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Epidemiological Survey of Shipyard Workers Exposed to Hand-Arm Vibration*

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Summary. All 169 caulkers employed at a ship yard were examined to determine the prevalence of vibration syndrome due to pneumatic portable tools (chipping hammer and grinders).

Vibration measurements and medical investigations were performed in the field between September 1977 and July 1978.

Vibration spectra recorded on pneumatic tools were compared to ISO Draft Proposal No. 5369. The chipping hammer produced the highest acceleration levels and exceeded the maximum ISO limits even for a short exposure time (30 min per shift).

The results of medical investigations pointed out that 78.7% of caulkers experienced paresthesia in their hands, 31.3% Raynaud's phenomenon (or VWF), 20.1% presented with radiological signs of osteoarthritis at wrist and shoulders, 10.0% with olecranon exostoses, and 31.3% with cysts of the carpal bones.

To diagnose VWF the skin temperature of the hands were recorded in all 169 caulkers and 60 controls at the shipyard. The basal skin thermometric map (recorded in 16 positions per hand) demonstrated an average difference of 2–2.5° C between the two populations.

The thermometric curve, monitored every 3 min for 40 min after a provocative cold-test (immersion of hands and wrists in melting ice for 2 min), well differentiated workers exposed and not exposed to vibrations.

The authors emphasize that skin temperature (before and after the cold-test) are suitable for epidemiological purposes to compare the prevalence rates of VWF in control-experimental groups.

Key words: Hand-arm vibration – Shipyard caulkers – Pneumatic portable tools – Osteoarticular lesions – Raynaud's phenomenon

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It has been well known for a long time that work involving vibrating tools may result in specific injuries to the hand-arm segment.

The main symptoms are due to neurological and vascular disorders and to involvement of tendons, muscles, joints, and bones.

Workers exposed to segmental vibrations complain of paresthesia in the hands, whitening and "dead" fingers, muscular weakness, fatigue, and pain in the joints of the upper limbs. Paroxysmal attacks of finger blanching are better known as "Raynaud's phenomenon of occupational origin" or, more recently, as "Vibration-Induced White Finger" (VWF). The complex of VWF with the other disabilities are now referred to as "Vibration Syndrome" [9].

The physical characteristics of vibrations (amplitude, frequency) and the duration of exposure are considered to be the most important factors in the development of vibration disease. According to current knowledge, vibrations of high amplitude and low frequency (< 40 Hz) give rise to osteoarticular lesions, while vibrations of higher frequency (40–1000 Hz) may cause neurovascular disorders.

Other factors must be kept in mind in determining the cause of the injuries: climatic (cold) and ergonomic conditions (method of holding the tool, strength of grip, working posture, etc.) and technical aspects (type of tool, hardness of material under work, etc.).

There are many reports about the prevalence of vibration syndrome in lumberjacks (using chain-saws), miners, rock drillers, and others [2, 5, 10].

Few authors, however, have studied the vibration disease in the shipyard industry [1, 8].

The present paper decribes a cross-sectional study of a homogeneous group of shipyard caulkers to determine the prevalence of vibration syndrome among those working with pneumatic hand-held tools.

Materials and Methods

The present survey was performed between September 1977 and July 1978 at Italcantieri of Monfalcone, which is a yard for ship-building and hull assembly in dock. Repairing operations on keels (paint remotion, etc.) are not carried out.

All of the caulkers employed at the shipyard ($N = 169$) were involved in our study.

Caulking (riveting, cutting, scaling, etc.) is less important now than it was in the past. At present the main task is arc-welding, gas-welding, and cutting.

In recent years, technological advances have improved the engineering design of portable tools, lowering, therefore, the vibration levels.

The job of caulking has now been reduced to:

a) chipping and scaling metal shavings of filled welds;

b) chamfering manhole borders;

c) scouring and grinding steel sheets.

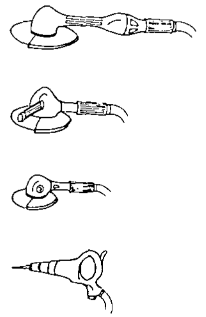
The work of caulking requires that the hand-arm segment and the body be in many different positions and often in narrow areas (i.e., cellular double bottom).

The technical characteristics of tools may be seen in Table 1.

All pneumatic hand tools are used by each of the caulkers. Total exposure time is 5–6 h during a shift of 8 h. Operators use only leather gloves.

Table 1. The technical characteristics of the pneumatic hand held tools used by the caulkers

Pneumatic hand tools		
Type	Weight (kg)	CPM
"Large" grinder (Riva-Calzoni Mod. 5 SA/N 60 R)	6.6	6,000
"Medium" grinder (Riva-Calzoni Mod. 5 SV/N 60 R)	4.6	6,000
"Small" grinder (Riva-Calzoni Mod. 3 SV/N 120 R)	2.0	12,000
Chipping hammer (Bohler & Co. Mod. M 40)	4.5	2,610
+ Mean air pressure supply ..... 6 atm.		



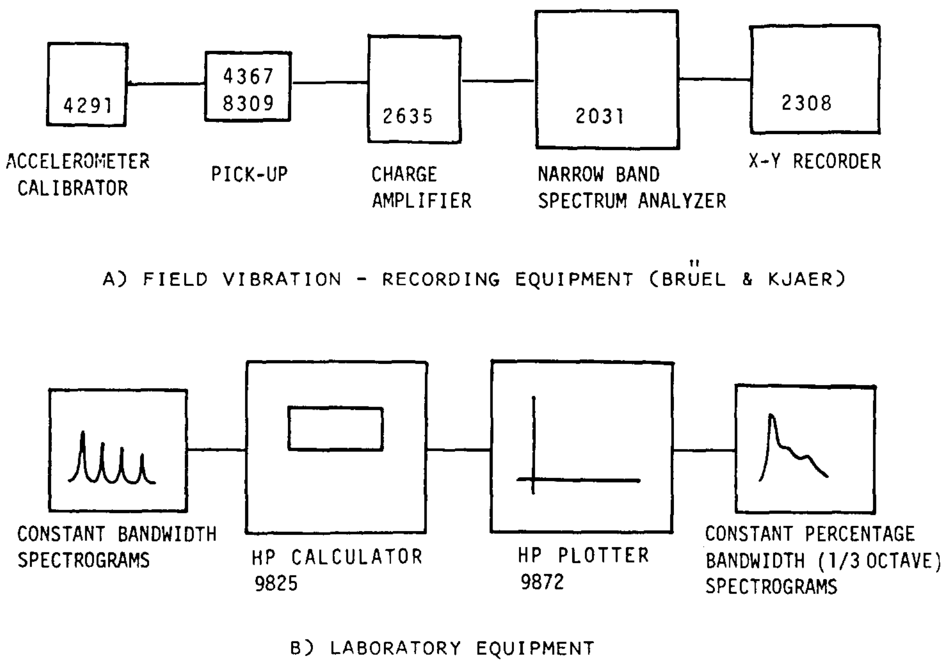


Fig. 1. Flow diagram of the vibration analysis equipment

Vibration Measurements

All vibration parameters were measured with Brül & Kjaer instruments, under real industrial conditions directly during the work operations. Therefore, it was impossible to guarantee the constancy of the "man-machine" system. Figure 1 shows the flow diagram of the analysis system.

Accelerometers were mounted on tool handles, in an orthogonal coordinate system: X, Y, Z. The pick-up was directly screwed in (for the chipping hammer and the medium grinder) or

Table 2. Age distribution of the population studied (169 caulkers and 60 controls) and the vibration exposure time of the caulkers

Population for study						
Exposed group: 169 caulkers; Control group: 60 electricians, welders, etc.						
		Age distribution (yr)				
		20–29	30–39	40–49	50–59	
Caulkers	*N*	3	62	81	23	mean age ... 40.7 yr
	%	(1.7)	(36.7)	(47.9)	(13.6)	(SD ± 6.5)
Controls	*N*	19	27	10	4	mean age ... 34.8 yr
	%	(31.6)	(45.0)	(16.67)	(6.6)	(SD ± 7.9)
Vibration exposure time: mean = 7.3 yrs (SD ± 6.9)						
		Exposure time distribution (yr)				
		0–5	6–10	11–15	> 16	
Caulkers	*N*	77	74	11	7	
	%	(45.5)	(43.8)	(6.5)	(4.1)	

placed on a thin metal sheet fastened with cyanoacrylate. An average of 35 vibration spectra was recorded for each orthogonal axis.

Vibration spectra were compaired with ISO Draft Proposal No. 5349 (ISO TC 108/SC 4/WG 3) [6].

Constant bandwidth spectrograms (of 400 lines) recorded in the field were transformed to constant percentage bandwidth spectrograms (⅓ octave) in the laboratory of the Applied Mechanics Institute of Trieste University.

Medical Investigations

All 169 caulkers and a control group of 60 workers from the same company were examined at the shipyard. The controls (50 welders and 10 electricians) were never exposed to hand-arm vibration. The age distribution of the population and the vibration exposure time of the caulkers are shown in Table 2.

The caulkers were mostly middle-aged (40.7 yr) and had not had a long-term exposure to vibrations: 90% of caulkers had worked with vibrating tools for less than 10 years.

The medical investigations included: specific questionnaire (containing questions about occupational and ergonomic aspects, osteoarticular and neurovascular complaints, etc.); medical exams; X-ray of upper limb (normally right, and only of the caulkers).

To diagnose Raynaud's phenomenon (or VWF) we recorded the skin temperature of the hands in the control and exposed groups. We have chosen the temperature measurement because of its simplicity and sensitivity for epidemiological purposes. In fact, among objective clinical tests, thermometry is well correlated with flow index as obtained by rheography [4]. In our Institute, photopletismography is not used; there is poor reliability because of the warming effect of light, and because of the difficulty of placing the photoelectric cell at the same side for each measurement after a cold-test (a small displacement of the cell causes a great variation in the measurement).

The temperatures were measured in the shipyard between December 1977 and February 1978. The range of external temperature in that period was +3°C/−2°C. The mean temperature of the room was 21.0°C (SD ± 1.5°C).

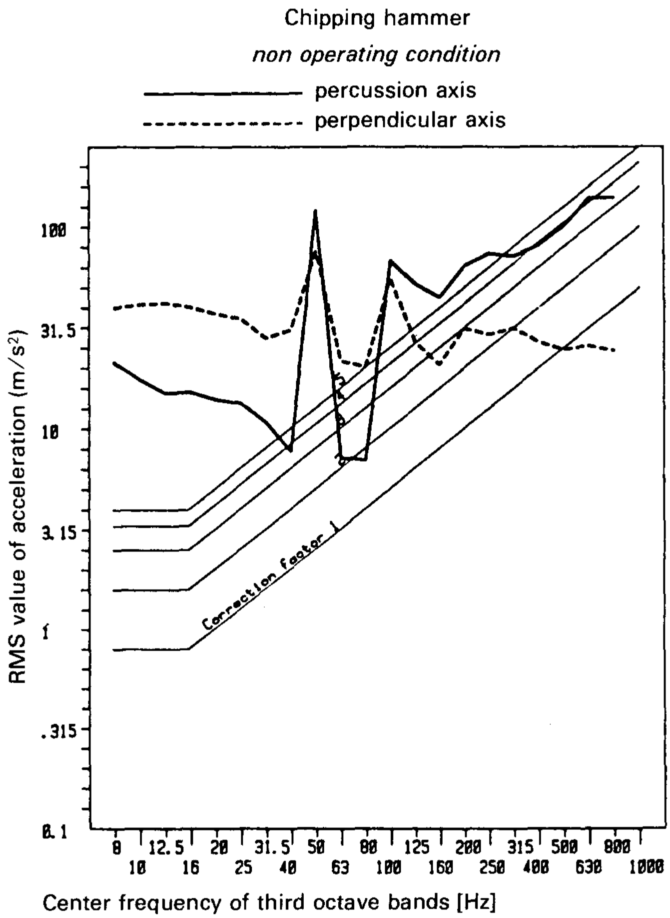


Fig. 2. Vibration spectra of the chipping hammer (non-operating condition)

A basal skin thermometric map was recorded by a resistance thermometer in 16 positions per hand (five phalanges, five distal epiphisis of metacarpals, proximal epiphysis of 5th, 3rd, 1st metacarpals, radial and ulnar side of wrist, ⅓ distal of forearm). After basal measurements we monitored (at middle phalanx of 3rd left finger) the curve of skin temperature recovery. This was done every 3 min for 40 min after provocative cold-test. The test was performed as recommanded by the Italian Society of Occupational Health (1978).

The subjects immersed their hands, up to the wrists, in melting ice (5° C) for 2 min. Then the hands were placed on a table, kept still, and dried carefully, so as not to change the temperature.

Results

Vibration Spectra Measurements

Vibration spectra of chipping hammer, in non-operating (not on metal sheet) and operating conditions are reported in Figs. 2 and 3. The ISO acceptable exposure boundaries for various exposure times (different correction factors) are drawn by a thin line in the background of the graphs.

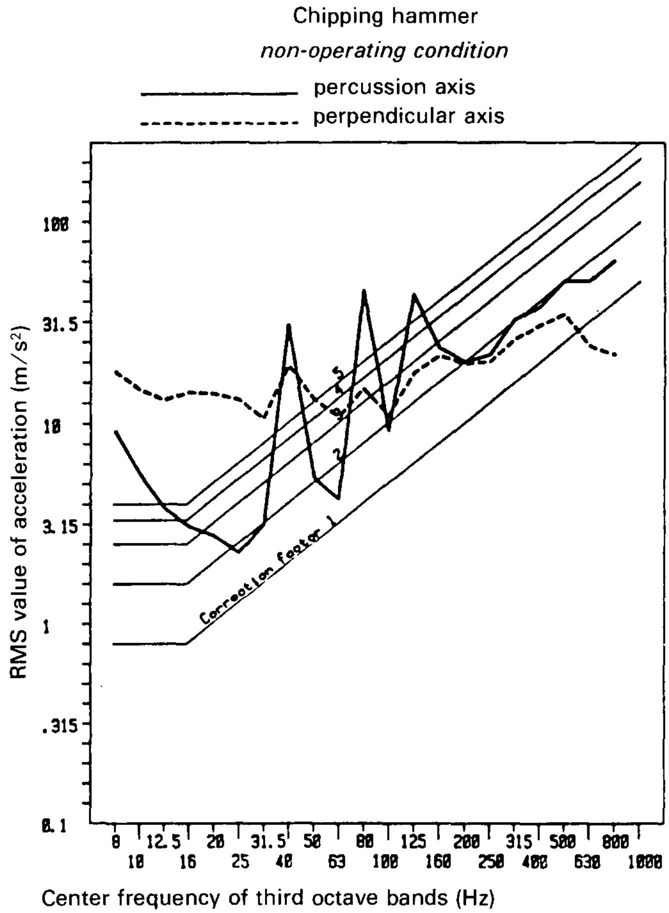


Fig. 3. Vibration spectra of the chipping hammer (operating condition)

The spectra recorded on chipping hammer widely exceed, in all frequency ranges, the maximum levels (correction factor 1) acceptable for usual exposure time of caulkers (5–6 h per shift). The chipping hammer produces a higher vibration amplitude when it is not in operation. This condition is, however, abnormal for two reasons:

a) the caulker hardly ever uses the machine when it is non-operating;

b) the tool in this condition presents a different mechanical behaviour.

The percussive non-operating machine moves back and forth more freely because of its internal active and reactive forces: impact with a hard material is lacking and the operator grips the tool handle with lesser strength.

The spectrograms recorded on the handles of the rotating tools are shown in Figs. 4–8.

Principal frequency acceleration (due to rpm of each tool), and acceleration peaks at frequencies above the fundamental, can be seen in all spectrograms.

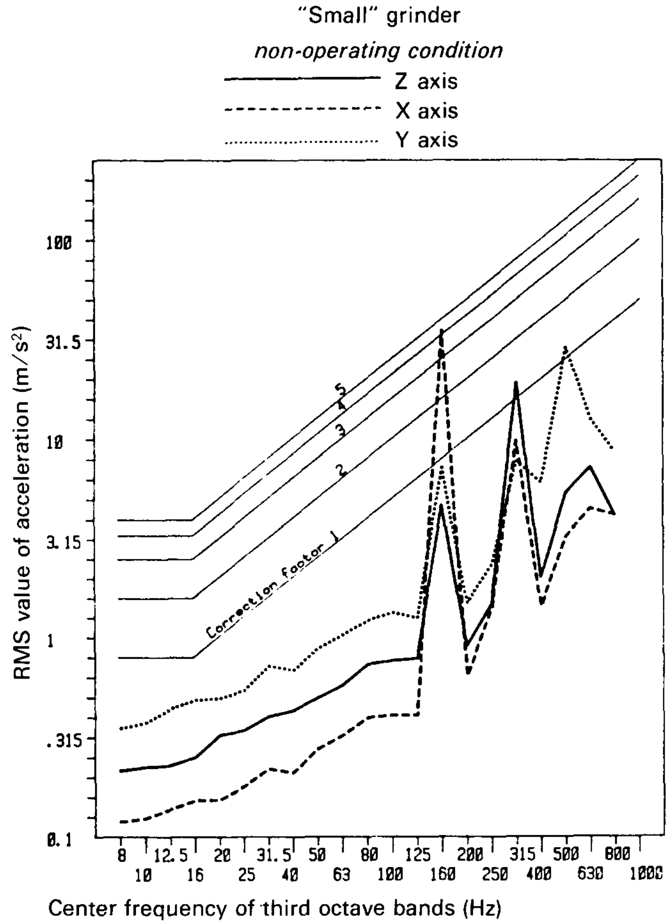


Fig. 4. Vibration spectra of the "small" grinder (non-operating condition)

Vibration amplitudes recorded on the handle of the large grinder never exceed ISO acceptable levels (Fig. 8). The small and medium grinders, unlike the large, generate acceleration levels which exceed exposure limit curves in some one-third octave bands, especially at the principal frequency of the machine. The small grinder spectra (Figs. 4 and 5) demonstrate higher peaks when the tool is not in operation. This effect is probably due to dynamic imbalance of the rotating masses. Different vibration intensities (Figs. 6 and 7) are also recorded on the main and lateral handles of the medium grinder: impulsive mechanical reactions of the workpiece generate the different vibration response of the tool handles.

Medical Investigation Results

The answers to the self-administered questionnaire (Table 3) demonstrated the prevalence of joint and neurovascular complaints among the caulkers and the control group.

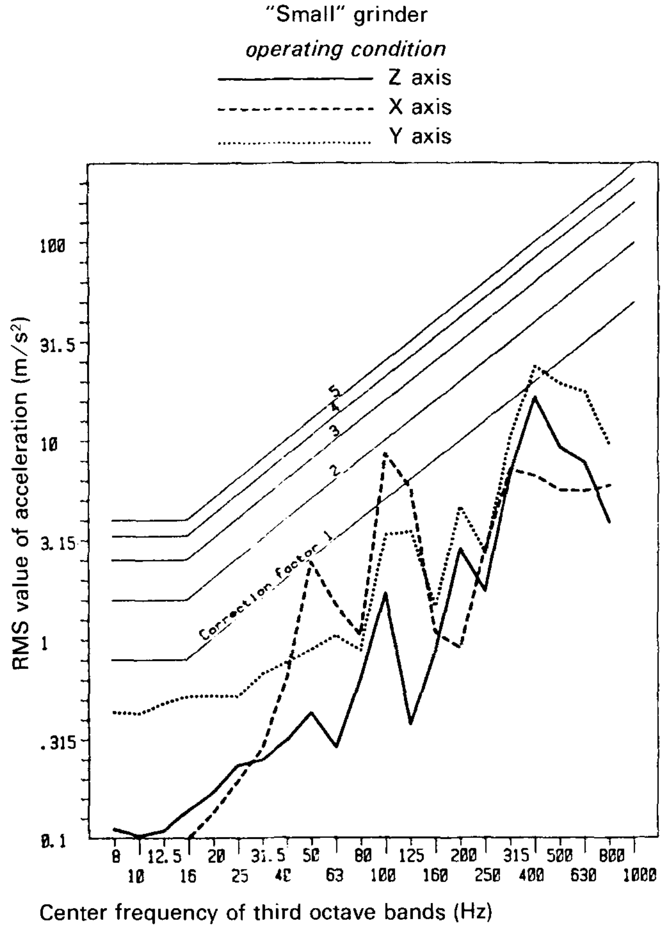


Fig. 5. Vibration spectra of the "small" grinder (operating condition)

The wrist and shoulder were the joints most affected. Many caulkers also pointed out arthralgia elsewhere (back and knees).

Preponderance of symptoms may be due not only to vibrations by themselves, but also to uncomfortable posture (especially when the caulker works in cellular structures), and static tension in the upper limb muscles due to the strength of the grip.

The results of X-ray of the right upper limb are shown in Table 4. The X-rays were not carried out in the control group for economical and ethical reasons.

The radiological findings more often seen in the caulkers are carpal cysts (31.3%), considered by some authors [3, 7] to be typical for vibration disease.

Some data about subjects reporting VWF in the questionnaire are reported in Table 5.

Cold and vibration exposure seem to be the most important provocative factors. During an 8 h shift the caulkers suffering from VWF mainly (42.5% of

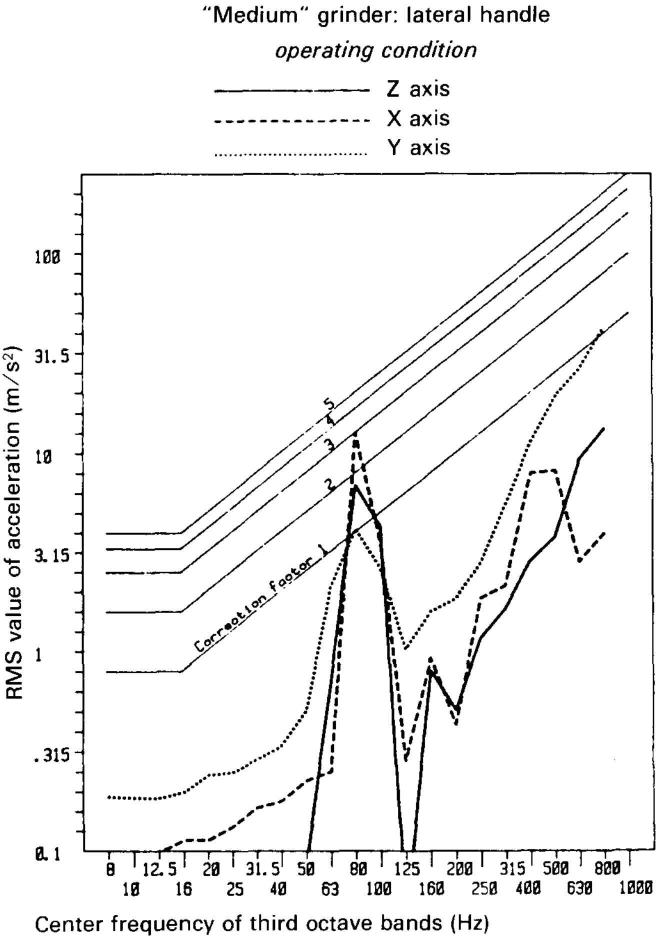


Fig. 6. Vibration spectra of the "medium" grinder on the main handle (operating condition)

the total time; see Table 5) used the chipping hammer which generates an acceleration level higher than that of the grinders.

Caulkers not affected by Raynaud's phenomenon used the portable machines for a different percentage of time during a shift: chipping hammer 32.5%, medium and large grinders 39.5%, small grinder 27.9%.

Statistical analyses (*t*-test) also point out that there is a significant difference ($P < 0.001$) in the total time of exposure to vibrations between caulkers affected by VWF (years of work : mean 10.2 ± 9.0) and those unaffected (years of work : mean 6.1 ± 7.2).

The mean basal skin temperatures, recorded on the dorsal side of the hands in the 16 positions, are reported in Table 6.

The difference between the mean temperatures of the 169 caulkers and the 60 controls was on the average 2–2.5° C. Student's *t*-test confirmed that this difference was, for each position, highly significant ($P < 0.0001$).

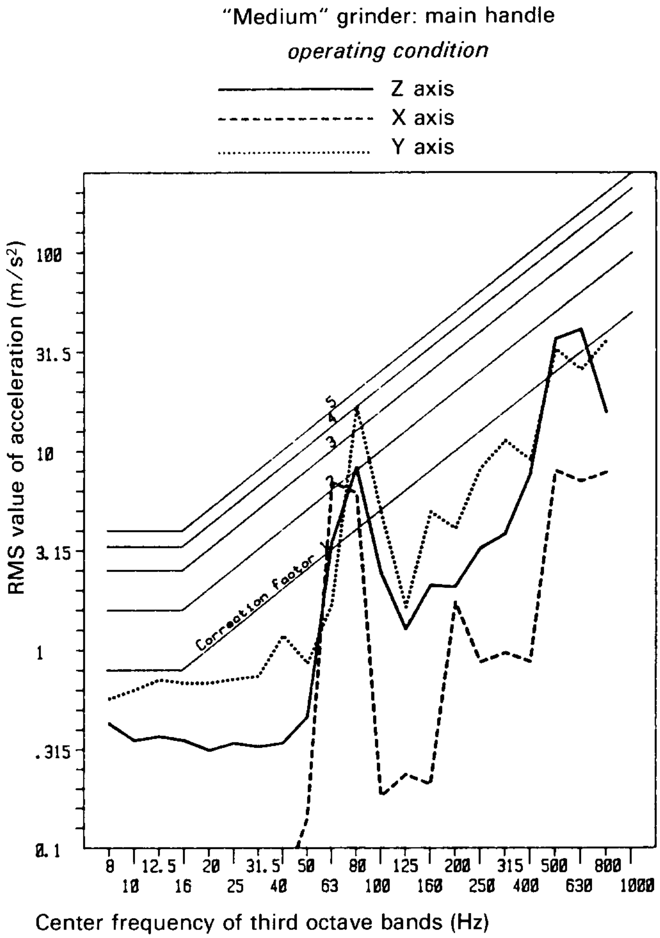


Fig. 7. Vibration spectra of the "medium" grinder on the lateral handle (operating condition)

The curve of skin temperature recovery after the provocative cold test is shown in Fig. 9. The mean skin temperatures of caulkers and controls are plotted against the recording time (every 3 min up to the 40th min).

Although the thermometric curves well differentiate workers exposed and not exposed, neither of the two curves reaches the mean basal value. Among controls there are also subjects with vascular hyperreactivity.

There are few reports in the recent literature about thermometric recovery curves in normal subjects and about the prevalence of vasospasm in unexposed populations. For our epidemiological purposes, the control group represented, nevertheless, an effective reference point and the differences between the mean temperature of two populations at each time of recovery (Student's *t*-test) are highly significant ($P < 0.01$).

The recovery up to 15th–18th min after the provocative cold test (under standardized laboratory conditions) is considered normal in our Institute, as also

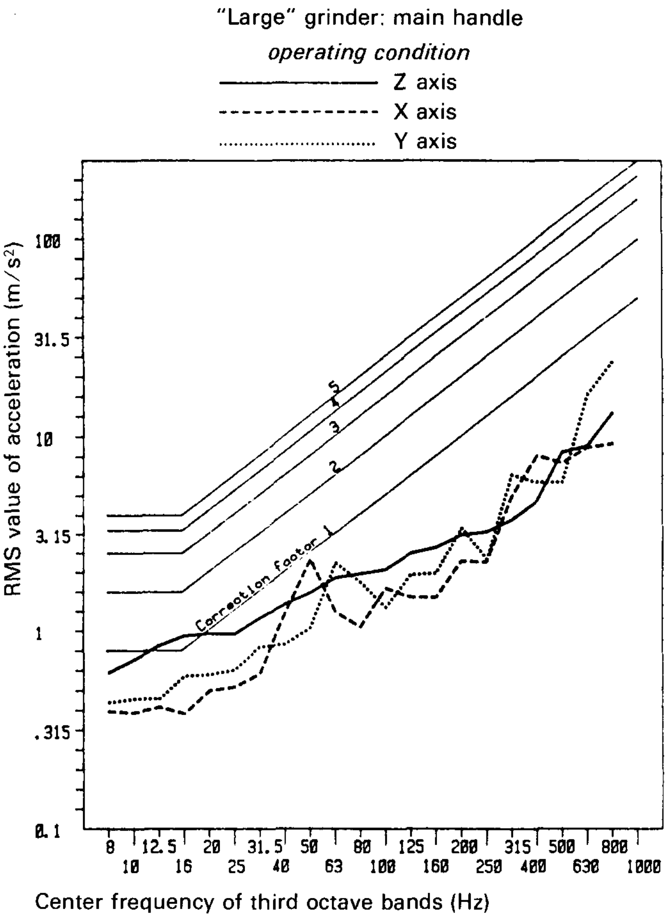


Fig. 8. Vibration spectra of the "large" grinder (operating condition)

recommended by the Italian Society of Industrial Medicine (1978).

Figure 10 shows the cumulative percentage rates of recovery for the two groups.

The graph agrees with what was previously observed: the two groups are differentiated from each other at 9 min. Statistical analysis confirms this difference at every interval, especially at the 18th min ($P < 0.0001$).

Discussion and Conclusions

The results of this survey point out that work involving portable tools is an important occupational risk for shipyard caulkers.

Vibration measurements show that percussive tools, i.e., chipping hammers, are the most powerful source of vibrations. Acceleration levels of operating chipping hammers exceed ISO limits even for short exposure times (30 min). The

Table 3. Questionnaire results: prevalence (%) of joint and neurovascular complaints in the caulkers and in the controls

Questionnaire results				
Caulkers		Answers	Controls	
N	Prevalence %		*N*	Prevalence %
		Joint complaints		
140	82.8	Wrist arthralgia	7	11.6
118	69.8	Elbow arthralgia	3	5.0
135	79.9	Shoulder arthralgia	5	8.3
142	84.0	Complaints rising during work	8	13.3
114	67.4	Complaints rising on awaking	6	10.0
130	76.9	Other joint complaints: back arthralgia	12	20.0
50	29.6	hip arthralgia	3	5.0
85	50.3	knee arthralgia	9	15.0
45	26.7	Former upper limb trauma or fracture	7	11.6
6	3.5	Gout	0	0
7	4.1	Dupuytren's contracture	0	0
		Neurovascular complaints		
133	78.7	Finger tingling	12	20.0
73	43.2	Finger numbness	6	10.0
53	31.3	Blanching + dead finger (Raynaud's phenomenon)	4	6.6

Table 4. Roentgenological findings in the right upper limbs of the caulkers

Lesions of bones and joints	*N*	%
Osteoarthritis		
Shoulder	34	20.1
Elbow	17	10.0
Wrist	34	20.1
Exostoses		
Olecranon	17	10.0
Radius tuberosity	9	5.3
Bone cysts and vacuoles		
Shoulder	3	1.7
Elbow	1	0.6
Wrist-hand	53	31.3

N.B. One case of aseptic necrosis of scaphoid bone

Table 5. History of the caulkers ($n = 53$) affected with VWF

Vibration-induced white finger: 53 caulkers (31.3%)	
Mean age	41.5 yrs (SD ± 7.1)
Mean exposure time	10.2 yrs (SD ± 9.0)
Smoking habits	
Ex-non smokers	17
Mild smokers (0–15 cig.)	16
Heavy smokers (> 15 cig.)	20
Mean hand-tools utilization	% of shift-work
Chipping hammer	42.5% (SD ± 21.4)
Large + medium grinder	33.2% (SD ± 15.2)
Small grinder	24.2% (SD ± 18.9)
Provocative factors	
Cold	41
Smoke	3
Vibration	42
Phenomena duration	
≤ 9 min	18
10–19 min	25
≥ 20 min	10
Affected fingers	
≤ 2 right hand	7
> 2 right hand	19
≥ 2 left hand	7
> 2 left hand	5
Both hands	15

vibration intensity of pneumatic grinders is lower than that of the percussive tool, exceeding the maximum ISO permissible levels (for 4–8 h) only in a few frequency bands.

The results of both the questionnaire and medical examinations demonstrate a high prevalence of neurovascular complaints in our population.

Among 169 shipyard caulkers, 53 (31.3%) are suffering from Raynaud's phenomenon of occupational origin (VWF). According to Taylor's classification the subjects with vibration disease are in stages 1 and 2 (that is, there was no definite interference at work, at home, or with social activities). In the control group, the prevalence of Raynaud's disease (6.6%) is comparable with other reports in the literature [11].

It is well known that intensity and duration of exposure to vibrations, in addition to other provocative conditions, are the critical factors in the pathogenesis of VWF. Our study confirms that the portable tools which generate higher vibration levels (i.e., chipping hammer) were used more frequently during a

Table 6. Mean basal skin temperatures of the hands (dorsal side) of the caulkers and the controls

Recording positions	Right hand (mean temperature in celcius degrees)		Left hand	
	Caulkers	Controls	Caulkers	Controls
Middle phalanx of fingers				
5th	26.0	28.3	25.6	28.0
4th	26.1	28.5	25.8	28.3
3rd	26.4	28.8	26.0	28.6
2nd	26.5	28.9	26.0	28.8
Terminal phalanx of thumb	27.8	29.7	27.3	29.5
Distal epiphysis of metacarpals				
5th	26.4	28.8	26.1	28.7
4th	26.9	29.2	26.7	29.2
3rd	26.7	28.9	26.5	28.9
2nd	26.7	29.2	26.2	28.8
1st	28.3	30.3	27.8	29.9
Proximal epiphysis of metacarpals				
5th	27.0	29.5	26.9	29.2
3rd	27.7	29.9	27.5	29.6
1st	28.9	30.8	28.5	30.5
Radial side of wrist	29.2	31.3	29.0	31.0
Ulnar side of wrist	27.6	29.9	27.4	29.8
⅓ distal of forearm	29.5	31.2	29.3	30.9

shift by the affected caulkers than by the workers who were not affected. The last group was also exposed to vibrations for a smaller number of years.

We found a moderate prevalence of typical ostheoarticular lesions: bone cysts were presents in 31.3% of the caulkers and elbow exostoses in 10.0%.

It is now necessary to consider thermometric methods, the test which we have chosen to evaluate blood flow in the extremities:

1. Skin temperature gives a good indirect evaluation of cutaneous circulation [4] and its measurement is a simple and economic test for screening a large population for peripheral vascular damage resulting from segmental vibration.

2. These methods (basal thermometric map, curve of thermometric recovery after the cold-test, cumulative percentage recovery rates) are consistently able to differentiate between the exposed and the control group even though the tests were performed under imperfectly standardized conditions.

3. Because there are poor data in the literature about the prevalence of vascular hyperreactivity, it is especially important for epidemiological purposes, to compare the prevalence rates of the control-experimental groups. The subjects

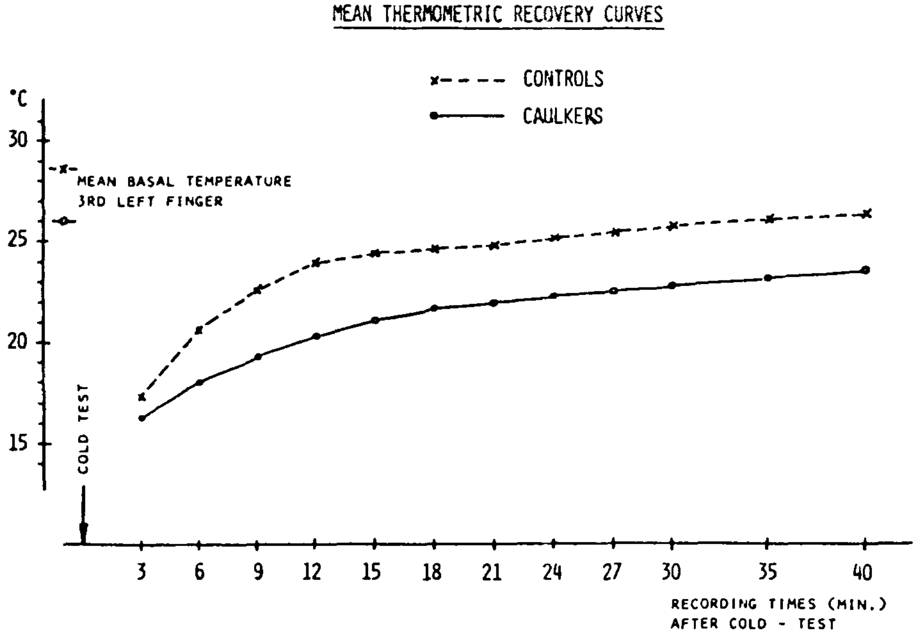


Fig. 9. Mean skin temperature recovery curves of the 3rd left finger of the caulkers and the controls after the provocative cold test. The temperature values are plotted against the recording time (every 3 min up to the 40th min)

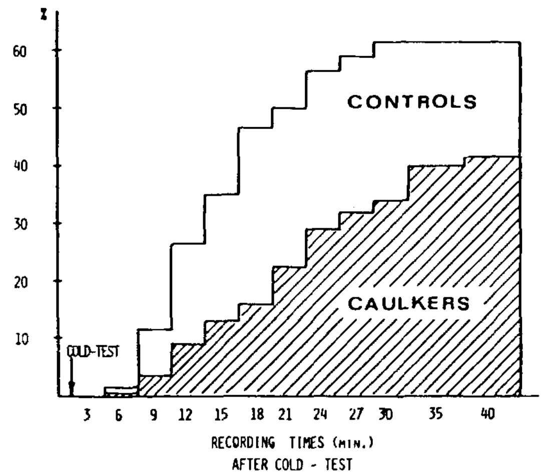


Fig. 10. Cumulative percentage rates of the vibration exposed and the controls recovering the basal skin temperature after the cold test

situated in a zone overlapping the normal and abnormal boundaries, must be studied further with thermometry and rheography under standardized laboratory conditions. This is especially important for developing a medico-legal definition of VWF.

At the conclusion of our survey we have some suggestions for preventative measures:

old tools must be replaced and the mechanical elements balanced periodically;

while the lowering of vibration levels involves complicated technical solutions at the present time, the tool handles should be covered with rubber insulators, and the damping effect of the rubber must be studied (personal gloves decrease the negative effects of cold, but do not reduce the transmission of vibrations to the hands);

because all the caulkers work with both rotating and percussive tools, it is recommended that the maximum daily exposure time to vibrations be shortened to 4 h.

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