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A new principle for assessing vibrotactile sense in vibration-induced neuropathy

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The early diagnosis of vibration-induced neuropathy is associated with several difficulties. Although nerve conduction velocity may be impaired in advanced stages (3, 5), neurophysiological tests and two-point discrimination tests may be perfectly normal (15). It has, however, been reported that the impairment of vibrotactile sense may be one of the first changes observed after occupational exposure to vibration (4, 11). Thus changes in vibrotactile threshold may predict the onset of vibration injury. We present a method for determining the vibrotactile sense at several frequencies. The purpose was to develop a diagnostic method for the early detection of vibration-induced neuropathy.

Materials and methods

The vibrometer

An audiometer of the Békésy type was modified in accordance with a previous description (14). To evoke stable vibration without compression circuitry, a powerful vibrator (Brüel & Kjaer, type 4809) was used (figure 1). The area of the vibrating head was 5 mm². The vibration exciter consisted of an audiometer (Brüel & Kjaer, type 1800) modified to operate at low frequencies. The signal was amplified with a power amplifier (Brüel & Kjaer, type 2706). The vibrating head of the exciter was placed into the center of a small opening in a testing table. The system provided a sinusoidal signal at controlled frequencies and amplitudes, and it could be applied to a finger pulp placed on top of the table (figure 2). Vibration at seven fixed frequencies ranging from 8 to 500 Hz were automatically delivered to the probe on the top of the exciter.

The signal was recorded on an X-Y recorder with a built-in test signal generator. The test frequency was presented on the X axis, the frequencies being automatically changed by the instrument itself. The Y axis deflection represents the perception threshold for vibration. The level of vibration is controlled by an automatic attenuator, operated by the subject by means of a hand-held switch (figures 3 and 4). Instructions were given to press the switch when the vibration of the probe could be felt, thus causing the automatic attenuator to decrease the intensity (amplitude). When vibration could no longer be felt, the switch was released. In this way the subjects could regulate the intensity of the vibration and thereby track their threshold levels. The perception threshold was recorded on a preprinted chart at frequencies of 8, 16, 33, 65, 125, 250, and 500 Hz, the frequencies being automatically changed through this frequency range. The level was recorded in decibels as acceleration re 10⁻⁶ m².

In all the subjects the third and fifth fingers of both hands, innervated by the median and ulnar nerves, respectively, were tested. The testing time for one finger was 5–6 min. Since the test is psychophysical and requires cooperation from the patient, a preliminary test was done for training purposes, before the actual testing procedure was carried out. The testing was usually performed by an occupational therapist. The equipment was mobile and could be brought to any desired place. The testings were performed in various local health care centers associated with the workplaces.
Figure 1. Testing table with vibration exciter in place and a finger resting on top of the probe.

Figure 2. Pulp of the finger placed on top of the vibration exciter.

Figure 3. Hand switch enabling control of increase and decrease in vibration intensity.

Figure 4. Vibrometer equipment in place.

Figure 5. Normal vibrogram obtained from 20 heavy manual workers not exposed to vibration. The curve indicates mean values ± 2 SD.

Reference subjects
Curves were obtained from 20 manual workers not exposed to vibration (carpenters, glass factory workers), and a "normal vibrogram" based on the values obtained ± 2 SD was established (figure 5).

Workers exposed to occupational vibration
Twenty-seven workers who had been using hand-held vibrating tools for various periods of time formed the exposed group. The mean age was 35 (range 18—60) years, the exposure time averaging 9 years (range 9 months — 27 years). The subjects tested included car mechanics and factory workers exposed to vibration from hand-held vibrating tools. In a questionnaire each patient indicated the occurrence of white fingers and/or numbness of the hand. The investigation did not include objective assessments of vasospastic disease. Vibrograms were obtained from the third and fifth fingers of both hands no less than 2 h after the cessation of exposure to vibration.

Results

Reference subjects
Vibrograms obtained from the reference group showed a typical shape with a mainly horizontal course in the lower frequencies, followed by a peak within the range of 125—250 Hz, indicating a better perception threshold for fast adapting type II (FA II) receptors (pacinian corpuscles) than for fast adapting type I (FA I) or slowly adapting type I (SA I) or II (SA II) receptors (figure 5). At 500 Hz there was an increase in the perception thresholds, indicated by a slope of the curve.
The level and shape of the curve was identical to curves obtained from 55 referents from the hospital staff, who were not involved in heavy manual work (14).

**Workers exposed to vibration**

There was a striking correlation between the subjective symptoms presented by the patients and the changes in the curve of the vibrogram. With increasing symptoms, changes in the curve corresponding to the results obtained from material of nerve entrapment patients were observed (14) so that “stage 1” was indicated by a flattening of the peak within the FA II receptor range of 125—250 Hz, “stage 2” was indicated by, in addition, a steeper slope of the curve starting at a frequency of 65 Hz, and “stage 3” was indicated by the disappearance of the vibration sense at the highest frequencies and deterioration of sensation also in the very low frequency range corresponding to the vibrotactile perception of the SA I receptor population. Typical curves are shown in figures 6—8, representing workers having used hand-held vibrating tools for 6 months, 18 months, and 27 years, respectively.

The changes in the vibrogram corresponded remarkably well to the subjective experience of numbness in the hand and to the occurrence of white fingers. Of six workers suffering from white fingers, the vibrogram was abnormal in five cases. Of five workers suffering from numbness of the hand, the vibrogram was abnormal in four cases. For seven workers with symptoms of both disturbed peripheral circulation and neuropathy the vibrogram was abnormal in six cases. Out

![Figure 6. Vibrograms from a car mechanic exposed to vibration for six months. Intermittent wrist pain, no numbness of the hand. Normal vibrogram.](image)

![Figure 7. Vibrogram obtained from a car mechanic working with hand-held vibrating tools for 18 months. Intermittent numbness of the hand, normal two-point discrimination. Abnormal vibrogram, stage 2—3 in both hands.](image)

![Figure 8. Vibrogram obtained from a car mechanic exposed to hand-held vibrating tools for 27 years. Constant numbness and pain. Abnormal curve in both hands, stage 3.](image)
of ten workers with no symptoms, three showed abnormal vibrograms (stage I).

Discussion

Vibration-induced neuropathy of the hand represents a puzzling condition, often imitating carpal tunnel syndrome. The nerve conduction velocity is often normal across the wrist level, and these cases are not always cured by decompression of the median nerve. These facts strongly indicate that the nerve lesion may be located more distally than in the carpal canal, and hypotheses have been proposed that intraneural edema in distal median nerve branches may constitute an important etiologic factor in early vibration-induced neuropathy (13).

In compression neuropathies changes in vibrotactile sense represent early signs, always appearing before changes in two-point discrimination and often appearing before impairment in nerve conduction velocity (6). Changes in the vibrotactile sense of the skin have been reported to represent an early objective sign also in vibration-induced neuropathy (4). The physiology of the vibrotactile sensation of the skin is complex in that vibration is perceived by several receptor systems of the skin. Two receptor populations have been defined on the basis of their properties for adaptation to constant pressure, ie, the SA and FA types. Depending on their response to sharp edges, each of these receptor types can be further divided into receptors responding to sharp contours (type I) and into diffuse contours (type II) (9). SA I receptors are anatomically linked to neurite complexes of Merkel’s cells and SA II receptors to Ruffini’s corpuscles, both of which respond to lower frequencies of vibration (0.1—60 Hz) at psychophysical threshold values. FA I receptors have been anatomically linked to Meissner’s corpuscles, and FA II receptors to pacinian corpuscles, the latter perceiving higher frequencies of vibration at psychophysical thresholds (10).

The psychophysical threshold (vibrogram) curve is linked to the activation of SA I receptors at low frequencies (below 16 Hz), to FA I receptors at middle frequencies (32 to 65 Hz), and to FA II receptors at high frequencies (above 65 Hz). The most sensitive frequency range in the evaluation of psychophysical vibrotactile perception is 250—350 Hz, where the FA II receptors in normal subjects can detect displacement of the skin at an amplitude of 0.1 μm (16). In our study this sensitive threshold of FA II receptors has been expressed in the peak of the vibrogram curve.

The earliest sign of decreased vibrotactile sensation was a flattening of this peak (stage I). Abnormalities in the curve within the lower frequencies occurred only at an advanced stage, which — paralleled by an increase in 2 PD — reflects a lesion in the SA I receptor population.

It is interesting to note that abnormalities of the curve correlated not only to numbness of the hand, but also to the occurrence of white fingers. This finding emphasizes the difficulties in separating neurological and vascular problems in the vibration syndrome and suggests a common etiology. Intraneural nerve fibers in vascular walls may play a role in the initiation of vasospasm. On the other hand, all peripheral nerve trunks are well vascularized, and disturbances in intraneural vascular function will rapidly interfere with nerve function. The fact that the intraneural microvessels are sympathetically innervated makes the picture even more complicated. A disorder of sympathetic nerve fibers may have consequences for the blood flow in the vessels of the hand and for the vessels in the peripheral nerves and hereby contribute to an even further impairment of peripheral nerve function.

The vibrotactile sense is dependent on local temperature, as well as on time and space variables such as frequency, temporal and intensity relationships between stimuli, area of stimulation, and surface gradients on the skin (20, 21). The significance of the transient threshold shifts for vibration perception is well known (11). These factors have to be considered when vibrotactile sense is used as an indicator of damage to components of peripheral nerves. All these factors can be completely controlled only under well-defined laboratory conditions. Our method, however, was developed with the purpose of using mobile equipment for screening tests in the field. By necessity, all factors considered in the preceding discussion could not be completely controlled. This deficiency has to be judged against other advantages of the method. However, as long as the testing procedure is standardized maximally in each individual case, we feel that the main sources of error have been excluded.

The results of this pilot study, with a striking correlation between subjective symptoms of neurological and circulatory disturbances and pathological vibrograms, as well as between exposure time and pathological vibrograms, indicate that our method is very useful for screening test purposes. Further investigations are needed to prove the statistical significance of the method. In an ongoing prospective field study including 350 manual workers doing heavy work, the method is now being used as a screening test to study the course of the neuropathy as related to factors such as continuous exposure to vibration and modifications of the work situation.

Acknowledgments

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