Scand J Work Environ Health 1987;13(4):317-322

<https://doi.org/10.5271/sjweh.2052>

Issue date: Aug 1987

Vibration-induced neuropathy. Detection by nerve conduction measurements.

by [Brammer AJ](#), [Pyykko I](#)

Affiliation: Division of Physics, National Research Council of Canada, Ottawa, Canada.

This article in PubMed: www.ncbi.nlm.nih.gov/pubmed/2829347

This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

Vibration-induced neuropathy

Detection by nerve conduction measurements

by Anthony J Brammer, PhD,¹ Ilmari Pyykkö, MD, PhD²

BRAMMER AJ, PYYKKÖ I. Vibration-induced neuropathy: Detection by nerve conduction measurements. *Scand J Work Environ Health* 13 (1987) 317–322. An analysis of electroneurographic studies of workers who operate hand-held vibrating power tools reveals that, when controlled for polyneuropathy and the effects of heavy manual work, significantly reduced sensory nerve conduction velocities occur within the hands. This finding is compatible with the available pathophysiological evidence. The detection of this presumed vibration-induced neuropathy and its distinction from compression neuropathies involving a localized primary lesion, such as carpal tunnel syndrome, thus requires a detailed investigation of nerve conduction within the hands. A technique well adapted to the detection of abnormalities in the most peripheral sensory nerve fibers and mechanoreceptors has been developed based on vibrotactile stimulation of a fingertip. The compound action potentials recorded noninvasively at the base of the finger and wrist from healthy male subjects possess peak-to-peak amplitudes of no more than 0.5 and 0.25 μV , respectively.

Key terms: action potentials, carpal tunnel syndrome, electroneurography, vibrotactile stimulation, white fingers.

Episodic numbing of fingers and paresthesias in the hands and arms, the latter often at night, have frequently been reported by operators of hand-held vibrating power tools such as rock drills, chipping hammers, and chain saws. In some cases pain and muscular weakness are reported in the upper extremities (9), while advanced cases may experience difficulty with tasks involving fine manipulative skills (eg, buttoning clothing), and many report interference with work. The latter are believed to be related to sensory loss in the fingers (5).

Both the clinical and pathophysiological features of this occupational neuropathy are incompletely understood. It has been shown that heavy manual work involving the operation of a vibrating power tool significantly increases the risk of distal compression in the median nerve when compared with heavy manual work alone (2). This neuropathy has been attributed, often without conclusive evidence, to nerve compression within the carpal tunnel – carpal tunnel syndrome. When localized by electroneurography, nerve entrapment in the cervical spine, elbow, or wrist has been detected in manual workers operating heavy vibrating power tools, though whether this was a consequence of the heavy work, repetitive movements, joint loading, vibration exposure, or a combination of these factors could not be established (13). In ad-

dition, the presence of polyneuropathy has recently been reported in some workers also suffering from vibration-induced white finger (VWF) (12).

In this paper the essential features of a vibration-induced neuropathy are identified by an analysis of electroneurographic data from vibration-exposed workers and referents. A refined technique for investigating nerve conduction in the most peripheral sensory fibers, which should permit its detection, is then described, together with the initial results from normal, healthy males.

Analysis of electroneurographic data

There have been many studies of nerve conduction in the hands and arms of workers who operate hand-held vibrating power tools (see table 1). Although significant decreases in conduction velocity have frequently been found, on the average, in the sensory and motor nerves of vibration-exposed workers, when compared with referents, no such reductions have been reported in some investigations. In these studies the changes, if any, have been restricted to reduced sensory action potentials, sometimes accompanied by increased motor distal latency (1, 8). The inconsistency of the findings in table 1 is, at first sight, disturbing. Yet it merely reflects the nonspecificity of nerve conduction measures and leaves unanswered the origin, or origins, of the changes observed. This lack of consistency does, however, suggest a procedure for evaluating the data, namely, a detailed analysis of those investigations that systematically explore peripheral nerve conduction, with particular reference to the exclusion of neuropathies unrelated to vibration exposure and the selection of appropriate reference groups.

¹ Division of Physics, National Research Council of Canada, Ottawa, Canada.

² Department of Physiology, Institute of Occupational Health, Helsinki, Finland.

Table 1. Detection of reduced motor and sensory conduction velocities, on the average, in the hands or arms of workers operating vibrating power tools.

Source	Reduced nerve conduction velocity	
	Motor	Sensory
Abbruzzese et al (reference 1)	..	No ^a
Alaranta et al (reference 3)	No ^b	Yes
Araki et al (reference 4)	No ^b	Yes
Chatterjee et al (reference 8)	No ^b	No ^a
Dylewska [Neurol Neurochir Pol 20 (1970) 27—32]	No	Yes
Färkkilä et al (personal communication, 1986)	Yes	..
Hisanaga [Jpn J Ind Health 24 (1982) 284—293]	Yes ^b	Yes
Hisanaga (reference 11)	Yes ^b	Yes
Jandova [CS Neurol 2 (1971) 64—68]	..	Yes
Juntunen et al (reference 12)	No	Yes
Komleva [Gig Truda 7 (1985) 31—33]	No	..
Lukáš [Work Environ Health 7 (1970) 67—69]	No	No
Lukáš et al [Int Arch Occup Environ Health 38 (1977) 283—294]	Yes	Yes
Lukáš (reference 13)	Yes	Yes
Nishi et al [Sangiyō Eisei Kenkyushu Nenpō 4 (1972) 1—5]	No	Yes
Nohara [J Juzen Med Soc 92 (1983) 953—966]	Yes	..
Pelmar et al [In: Vibration effects on the hand and arm in industry (1982)]	No	No ^a
Sakurai et al [Scand J Work Environ Health 12 (1986) 432—434]	Yes	Yes
Seppäläinen [In: Vibration and work (1976)]	Yes	Yes
Seppäläinen [Work Environ Health 7 (1970) 82—84]	No ^c	..
Seppäläinen [Work Environ Health 9 (1972) 106—111]	Yes ^{b, c}	..
Seppäläinen et al [Scand J Work Environ Health 12 (1986) 420—422]	No	Yes
Torii et al (reference 18)	Yes	Yes

^a Reduced sensory action potentials.

^b Increased distal or residual motor latency.

^c Reduced motor conduction velocity of slow fibers.

There are only five studies in which motor and sensory conduction in ulnar and median nerves have been measured throughout the arms and hands of workers who operate vibrating power tools (3, 8, 11, 12, 18). The results of these investigations, including the numbers and ages of subjects and referents, and the occupations of the former, are summarized in tables 2 and 3. Hisanaga (11) and Torii et al (18) (table 2) employed unspecified reference groups, being described only as age-matched “healthy males” in the former with not even these restrictions indicated in the latter. Neither of these studies discussed the nature of the work performed by members of the reference group nor their exposure to vibration or neurotoxic chemicals. In contrast, Alaranta & Seppäläinen (3) and Chatterjee et al (8) (table 3) each employed an age-matched reference group consisting of manual workers with no history of exposure to vibration or to neurotoxic chemicals. The reference group in the former investigation was also screened for neurological diseases. No reference group was included in the investigation of Juntunen et al (12) (table 3). The assignment of a reference group to their vibration-exposed subjects is made possible, however, by the nerve conduction measurements having been performed in the same laboratory, using the same apparatus and measurement procedures, as those reported by Alaranta & Seppäläinen (3). Accordingly, the reference group designated by Alaranta & Seppäläinen for “subgroup 2,” being a better age match to the subjects, is employed in the present analysis as the reference group for the subjects of Juntunen et al (12).

To enable a direct comparison to be made between the results of the five studies, the data of Chatterjee et al (8), for individual fingers, and those of Chatterjee et al (8) and Torii et al (18), for left and right hands, need to be combined into one value for both hands, as do those of Juntunen et al (12) for the two vibration-exposed subgroups. This is done by forming the mean value M and standard deviation S from m data sets using:

$$M = \left\{ \frac{\sum_{i=1}^m n_i \bar{x}_i}{\sum_{i=1}^m n_i} \right\} \quad \text{equation 1}$$

and

$$S^2 = \left\{ \frac{\sum_{i=1}^m [(n_i - 1)s_i^2 + n_i(\bar{x}_i - M)^2]}{\left\{ \left(\sum_{i=1}^m n_i \right) - 1 \right\}} \right\} \quad \text{equation 2}$$

where the i^{th} set of observations, n_i in number, have a mean value $\bar{x}_i$ and a standard deviation s_i . It should be noted that these equations treat the data for each finger in the study by Chatterjee et al (8) as being independent of the values recorded in other fingers. An increased total number of observations, N , hence results, particularly for sensory conduction in the median and ulnar nerves from finger to wrist (table 3, column 2). This procedure is considered justified, as pathological changes, which may develop independently, have been found in the fingers of vibration-exposed persons (17). A corresponding increase in N results from combining data from the left

Table 2. Motor and sensory conduction velocities (m/s), and motor residual latencies (ms) in the hands and arms of workers operating vibrating power tools and of referents. The studies include a minimum of 30 hands exposed to vibration and data for six, or more, of the parameters listed. (MCV = maximal motor conduction velocity, SCV = maximal sensory conduction velocity, MCVSF = motor conduction velocity of slow fibers, RL = motor residual latency, E-W = elbow to wrist, W-H = wrist to hand, W-F = wrist to finger)

Nerve	1 Hisanaga (11)				2 Torii et al (18)			
	Subjects ^a [50 (SD 7.4) years ^c] (N = 219–233)		Referents [48 (SD 7.2) years ^c] (N = 30)		Subjects ^b [35–65 years ^d] (N = 55–56 ^e)		Referents [50–69 years ^d] (N = 181)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Median								
MCV (E-W)	57.4 ****	4.4	60.9	4.1	58.8 *	6.2	57.2	3.8
RL (W-H)	2.5 ***	0.5	2.2	0.3	..	..	..	..
SCV (E-W)	61.6 ***	6.4	65.8	4.1	63.1	6.3	62.3	4.0
SCV (W-F)	53.8 ***	6.5	58.4	4.3	62.3 ****	5.8	55.8	5.4
Ulnar								
MCV (E-W)	57.7 *	5.8	60.4	4.1	56.4	6.2	59.9	4.4
RL (W-H)	1.7 ****	0.4	1.5	0.3	..	..	..	..
MCVSF (W-H)	..	..	..	..	..	..	..	..
SCV (E-W)	58.9 ***	5.6	65.3	4.2	57.7 ****	13.4	64.6	4.8
SCV (W-F)	49.4 ****	7.1	57.5	4.5	56.2 *	10.3	54.1	4.1

^a Chain-saw, rock-drill, chipping-hammer, compactor and brush-cutter operators.

^b Chain-saw operators.

^c Mean age.

^d Age range.

^e Number of hands.

* P < 0.05, ** P < 0.01, *** P < 0.001, **** P < 0.0001, Student's t-test with pooled variance, two-sided probability values.

Table 3. Motor and sensory conduction velocities (m/s) and motor distal latencies (ms) in the hands and arms of workers operating vibrating power tools and of age-matched manual workers unexposed to vibration or neurotoxic chemicals. Studies include a minimum of 30 hands exposed to vibration and data for six, or more, of the parameters listed. (MCV = maximal motor conduction velocity, SCV = maximal sensory conduction velocity, MCVSF = motor conduction velocity of slow fibers, DL = motor distal latency, E-W = elbow to wrist, W-H = wrist to hand, W-F = wrist to finger)

Nerve	1 Alaranta & Seppäläinen (3)				2 Chatterjee et al (8)				3 Juntunen et al (12)				4 Juntunen et al (12)			
	Subjects ^a [44 (SD 9.6) years ^e] (N = 38)		Referents [43 (SD 11) years ^e] (N = 20)		Subjects ^b [36 (SD 12) years ^e] (N = 32 ^f)		Referents [38 (SD 9.6) years ^e] (N = 30 ^f)		All Subjects ^c [48 (SD ?) years ^e] (N = 103)		Referents [47 (SD 9.7) years ^e] (N = 15)		Subgroup ^d [47 (SD ?) years ^e] (N = 61)		Referents [47 (SD 9.7) years ^e] (N = 15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Median																
MCV(E-W)	58.3	7.0	59.0	4.9	59.3	4.5	58.8	3.1	58.2	6.0	58.1	5.4	58.5	5.0	58.1	5.4
DL(W-H)	4.3 *	0.7	3.9	0.7	4.1 **	0.6	3.7	0.3	..	..	..	..	..	..	..	..
SCV(E-W)	58.6 *	5.1	62.1	7.1	..	..	..	..	55.2 **	6.0	59.9	6.5	56.1 *	5.0	59.9	6.5
SCV(W-F)	44.2 ***	6.0	50.1	5.1	48.4 ***	7.5	51.0 ^h	5.4	40.8 ****	5.8	49.3	5.3	42.1 ***	5.9	49.3	5.3
Ulnar																
MCV(E-W)	57.8	6.1	59.1	6.2	59.3	3.6	58.3	2.9	58.4	6.3	57.3	3.8	60.1	6.2	57.3	3.8
DL(W-H)	3.5	0.5	3.5	0.4	3.1	0.4	3.0	0.5	..	..	..	..	..	..	..	..
MCVSF(W-H)	40.0 ***	4.9	45.4	4.5	..	..	..	..	42.6	6.1	45.2	4.9	44.0	5.1	45.2	4.9
SCV(E-W)	56.7	6.6	59.3	7.3	..	..	..	..	54.9	7.1	57.7	6.5	56.6	6.2	57.7	6.5
SCV(W-F)	50.4 *	4.9	53.7	6.4	51.5 ⁱ	8.3	52.0 ^j	4.9	45.6 ****	5.5	51.9	5.5	47.1 ***	4.5	51.9	5.5

^a Chain-saw and pneumatic-tool (mainly chipping hammer) operators.

^b Rock drillers.

^c Chain-saw operators.

^d Chain-saw operators screened to exclude polyneuropathy.

^e Mean age.

^f Number of hands.

^g N = 128.

^h N = 120.

ⁱ N = 64.

^j N = 60.

* P < 0.05, ** P < 0.01, *** P < 0.001, **** P < 0.0001, Student's t-test with pooled variance, two-sided probability values.

and right hands (table 2, column 2, and table 3, column 2).

The statistical significance of the differences between the mean nerve conduction velocities of the subjects and referents has been estimated for all the data with

Student's t-test with a pooled variance. Two-sided probability values of P < 0.05 are noted in tables 2 and 3.

When the data from the nerve conduction studies are analyzed by the same procedures, it appears that

differences in velocity and latency between vibration-exposed workers and referents occur more commonly, and with greater statistical significance, in table 2 than in table 3. Close inspection of the former, however, reveals that the findings in this table are inconsistent, the nerve segments most affected in one study frequently being the least affected in the other (as in table 1). The reason for these discrepancies is not clear, though it is probably related to the absence of meaningful selection criteria for the reference groups in table 2.

When reference groups are formed from manual workers who have not been exposed to vibration or neurotoxic chemicals (table 3), it is evident that most of the changes in nerve conduction occur from the finger to wrist of vibration-exposed workers. The subjects in columns 1–3 of table 3 have not, however, been screened for polyneuropathy, a condition that has also been found in some chain-saw operators (9, 12). In consequence, although the results in table 3 together provide the most complete information on peripheral nerve conduction in workers who operate vibrating power tools and have probably minimized the effects of heavy manual work by the choice of the reference

group, they cannot be taken to indicate conclusively a peripheral neuropathy confined to the upper extremities. In contrast, the subjects in column 4 have been screened by clinical examination, sensory testing, and subjective symptoms to exclude polyneuropathy. Hence, when polyneuropathy is controlled for and the effects of heavy manual work are minimized, it appears that the most significant electroneurographic finding from vibration-exposed workers ($P < 0.001$) is a marked reduction in conduction velocity of the sensory nerves within the hand. This conclusion has been reached elsewhere in a study of chain-saw operators with no electroneurographic findings of polyneuropathy (4). Unfortunately, the question of prolonged motor distal latency in the median nerve remains unresolved.

Vibrotactile stimulation of digital sensory nerve endings

The main finding of nerve conduction studies implies that pathological changes occur in the most peripheral sensory fibers within the hand and, possibly, in the nerve endings. A technique ideally adapted to this form of peripheral neuropathy would involve, in principle, stimulation of cutaneous sensory nerve endings. To explore the feasibility of such techniques, a noninvasive method has been developed for recording sensory nerve action potentials in the finger, palm, and wrist; the nerve action potentials are produced by vibrotactile stimulation of a fingertip.

A simplified block diagram of the apparatus is shown in figure 1. The subject lies supine with arm extended and fingers naturally curved, so that the tips are nearly vertical. Both the subject and the stimulator are within a Faraday cage to reduce electromagnetic interference. The electrical signals detected either by wire electrodes looped around the finger (as shown in figure 1) or by disc electrodes positioned above the nerve at the palm or wrist are amplified and fed to a signal averager triggered by a pulse derived from the stimulus waveform. Although the hand is restrained from moving, the signals recorded during fingertip vibration are at least an order of magnitude less than the near-random activity detected by the electrodes. This noise of physiological origin is poorly correlated with the stimulated nerve activity, and so may be reduced by signal averaging (typically 500–3 000 events), bandwidth limiting, and peak amplitude rejection.

With pulsed stimulation 35 dB above the threshold of sensation, signals of approximately 0.5- μ V and 0.25- μ V peak-to-peak amplitudes have been recorded at the finger base and wrist, respectively, of healthy, adult male, laboratory workers (see figure 2). These signals are not detected by finger electrodes when another fingertip is vibrated, nor by wrist electrodes when they are positioned away from the nerve, nor when the stimulator is operating but not quite touching

Figure 1. Block diagram showing essential elements for nerve conduction measurements involving vibrotactile stimulation of a fingertip.

Figure 2. Compound sensory nerve action potentials recorded at the finger base and wrist with pulsed vibrotactile stimulation of a fingertip (35 dB sensation level).

the skin. Furthermore, the magnitudes of the signals in figure 2 are consistent with those recorded invasively from the sural nerve with tactile stimulation (6). For these reasons the waveforms are believed to represent the compound nerve action potentials generated under these conditions.

A detailed report of this work will be published elsewhere.

Discussion

The pathophysiological changes occurring in vibration-induced neuropathy are not completely understood. Recent animal experiments have demonstrated that acute exposure of a rat limb to intense vibration induces epineural edema (14). This edema is associated with increased intraneural pressure which also retards the microcirculation of the nerve. Symptoms resulting from nerve entrapment may then be expected to occur until the intraneural pressure returns to normal (10). The relevance of this process to vibration-induced neuropathy can be appreciated from pathological changes recently observed in finger biopsies of persons suffering from VWF (17). In cross-sections of nerves from these fingers a circular fibrosis was noted, increasing the thickness of the epineurium or perineurium, together with extensive destruction of the myelin sheath and a reduction in number of nerve fibers. The perineural fibrosis was considered by Takeuchi et al (17) to be characteristic of VWF and, from its form, was attributed, independently, to the past existence of intraneural edema.

This link between the effects of acute and chronic exposure to vibration provides evidence for two phases of nerve injury: one reversible with a rate of recovery dependent on the elimination of edema from the nerve and the other involving pathological changes with destruction of the myelin sheath and axons and the disappearance of nerve fibers from mechanoreceptors (1, 17). It thus appears that vibration-induced neuropathy should be considered a biphasic compression neuropathy, which hence may mimic other compression neuropathies occurring in the hands of manual workers. In particular, the symptoms may often be very similar to those reported in carpal tunnel syndrome, though they usually also involve the territory innervated by the ulnar nerve. Note, however, that the data of Chatterjee et al (8) in table 3 are unlikely to display similar involvement of both ulnar and median nerves even after screening for polyneuropathy. This result lends credence to the authors' suggestion of median nerve compression within the wrists of some of these workers (8), which was supported by the relative magnitude of the sensory action potentials recorded from median and ulnar nerves when digits 1-4, and 4 and 5, respectively, were stimulated (15).

A major impediment to establishing the contributions of vibration and heavy manual work, the latter involving significant joint loading and/or repetitive movements of the wrist, to the peripheral neuropathy

found in operators of hand-held vibrating power tools is the clinical basis used for diagnosis. Unfortunately Phalen's dictum "a patient with any numbness or tingling in the fingers or with any weakness or atrophy of the thenar muscles must be considered as having carpal tunnel syndrome" still appears to influence some clinicians (16), while others attribute the same symptoms in operators of vibrating power tools, without further evidence, to vibration-induced neuropathy. Clearly there is a need for more precise diagnostic criteria. For carpal tunnel syndrome the primary lesion must lie within the carpal tunnel, whereas for vibration-induced neuropathy it apparently occurs diffusely throughout the fingers and, presumably, elsewhere in nerves and nerve endings subjected to intense vibration.

A primary aid to diagnosis is provided by electro-neurography. An assessment of conduction, at least in the median, ulnar and sural, or peroneal, nerves, with appropriate clinical tests will provide sufficient information to exclude polyneuropathy and localize the lesions to the most distal parts of the ulnar and/or median nerves. More precise localization of the site of nerve damage requires a technique adapted to the measurement of nerve conduction within the hand. Careful electrical stimulation of a finger can provide information on two segments within the hand, ie, from the finger base to the palm and from the palm to the wrist. In this way the primary lesion associated with carpal tunnel syndrome may be detected in both mild and severe cases as an excess reduction in conduction velocity in that section of the median nerve involving the carpal tunnel (7). A similar technique could be used to detect localized entrapments of the ulnar nerve within the hand (15).

The detection of nerve pathology within the fingers will probably require a technique based on vibrotactile stimulation of a fingertip, as described in this report. Such a technique is, of course, equally well adapted to the study of sensory nerve conduction in other parts of the hand. That measurement procedures exist to detect noninvasively the extremely small compound action potentials generated by this form of mechanical excitation has been demonstrated in this paper.

Conclusions

An analysis of electroneurographic studies of workers who operate hand-held vibrating power tools reveals that, when controlled for polyneuropathy and the effects of heavy manual work, a residual neuropathy occurs primarily in the sensory nerves within the hands. The detection of this presumed vibration-induced neuropathy and its distinction from compression neuropathies involving a localized primary lesion, such as carpal tunnel syndrome, thus requires a detailed investigation of nerve conduction from fingertip to wrist. A technique well adapted to this purpose has been

developed based on vibrotactile stimulation of a fingertip. The compound sensory action potentials recorded in healthy subjects are, however, extremely small, consisting of peak-to-peak amplitudes of no more than 0.5 μ V at the base of the finger and 0.25 μ V at the wrist.

References

1. Abbruzzese M, Loeb C, Ratto S, Sacco G. A comparative electrophysiological and histological study of sensory conduction velocity and Meissner corpuscles of the median nerve in pneumatic tool operators. *Eur Neurol* 16 (1977) 106—114.
2. Ahlborg G, Voog L. Vibration exposure and distal compression of the median nerve ("carpal tunnel syndrome"). *Läkartidningen* 79 (1982) 4905—4908.
3. Alaranta H, Seppäläinen AM. Neuropathy and the automatic analysis of electromyographic signals from vibration exposed workers. *Scand J Work Environ Health* 3 (1977) 128—134.
4. Araki S, Honma T, Aoyama K. Peripheral nerve conduction velocities in chain-saw operators. *Jpn J Ind Health* 18 (1976) 516—520.
5. Brammer AJ, Taylor W, Lundborg G. Sensorineural stages of the hand-arm vibration syndrome. *Scand J Work Environ Health* 13 (1987) 279—283.
6. Buchtal F. Human nerve potentials evoked by tactile stimuli. *Acta Physiol Scand Suppl* 502 (1982) 5—32.
7. Buchtal F, Rosenfalck A. Sensory conduction from digit to palm and from palm to wrist in the carpal tunnel syndrome. *J Neurol Neurosurg Psychiatry* 34 (1971) 243—252.
8. Chatterjee DS, Barwick DD, Petrie A. Exploratory electromyography in the study of vibration-induced white finger in rock drillers. *Br J Ind Med* 39 (1982) 89—97.
9. Färkkilä M, Aatola S, Starck J, Pyykkö I, Korhonen O. Vibration-induced neuropathy among forest workers. *Acta Neurol Scand* 71 (1985) 221—225.
10. Gelberman RH, Szabo RM, Williamson RV, Dimick MP. Sensibility testing in peripheral nerve compression syndromes. *J Bone Jt Surg* 65A (1983) 632—638.
11. Hisanaga H. Impairment of peripheral nerve in vibrating tool operators examined by nerve conduction velocity. *Kurume Med J* 28 (1981) 303—313.
12. Juntunen J, Matikainen E, Seppäläinen AM, Laine A. Peripheral neuropathy and vibration syndrome. *Int Arch Occup Environ Health* 52 (1983) 17—24.
13. Lukáš E. Peripheral nervous system and hand-arm vibration exposure. In: Brammer AJ, Taylor W, ed. *Vibration effects on the hand and arm in industry*. John Wiley & Sons, New York, NY 1982, pp 39—43.
14. Lundborg G, Dahlin LB, Danielsen N, Hansson HA, Necking LE, Pyykkö I. Intraneural edema following exposure to vibration. *Scand J Work Environ Health* 13 (1987) 326—329.
15. Oh SJ. *Clinical electromyography: Nerve conduction studies*. University Park Press, Baltimore, MD 1984.
16. Phalen GS. The carpal tunnel syndrome. *Clin Orthop Relat Res* 83 (1972) 29—40.
17. Takeuchi T, Futatsuka M, Imanishi H, Yamada S. Pathological changes observed in the finger biopsy of patients with vibration-induced white finger. *Scand J Work Environ Health* 12 (1986) 280—283.
18. Torii J, Kohsaka K, Imanishi H. Peripheral nerve impairment in chain-saw workers. *Jpn Med J* 2829 (1978) 32—34.