-invasive methods for quantitative evaluation of the peripheral nervous system of the upper extremities. Possible employment of the VPT measurement results for prophylactic purposes in case of workers exposed to occupational agents calls for a unification of measurement methods, interpretation principles and guidelines for result evaluation. This task was undertaken in 1995 by experts of the WG8 work group at the TC 108/SC4 Technical Committee of the International Organization for Standardization, who developed the ISO 13091-1:2001 international standard determining the quantitative method for measurement of VPT values at fingers[6, 7]. In order to address the pressing need for verification of the Polish guidelines on methods used to diagnose the vibration syndrome, the Polish P8 pallesthesiometer was developed, which complies with the ISO 13091-1:2001 requirements. The meter uses one of the two possible ways in which the pulp of the finger can contact the stimulating probe, i.e. the

Table 3. Comparison of vibrotactile perception thresholds in 81 subjects obtained with a system MS1 and with a system MS2

Frequency (Hz)	Mean values of vibrotactile perception thresholds ± SD (dB re.10^{-6} ms^{-2})		Differences between mean values of VPTs obtained with two systems (dB re.10^{-6} ms^{-2})	T-test	
	System MS1	System MS2		t	p
4	88.7 ± 5.2	–	–	–	–
25	101.9 ± 6.7	–	–	–	–
31.5	105.1 ± 6.5	–	–	–	–
63	109.5 ± 7.6	103.1 ± 6.2	6.4	13.97	<0.0001
125	111.3 ± 9.5	106.9 ± 6.4	4.4	8.10	<0.0001
250	118.2 ± 10.8	114.4 ± 6.3	3.8	5.95	<0.0001
400	128.0 ± 11.0	122.2 ± 7.9	5.8	9.26	<0.0001
500	134.6 ± 10.7	128.6 ± 9.0	6.0	9.87	<0.0001

T-test for paired data. t-Student t-distribution, p-value.

Table 4. Results of correlation analysis of vibration perception thresholds obtained with a system MS1 and with a system MS2 (n=81)

Frequency (Hz)	Comparison of measurement methods with systems MS1 and MS2 Pearson line correlation coefficient	
	r	p
63	0.521	< 0.00001
125	0.538	< 0.00001
250	0.505	< 0.00001
400	0.555	< 0.00001
500	0.542	< 0.00001

p-value.

fingertip rests only on the surface of the stimulating probe with no surround.

The MCW 2K vibrotactile meters designed in accordance with the national guidelines set out in 1973 and used in Poland for the evaluation of the pallesthesiometric results operate on different parameter of the oscillatory motion and generally fail to fulfill the technical parameters contained in the ISO 13091-1:2001 standard (Table 2). The VPT values expressed in dB, without giving the motion parameter and a reference value, may be significantly different from the results obtained using the meters more or less conforming to the ISO 13091-1 requirements. The adoption of a different motion parameter, i.e. vibration velocity or vibration acceleration, may alone produce considerably different VPT values.

In both of the compared measuring systems the experimentally obtained mean differences in VPT values due only to different technical parameters were 5.3 dB, i.e. from 3.8 dB at a frequency of 250 Hz to 6.4 dB at a frequency of 63 Hz (Table 3, Fig. 1). The mean differences in VPT values obtained in another study carried out in 38 men and using the same two measuring systems were 4.4 dB[9]. The results obtained by Whitehouse *et al*. indicate that the VPT values are higher when a probe with a surround is used in the frequency range of 16–31.5 Hz and lower above 125 Hz in comparison with the VPT values obtained using a probe without a surround[10]. Similar dependencies were observed by Maeda and Griffin[11] when they compared vibration thresholds in 9 subjects using two meters with different diameter of the vibrating probe and its surround. The observed differences between VPT values were 4.7 dB at 63 Hz, 3.5 dB at 125 Hz and 0.9 dB at 250 Hz. Maeda *et al*. repeated the examinations at a frequency of 125 Hz in 9 men and one woman and obtained the mean difference in VPT values of 4.3 dB[12]. This shows that the way the fingertip contacts the vibrating probe may be critical in determining reference VPT values.

The VPT values may also be affected by the way the vibration magnitude is generated, i.e. whether a method of ascending thresholds or von Békésy algorithm is employed. Maeda and Griffin concluded that the psychophysical algorithm does not play any role if the vibration stimulus is changed at a rate faster than 2.5 dB/s[13].

The VPT curve is also significantly influenced by the size of the probe. For a probe 1 mm in diameter, the VPT values were lower at the stimulus frequencies of 8 and 16 Hz and higher at frequencies of above 125 Hz in comparison with the values obtained using a 6-mm probe[14].

The mean VPT values obtained with a P8 pallesthesiometer in this study are higher at the frequencies of 4 Hz, 25 Hz, 31.5 Hz and 125 Hz in comparison with the VPTs contained in Annex A of the ISO 13091-2[15]. The observed differences, which decrease with the increase of frequency and equal from 11.2 dB at 4 Hz up to 3.8 dB at 125 Hz, may result from the fact that the ISO 13091-2 standard data were obtained from several studies. Certain departures from the ISO 13091-1 requirements were not uncommon in these studies while the mean VPT values were in fact arrived at as a result of extrapolation of the measurement data.

In this study the correlation coefficients between the VPT values obtained with the two measurement methods did not exceed 0.6. A similar degree of correlation between the two methods was obtained by Venemark *et al*.[16] and Harazin *et al*.[17].

The practical employment of the obtained results enables initial calculation of the correction value, including the total difference between the VPT values, i.e. the difference resulting from the use of different motion parameters and the difference that emerged due to the application of a different VPT measurement method. According to the Polish guidelines on vibrotactile perception, an arithmetic mean should be calculated for three fingers, i.e. the index, middle and ring fingers, at frequencies of 250, 400 and 500 Hz. The mean VPT value at these frequencies determined using the ISO13091-1:2001 method equaled in this study 126.9 dB (re. 10^{-6} ms^{-2}) while the mean VPT value obtained in the same subjects but according to the Polish guidelines based on vibration velocity measurements (re $5 \cdot 10^{-8}$ ms^{-1}) was 80.4 dB. The mean difference in the VPT values between the two methods was 46.5 dB and this is by how much the mean VPT value determined using the ISO 13091-1:2001 should be lowered in order to comply with the current Polish requirements on vibrotactile perception evaluation. Conversely, possible adoption of the ISO 13091-1:2001 in the future would mean that the VPT values determined with an MCW meter would have to be increased by 46.5 dB. A slightly lower correction value of 45.5 dB was calculated in a study of only 38 men, using the same two measurement methods[18]. Due to low repeatability of the results obtained using the MS2 system, such correction in dB can only be considered as an approximate figure.

Conclusions

The following conclusions can be drawn as a result of this study:

1. Mean VPT values obtained using the ISO 13091-1 are significantly higher in comparison with the values determined according to the Polish guidelines.
2. The results of the VPT measurements obtained employing the standard method adopted in Poland may be used in further diagnostic examinations carried out with the ISO 13091-1 method only if an appropriate correction value is calculated in order to determine the difference in the VPT levels at a selected frequency.

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