Vibrotactile sense and hand symptoms in blue collar workers in a manufacturing industry

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Abstract

Objectives—To study whether vibrotactile sense combined with questionnaires (subjective complaints) and a clinical examination (including scoring of the Stockholm workshop scale (sensorineural staging)) could serve as a screening procedure, in the health care service, for sensorineural symptoms. A group of blue collar workers exposed to vibration in a manufacturing industry (rock crushing plants) was used as the study group. Another group of workers not exposed to vibration but subjected to heavy manual work served as the control group.

Methods—Vibrotactile sense was determined. The index and the little fingers of both hands were investigated. A clinical examination was performed. Questionnaires were used for exposure data and for assessment of symptoms.

Results—Important findings were that impairment in vibrotactile sense correlated with impairment in grip force, cold sensitivity, and other sensorineural symptoms—such as numbness and tendency to drop items. Clinical findings such as Phalen's test and two point discrimination were related only in those workers with the poorest vibrotactile sense. There was a relation between vibrotactile sense and the Stockholm workshop scale (sensorineural staging) for the sensorineural symptoms. Muscle and joint problems were more often seen in workers with decreased vibrotactile sense.

Conclusions—Tactilometry for assessment of vibrotactile sense is a useful tool in assessing and evaluating the severity of vibration induced neuromuscular symptoms and verifying the patients' clinical complaints. Heavy manual work without exposure to vibration may contribute to impairment of vibrotactile sense. The relation between impairment in vibrotactile sense and grip strength indicates that impaired sensory feedback may contribute to muscle weakness.

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Musculoskeletal disorders can result in pain and impaired work performance. The prevalence of extensive muscle fatigue in the hands and arms in forest workers seems to be in the

range of 14%–35 %.¹ Physiological responses include electrochemical and metabolic changes. These local changes are conveyed to the central nervous system by sensory afferent nerves.² Repetitive muscle contractions, joint positions, and joint movements may induce pressure to the nerves, which ultimately can lead to impaired nerve function. Nerves can also be affected by exposure to vibration. Impairment in nerve function can be reflected in changes in nerve conduction velocity or vibrotactile sense.³⁻⁶ The maximum hand grip compression correlated significantly with vibrotactile sense and the muscle fatigue process affected mainly the maximum hand grip force.⁷ A study by Starck and Toppila⁸ confirmed earlier findings on the importance of grip force to the transmission of vibration. Åkesson *et al*⁹ also noticed a relation between impaired vibrotactile sense and decreased muscle strength in the full hand grip. Vibrotactile sense may be one of the first changes found after exposure to vibration.¹⁰ According to several investigations¹¹⁻¹³ the sensorineural component of the hand-arm vibration syndrome develops earlier than the vascular component, white fingers, which has been the most common complaint among workers with many years of exposure to vibration. Lately, there has been a decline in the prevalence of occupational white fingers—for example, among forestry workers using chain saws¹¹—whereas there is increasing interest in the sensorineural symptoms.

Our aim was to study whether vibrotactile sense combined with questionnaires (subjective complaints) and a clinical examination (including scoring on the Stockholm workshop scale (sensorineural staging)) could serve as a screening procedure for sensorineural symptoms in the health care service. A group of blue collar workers exposed to vibration in a manufacturing industry (rock crushing plants) was used as the study group. Another group of workers not exposed to vibration but subjected to heavy manual work served as the control group.

Subjects and methods

The study was performed in a rural community, with about 17 000 inhabitants, in the south of Sweden. The study period was from January to the end of April 1993.

SUBJECTS

All male workers exposed to vibration (presently and formerly) in the industry were invited. The control subjects, all men, were subjected to heavy manual work, but without

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Table 1 Subjects in the study (all workers subjected to heavy manual work)

Subjects	Participated	Refused	Excluded for medical reasons	Total number
Vibration exposure:				
Presently	71	3	8	82
Formerly	23	3	0	26
No vibration exposure	22	5	5	32
Trainees at the workshop school	19	0	0	19
Total (n (%))	135 (85)	11 (7)	13 (8)	159 (100)

Table 2 Subjects exposed to vibration (%) and the different types of vibrating tools they have used (some workers used several tools)

	Presently exposed to vibration (n=71)	Previously exposed to vibration (n=23)
Grinders	76	87
Chisel hammers	35	61
Impact wrenches	35	22
Drills	31	39
Other types	15	17

exposure to vibration. They were selected, by the secretary of the safety committee, to be the same age as the men exposed to vibration. However, some of the control subjects were found to have been formerly exposed to vibration, so the control subjects were fewer than planned.

The material consisted of the following groups (table 1); (a) heavy manual work and exposure to vibration (presently and formerly), (b) heavy manual work without exposure to vibration, and (c) trainees at the workshop school (as it is interesting to screen people before employment in industry). The mean ages of the participants were; presently exposed to vibration 39.0 (range 20–63) years, formerly exposed to vibration 42.7 (range 23–61), no exposure to vibration 42.5 (range 21–64), and

the trainees at the workshop school 17.8 (range 17–19). In total 135 people (85%) were included of the 159 people invited. The total number of blue collar workers in the industry was 260.

QUESTIONNAIRES

A questionnaire¹⁵ distributed to all participants in the study contained questions about exposure to vibration (years, hours a day), smoking, and nine subjective symptoms (numbness of the hand, grip strength, tendency to drop items, difficulties in handling buttons, pain in the wrist, pain in fingers, cold sensitivity, white fingers, or tremor in hand or arm). White fingers was used irrespective of origin; vibration white finger, Raynaud’s disease, or Raynaud’s phenomenon of other origin. The questionnaire has been validated¹⁶ and used by others.¹⁷ The steps were 1–4 (1=no symptoms, 2= yes insignificant, 3= yes some, and 4=yes a lot). Questions were also asked about start of symptoms and occurrence of other diseases which would exclude them from the study—such as diabetes mellitus, hypertonia, rheumatological diseases, heart disease, hyperthyroidism or hypothyroidism—as well as medication against migraine, hypertonia, or cardiac disease.

No actual measures of exposure to vibration were made for practical reasons as many different vibrating tools (grinders, chisel hammers, impact wrenches, and drills) had been used for many years (table 2). The control subjects were also asked at the medical examination whether they were formerly exposed to vibration or not. The workers exposed to vibration were grouped into exposure categories on the basis of their reported cumulative number of hours of exposure to vibratory tools.¹⁸ The cut off points selected were 0 and 4800 hours, which correspond to none and the equivalent of 3.0 full time years of use of vibratory tools (eight hours a day and 200 working days a year).

Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms were used. The validity of these has been tested against clinical history (the questionnaire responses were compared with those obtained when a physiotherapist filled out the questionnaire after a thorough interview about medical history).¹⁹ The main questions were “Have you at any time during the past 12 months had trouble (ache, pain, discomfort) in the; (1) neck? (2) shoulders? (3) elbows? and (4) hands? (yes/no)”.

The sensorineural symptoms were graded, at the medical examination, according to the sensorineural staging of the Stockholm workshop scale²⁰ (stages; 0, 1, 2, and 3). The occurrence of vasospastic symptoms was graded according to the vascular staging of the Stockholm workshop scale²¹ (stages; 0, 1, 2, 3, and 4).

CLINICAL EXAMINATION

Clinical examination by one of us (BTF) included tests for median nerve function (opposition of thumbs as well as occurrence of Tinel’s sign and Phalens’s test), ulnar nerve function (abduction or adduction of fingers),

Figure 1 Vibrotactile sense for the four fingers tested among people presently exposed to vibration (n=71). The results were split into three subgroups (SI; >0.64 (n=29), 0.50–0.64 (n=24), and <0.50 (n=18)). Statistics were by Wilcoxon signed rank test (paired test with right index finger as a control).

Figure 2 Relative changes in vibrotactile sense (SI) in the tested frequencies (8–500 Hz) for all workers ($n=135$) (divided into subgroups based on SI; >0.64 ($n=50$), $0.50-0.64$ ($n=51$) and <0.50 ($n=34$)) are shown as the difference (Δ dB) between each individual test frequency and the age matched reference value.¹⁰ These figures were normalised to an age of 40 years. Statistics was by Student's t test. Error bars are 95 % CIs.

two point discrimination, and Allen's test for ulnar artery function.¹⁵

ASSESSMENT OF VIBROTACTILE SENSE

The vibrotactile sense was determined as previously described by Lundborg *et al.*^{3, 22, 23} The index and little fingers of both hands were investigated. Briefly, the pulp of the tested finger was allowed to rest against a vibrating probe (a flat topped cylindrical probe with a surface area of 5 mm²) placed on top of the vibration exciter. This design, and a different design (the vibration exciter was mounted in a manner similar to a beam balance to provide a constant static pressure of 3.5 N/cm² to the skin) gave almost equal results.¹⁰ The vibration exciter delivered sinusoidal vibrations at seven frequencies ranging from 8–500 Hz. It was driven by a power amplifier controlled by a modified

version of an audiometer of von Békésy-type. The amplitude within its frequency was regulated by remote control through a button on a hand switch operated by the patient's other hand. Pressing the button caused a gradual decrease in amplitude whereas releasing the button caused an increase. The frequency of the vibration stimulus was automatically changed by the instrument itself in ascending order (8, 16, 32.5, 65, 125, 250, and 500 Hz). A vibrogram was obtained, normally with a characteristic shape. Sensory dysfunction was expressed as changes in the shape of the curve, first seen at higher frequencies. Vibrotactile sense was expressed as a sensibility index (SI)²³ The SI was defined as the ratio between the integrated area under the test curve and the area under an age matched control curve.¹⁰ An SI of 1.0 indicates equivalent areas below the test curve and the control curve. As vibrotactile perception thresholds increase the vibrogram shifts to a lower position and the SI decreases. It was not practically possible to avoid either vibration or manual work before the tests were performed, as production had to be maintained during working hours. The total test procedure took about 60 minutes when performed by the company nurse. The time interval between the first and the last finger tested was at least 20–30 minutes. All tested people had ear protectors during the test. The room temperature was in the normal ambient range (about 20°C).

STATISTICAL ANALYSIS

Fisher's exact test was used for determining differences in frequencies; in table 4 the smallest group was 11 people, and in table 6 the smallest group was nine people. The χ^2 test for trends²⁴ was used for table 5. Wilcoxon signed rank test was used for comparing the four fingers (the right index finger was the first finger tested and was used as a control) for the vibrotactile sense (fig 1). In fig 2 Student's t test was used. The Mann-Whitney U test (probabilities without correction for ties) was used in tables 3–5, as the assumptions required to perform a t test were not satisfied in all cases. All tests were two tailed.

Results

EXPOSURE TO VIBRATION TIME VERSUS VIBROTACTILE SENSE AND SUBJECTIVE SENSORINEURAL AND VASCULAR SYMPTOMS

Table 3 shows the duration of exposure to vibration for those workers with sufficient data presently exposed to vibration versus subjective sensorineural and vascular symptoms. Impaired grip strength was the only symptom which was significant for those with an exposure to vibration of more than four years. There were (with one exception) no significant differences in SI for the four fingers tested (fig 1). A mean value of SI was therefore calculated for all four fingers (SI total).

VIBROTACTILE SENSE VERSUS SENSORINEURAL AND VASCULAR SYMPTOMS

With grouping based on the Stockholm workshop scale (sensorineural staging), in-

Table 3 Duration of exposure to vibration in blue collar workers presently exposed to vibration with sufficient data on exposure to vibration versus subjective sensorineural and vascular symptoms

Group	A	B	C
Full time (equivalent) vibration exposure (y)	>4 år	1–3 år	0 år
Mean years of 8 h/day with vibration exposure†	12.6***	1.8***	0
Number of people	20	29	22
SI total (mean)	0.57 NS	0.62 NS	0.63
Symptom scores:			
Numbness	1.7 NS	1.8 NS	1.4
Impaired grip strength	1.7*	1.5 NS	1.1
Tendency to drop items	1.3 NS	1.4 NS	1.1
Pain in wrist	1.8 NS	1.9 NS	1.4
Pain in fingers	1.7 NS	1.6 NS	1.2
Difficulties in handling buttons	1.2 NS	1.4 NS	1.0
Tremor in hand or arm	1.2 NS	1.6 NS	1.1
Cold sensitivity	2.0 NS	1.7 NS	1.3
White fingers	1.7 NS	1.5 NS	1.1
Stockholm workshop scale:			
Vascular staging	0.3 NS	0.2 NS	0.0
Sensorineural staging	0.5 NS	0.5 NS	0.2
Background data:			
Age (y)	45.3 (12.1)	37.0 (12.1)	42.5 (13.0)
Calendar years with vibration tools	24.3 (11.8)	12.4 (9.0)	0
Mean h/day of vibration exposure	4.9 (2.7)	1.8 (1.7)	0
Minutes yesterday of vibration exposure	217 (176)	97 (110)	0
Years in current work	19.0 (15.2)	11.5 (8.6)	14.2 (10.4)
Body mass index	25.3 (3.4)	25.1 (2.2)	24.9 (3.0)

* $P<0.05$; ** $P<0.01$; *** $P<0.001$.

†Also significance between each group ($P<0.001$). Symptom scoring is 1–4 (see subjects and methods). For background data mean (SD) are given.

Table 4 Sensorineural and vascular symptoms among workers exposed to vibration (n=94; 71 presently exposed and 23 previously exposed to vibration)

Group	A	B	C
Grouping based on Stockholm workshop scale (sensorineural staging) Scores	Numbness perpetual ≥ 2	Numbness periodically $=1$	No symptoms $=0$
People (n)†:			
Total	11	21	62
Presently exposed	8	18	45
Previously exposed	3	3	17
SI total (mean)	0.39***	0.55*	0.63
Symptom scores:			
Numbness	3.5***	2.1***	1.1
Impaired grip strength	2.5**	1.5 NS	1.2
Tendency to drop items	2.3**	1.6 NS	1.1
Pain in wrist	2.4*	2.1*	1.3
Pain in fingers	2.6***	1.9*	1.1
Difficulties in handling buttons	1.7 NS	1.5 NS	1.1
Tremor in hand or arm	2.3*	1.8 NS	1.3
Cold sensitivity	2.8**	1.9 NS	1.5
Vibration white finger	2.4*	1.9 NS	1.3
Stockholm workshop scale:			
Vascular staging	0.4 NS	0.5 NS	0.1
Cold sensitivity	0.3*	0.1 NS	0.1
Clinical examination:			
2 Point discrimination (mm)	6**	3 NS	3
Opposition of fingers: pathological (%)	27**	0 NS	0
Abduction of fingers: pathological (%)	18*	0 NS	0
Tinel's sign positive (%)	45 NS	29 NS	19
Phalen's test positive (%)	55**	29 NS	13
Allens' test (%)	0 NS	0 NS	0
Background data:			
Age (y)	41.3 (10.3)	38.4 (11.0)	40.2 (13.0)
Calendar years with exposure	18.8 (10.6)	15.4 (11.0) (n=20)	14.4 (11.9) (n=57)
Full time (8 h/day) exposure (y)	8.3 (7.9) (n=9)	5.9 (8.0) (n=14)	4.9 (5.7) (n=46)
Mean h/day of exposure	3.6 (2.6) (n=9)	3.1 (2.5) (n=14)	3.2 (2.9) (n=46)
Minutes yesterday of exposure	181 (193) (n=7)	128 (114) (n=14)	156 (160) (n=38)
Calendar years since stopped working with vibrating tools	2.3 (2.4) (n=2)	8.0 (7.1) (n=2)	13.2 (12.3) (n=16)
Years in current work	13.2 (13.6)	11.9 (10.2)	12.8 (11.9)
Smokers (%)	45	62	44
Body mass index	26.5 (3.4)	25.5 (3.2)	25.3 (3.5)

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.†=Group A v B only $P < 0.05$.‡n=11, 21, and 62 in groups A–C if not otherwise stated. Symptom scoring is 1–4 (see subjects and methods). For background data mean (SD) are given. Grouping based on Stockholm workshop scale (sensorineural staging). Statistical test is Mann-Whitney *U* test except for proportions when Fisher's exact test was used. Groups A and B are compared with group C.

creasing severity of sensorineural symptoms in workers exposed to vibration was reflected in an increased tendency for symptoms—such as numbness in the hands and fingers, impaired grip strength, pain in the wrist, pain in the fingers, and tremor in the hands or arms (table 4). The Stockholm workshop scale (sensorineural staging) was related to vibrotactile sense, as were cold sensitivity and white fingers. Only in the group “perpetual numbness”, were there significant clinical findings such as two point discrimination, and pathological findings such as opposition and abduction of fingers.

Table 5 shows various ranges of SI (all blue collar workers and the trainees at the workshop school) are matched against sensorineural, muscular, and vascular symptoms. An important finding was the impaired grip strength with decreased SI. With SI > 0.79 there were few complaints of nocturnal numbness in the hand whereas such complaints occurred increasingly often with decreased SI. Also most of the other sensorineural symptoms followed the same tendency. For SI < 0.50 there was a high frequency of sensorineural, vascular, and muscular symptoms. Clinical findings were noted mainly in the group with SI < 0.35 .

CHANGES IN VIBROTACTILE SENSE FOR THE TESTED FREQUENCIES (8–500 HZ)

Changes in vibrotactile sense for the tested frequencies (8–500 Hz) for all workers (n=135) (divided in subgroups based on SI > 0.64 ,

0.50–0.64, and < 0.50) are shown as the difference (Δ dB) between each person's test frequency and the age matched control figure.¹⁰ These figures were then normalised to an age of 40 years. A lower mean figure of the SI groups gives the results that all tested frequencies (8–500 Hz) are affected (fig 2).

SMOKING VERSUS VASCULAR AND SENSORINEURAL SYMPTOMS

Table 6 shows the occurrence of vascular and sensorineural symptoms in manual workers exposed to vibration (previously and presently) versus those not exposed to vibration among smokers and non-smokers. In the non-exposed group no cases of white fingers occurred among the non-smokers whereas white fingers were noticed among smokers. All smokers showed higher frequencies of white fingers, cold sensitivity, and impaired grip strength, but the differences were significant only for the workers exposed to vibration. No other sensorineural symptoms reached significance.

Discussion

EXPOSURE TO VIBRATION VERSUS SENSORINEURAL SYMPTOMS AND VIBRATION WHITE FINGER

There was a clear relation between a lower vibrotactile sense and more pronounced sensorineural symptoms (table 5) and between vibrotactile sense and the Stockholm workshop scale (sensorineural staging), (table 4). This

Table 5 Vibrotactile sense in a total of 135 people (all blue collar workers exposed to vibration; presently (n=71), formerly (n=23), and non-exposed (n=22), and the trainees at the workshop school (n=19) versus subjective sensorineural and vascular symptoms

Group	A	B	C	D	E	P value
Grouping based on SI total	<0.35	0.35–0.49	0.50–0.64	0.65–0.79	>0.79	
SI total (mean)	0.25	0.45	0.58	0.71	0.85	
Number of people (n)	9	25	51	39	11	
Symptoms (%):						
Numbness (%)	78	56	29	15	9	<0.001
Impaired grip strength (%)	33	36	14	10	9	<0.01
Tendency to drop items (%)	56	28	14	3	0	<0.001
Pain in wrist (%)	56	44	27	28	18	<0.05
Pain in finger (%)	67	32	20	23	9	<0.01
Difficulty with buttons (%)	33	8	12	8	0	NS
Tremor in hand or arm (%)	89	24	18	21	18	<0.001
Pain in past year:						
Neck (%)	44	24	10	33	38	NS
Shoulders (%)	56	20	18	36	45	NS
Elbows (%)	33	20	10	8	9	<0.05
Hand (%)	56	36	25	21	27	NS
Cold sensitivity (%)	56	32	27	26	27	NS
White fingers (%)	44	32	24	13	18	<0.05
Clinical examination:						
2 Point description (mm)	5	3	3	3	3	
Opposition of finger: pathological (%)	22	4	0	0	0	<0.01
Abduction of finger: pathological (%)	22	0	0	0	0	<0.01
Tinel's sign positive (%)	56	28	14	15	9	<0.01
Phalen's test positive (%)	67	16	14	15	27	NS
Allens' test (%)	0	0	0	0	0	NS
Background data:						
Age (y)	35.8 (11.5)	41.0 (12.8)	37.3 (15.0)	34.8 (13.7)	38.3 (14.0)	
Body mass index	25.5 (4.5)	26.4 (3.1)	24.9 (3.2)	24.6 (3.4)	24.4 (3.1)	
Smokers(%)	56	56	49	51	36	

Groups are divided according to the results of the SI and all groups are significantly different from each other (Mann-Whitney U test $P < 0.001$). χ^2 for trends were used for frequencies. For background data means (SDs) are given.

finding and it is also supported by the results of Yamada *et al.*²⁵ The relation was not so pronounced for cold sensitivity and white fingers.

Results from an epidemiological study indicated that there may be an exposure-response relation for exposure to vibration and neurological disturbances.¹² In our study there was no clear correlation between time of exposure to vibration and changes in vibrotactile sense (table 3) but there was a trend when grouping was based on the Stockholm workshop scale (sensorineural staging, table 4). The explanation may be that the questionnaires, although they have been validated, are not very good for assessment of time of exposure to vibration. The possibility that the vibrotactile sense is affected early in exposure may be an explanation for the findings that there was no significance difference between the mean SI for all the groups exposed to vibration and the non-exposed groups. Many factors may help to explain this finding such as individual variations in vulnerability to vibration trauma, variations in working technique and grip force around the tool, and variations in type of hard manual work, which also may affect the transmission of vibration to the hand.

Table 6 Smoking in blue collar workers not exposed and previously and presently exposed to vibration versus vascular and sensorineural symptoms

Symptom	Exposure	Non-smokers (%)	Current smokers (%)	P value
White fingers	Non-exposed	0 (n=9)	23 (n=13)	NS
	Previously and presently exposed	18 (n=49)	38 (n=45)	<0.05
Cold sensitivity	Non-exposed	11	23	NS
	Previously and presently exposed	22	49	<0.01
Impaired grip strength	Non-exposed	0	8	NS
	Previously and presently exposed	14	33	<0.05

Frequencies (%) of symptoms (according to questionnaires). Statistics by Fisher's exact test.

It was not possible to establish a valid quantitative relation between sensorineural disturbances and exposure to vibration.^{13 14 26} Perhaps the lack of this relation could be explained by the healthy worker effect, as a very healthy worker may tolerate exposure to vibration much better than an average worker. The healthy worker effect has been known for more than 100 years, but the term first appeared in print in 1974.²⁷ It comprises the healthy hire effect, the healthy worker survivor effect, and the decline in health with time since hire.²⁸ Changes in lifestyle (improved economic status, better access to medical care, and changes in lifestyle) accompanying employment should also be included.²⁹ Ohlson *et al.*³⁰ found that among assembly workers those who worked fastest had a lower prevalence of musculoskeletal symptoms of the neck and hand-arm system. Interestingly, the group with the longest exposure to vibration sometimes gives unexpectedly good results. According to table 3 a healthy worker effect may exist. The mean SIs are about the same in the groups exposed to vibration (table 3). Letz *et al.*¹⁸ found that there were no further increases in reporting sensorineural symptoms in workers with more than 17 000 hours of exposure to vibratory tools. However, the healthy worker effect has seldom been discussed for hand-arm vibration.¹⁴

IMPAIRED GRIP STRENGTH

A two year follow up study on the hand grip force in lumberjacks³¹ suggested that long term exposure to vibration causes a decrease in muscle force, and not only in laboratory experiments.^{32 33} Decreased grip strength and a correlation with vibrotactile sense was also found in a study of 462 chainsaw operators.²⁵

It is important to find the frequencies which may have serious effects on the musculoskeletal symptoms. Low frequencies (<50 Hz) are mainly transmitted to the hand and the forearm, whereas higher frequencies are mostly absorbed by the hand.¹⁴ A study by Okada³⁴ showed that after vibrating the hind legs of a rat, the activity of plasma creatine phosphokinase was significantly increased at 30, 60, 120, 240, and 480 Hz and was especially high at 30 Hz.

The transmission of vibration may be dependent on body weight³⁵ but we did not find any correlation in our study (tables 3–5) when using the more accurate body mass index (BMI).

Vibration induced muscle injury in the hind limb of rats has been shown by Necking *et al.*³⁶ When the hind limb was subjected to vibration over periods of two to five days early signs of muscle fibre degeneration were noticed as an increased frequency of internal nuclei in the muscle fibres³⁷ as well as changes in the muscle fibre area.

Martin and Armstrong presented a model to describe the way in which vibration induced alterations of motor control may cause or aggravate musculoskeletal and peripheral nerve disorders.³⁸

The relation between impairment in vibrotactile sense and grip strength indicates that impaired sensory feedback may contribute to muscle weakness. The results of our findings with higher frequencies of impaired grip strength in the hands (table 4) in blue collar workers exposed to vibration are in accordance with these studies.

COLD SENSITIVITY

The results in table 4 show a relation between cold sensitivity and white fingers in the group with the lowest SI values (mean 0.39). The symptom cold sensitivity (or cold intolerance) is often experienced as a vascular problem. The decreased occurrence of cold sensitivity parallel to the increased occurrence of white fingers after 11 to 20 years of exposure (fig 3 in the study by Strömberg *et al.*¹³ indicates that cold sensitivity may be a pre-stage of white fingers). Our groups were not large enough to support such conclusions.

VIBROTACTILE SENSE

In a study on 171 healthy men¹⁰ not exposed to vibration or hard manual work, SI was considerably higher (>0.80) than in our study. Not only vibration but also manual work may affect vibrotactile sense (see the unexposed group with an SI mean of 0.63, table 3). A possible explanation may be a subclinical level of interference with the median nerve at wrist level induced by hard manual work.³⁹

Our results indicate that an SI of 0.50–0.64 may be a critical range, as when SI is <0.50 there is a clear rise in frequencies of sensorineural symptoms.

In the study by Lundborg *et al.*²³ a high (83%) incidence of sensorineural symptoms was noted for all four fingers tested in patients with brachialgia (n=30) without any obvious cause,

but also in workers exposed to vibration (n=146, 53%). This is in line with our results (fig 1).

Neurophysiological studies have shown that most of the increase in tactile perception threshold involves peripheral receptor mechanisms.¹⁴ The earliest sign of decreased vibrotactile sensation is a flattening of the peak of the curve of the vibrogram. In more advanced stages both higher and lower frequencies are decreased.³ Figure 2 shows that all tested frequencies were affected. When a correlation was made between different biological factors of the subjects' hand-arm systems and the mechanical impedance as a function of the frequency, in the frequency range of about 200 to 300 Hz where the impedance has a low point, the highest correlation was found for the grip force applied by the subject.⁴⁰ A comparison of single (100 Hz) and multifrequency (8–500 Hz) tactilometry with neurological symptoms was made by Wenemark *et al.*¹⁷ The results showed a relation (not very strong) between the instruments used, but there were technical differences such as probe size and contact force that may have influenced the results. According to our results (fig 2) it seems most appropriate to use a multifrequency method. This is also desirable from a neurophysiological point of view.⁴¹

In compression neuropathies changes in vibrotactile sense are early signs, always appearing before changes in two point discrimination and often appearing before impairment in nerve conduction velocity.¹¹ We found pathological two point discrimination only in the group with the lowest vibrotactile sense (SI mean 0.39 (table 4)). Many investigators have found a modest relation between vibrotactile thresholds and nerve conduction measurements. The results indicated that vibrotactile thresholds do not measure the same neurological attributes as nerve conduction velocity and electromyography, and thus are not fully equivalent to electrophysiological evaluation.^{6, 42}

There is no systematic influence of time of day on vibration sensation threshold.⁴³ Vibrotactile thresholds are not affected by skin temperature over the range usually encountered in study subjects tested at normal ambient temperature.⁴² There is no correlation between skin thickness and vibration perception threshold.⁴⁴

Alcohol consumption is commonly presumed to affect neurological performance and measurement of vibrotactile threshold. Only those subjects with serious social or medical consequences of ethanol consumption have been found to have increased vibrotactile thresholds.⁴² It can be of only minor importance in this study, as the company nurse (industrial health care service) has had knowledge of all the blue collar workers for more than 30 years (most of them live in the same small town). Most of the workers were skilled men doing a heavy job, which would have been impossible if they were alcoholics.

The use of tobacco seems to aggravate the symptoms of white finger and to result in

increased reactivity in a cold provocation test.⁴⁵ According to Nilsson *et al*⁴⁶ nicotine is of minor importance relative to exposure to vibration. Letz *et al*⁴⁸ noticed that smoking was significantly related to vascular and sensorineural symptoms but age was not. Our study gives some support to the negative effects of smoking on white finger, cold sensitivity, and impaired grip strength (table 6).

STOCKHOLM WORKSHOP SCALE (SENSORINEURAL STAGING) AND CLINICAL EXAMINATION

Table 4 shows that the clear differences in mean SI for the different stages could actually serve as a validation of the Stockholm workshop scale. This staging seems to be more sensitive than the clinical examination, as a clinical examination identifies only the pathological symptoms found in the most severe cases and is not sensitive enough to prevent vibration related injuries.

CONSIDERATIONS OF STUDY DESIGN AND BIAS

There are several considerations involving potential bias in a cross sectional study. As 7% of the study participants refused to participate in all parts of the study, the prevalences of the symptoms reported for the responders are biased estimates of the true prevalences among the entire population. However, this bias is of minor importance as we have complete data from 93% of the group. The exclusion of people with medical conditions that cause symptoms similar to hand-arm vibration syndrome would cause underestimation of the prevalence of disease. However, only 13 people (8%) were excluded because of such a disease or medication. As not only active workers were studied, but also those formerly exposed to vibrating tools (with the exception to the few who had left the industry), the figures should be fairly accurate. There is a lack of exact data on exposure to vibration, but as the workers had been working with many different tools (table 2) for between one and 47 years, a questionnaire is a compromise. The participants may have overreported symptoms as they were aware of the purpose of the study. The agreement between the objective vibrotactile sense and subjectively reported symptoms (table 5) argue against the symptoms having been overreported. Impaired hand grip was only measured by questionnaires, which is a weakness in the study. All questionnaires have been validated.

Non-parametric statistical tests were mostly used because of small sample size and skewed distributions. Mean values are given for symptom scores despite a rank scale being used. The problems this raises have been discussed,⁴⁷ as it can both overestimate and underestimate the true figures. This cannot be the only explanation for the results showing relation between vibrotactile sense and sensorineural symptoms (table 4 and 5). The results are also unlikely to occur from so called mass significance as our results accord with what would be expected and other research.²⁵

Normally there is only one vibrotactile sense test per person in a cross sectional study like

this, but as we used the mean of the four fingers tested (SI total), the results at least at a group level still can be of value. The SI as used in this study followed the standard description.²³

Conclusions

The relation between impairment in vibrotactile sense and grip strength indicates that impaired sensory feedback may contribute to muscle weakness. We think that the SI is a useful tool in assessing vibrotactile sense and evaluating the severity of sensorineural symptoms induced by vibration and in verifying the patients' clinical complaints. Vulnerability to vibration trauma may vary considerably from person to person, and the technique is probably most valuable on an individual basis in the long term to verify or exclude the development of nerve injury induced by vibration. Ideally there must be measures of the combination of exposure to vibration and all other biological factors affecting the hand-arm system. The SI could be such a measure for distal hand-arm symptoms.

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