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Preface

This multi-disciplinary conference provided an opportunity to:

- exchange information on the potential for injury associated with the usage of vibrating hand-held tools,
- to increase understanding of the mechanisms of injury, to improve methods for exposure measurements and risk assessments,
- to increase knowledge regarding diagnostics and quantitative relationships to exposure, to facilitate understanding of the means of preventing injury.

The proceedings volume laying before you is a compilation of papers which addresses the above mentioned issues and was presented at the Eighth International Conference on Hand-Arm Vibration. The conference was organised under the auspices of:

- International Commission on Occupational Health (ICOH), Scientific Committee Vibration and Noise (SCVN)
- International Advisory Committee of International Conferences on Hand-Arm Vibration
- European Research Network on Detection and Prevention of Injuries due to Occupational Vibration Exposures (BIOMED 2, Contract No: BMH4-CT98-3251).

On behalf of the National Organising Committee, the International Advisory Committee, the National Institute for Working Life, the Västerbotten County, the City of Umeå and my co-editors for this proceedings volume, I wish to express my gratitude to the contributing authors, session chairs, participants, exhibitors and sponsors for making this conference feasible.

Finally, I would like to mention that without enthusiastic work by members of the National Organising Committee, Conference secretariat, staff at NIWL's Programme for Technical Risk Factors and KONFERERA Conference Bureau, this meeting would not have been possible to realise.

Umeå, Sweden, March 2000

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Contents

Page

Vibration and ergonomic exposure

Medical aspects

Vascular effects

Quantative sensory testing, QST

Neurological effects

Miscellaneous aspects

Exposure-response relationship and epidemiology

Prevention, standards and modeling

Posters

Upper limb disorders associated with manual work and hand-transmitted vibration

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Introduction

This paper examines ”work related musculoskeletal disorders” or ”WMSDs” and ”hand arm vibration syndrome” or ”HAVS.” It shows that there are many similarities in the causes and manifestations of these disorders. It also shows that hand and arm exposure to vibration is inherently linked to exposure to ergonomic stresses. Both ergonomic and vibration factors need to be considered when workers present with symptoms of WMSDs or HAVS and in future studies of these disorders.

WMSDs and HAVS

WMSDs of the upper limb are a major cause of work impairment, lost work and compensation in the United States. There is a growing body of literature showing that musculoskeletal disorders may be caused, precipitated or aggravated by certain types of work. The extent to which work is a primary cause of musculoskeletal disorders versus an aggravating cause is subject to debate; however, these conditions are usually compensatable in either case. The term ”work related” was suggested by the World Health Organization for conditions that involve multiple causal factors (1).

The term WMSDs is not a diagnosis; it is a collective name for disorders that involve common risk factors and common intervention strategy. WMSDs may involve bones, joints, muscles, tendons, nerves or blood vessels. Specific examples of WMSDs include tendinitis, synovitis, epicondylitis, carpal tunnel syndrome, hand arm vibration syndrome, or even ”sore hand.” As a practical matter workers often begin to experience symptoms before specific conditions can be accurately diagnosed and the ICD-9 coded ”painful hand or arm” may be an appropriate diagnosis. Reported factors of WMSDs include personal and work related factors. Frequently cited work or ”ergonomic” factors include: repeated and sustained exertions, forceful exertions, contact stresses, certain postures, low temperatures, vibration, and psychosocial stresses (1).

A model describing the relationship between work activities, ergonomic stresses, and various physiological and biomechanical responses was proposed by investigators from several countries (1) and is shown in Figure 1. The distinctive characteristic of this model is that it shows how multiple exposure factors interact with personal and environmental factors to produce a cascading series of events, in which one response is the dose for the next. This accounts for the progression of transient to long term responses, some of which are desirable, e.g., strengthening, and others are undesirable, e.g., tendon and nerve irritation.

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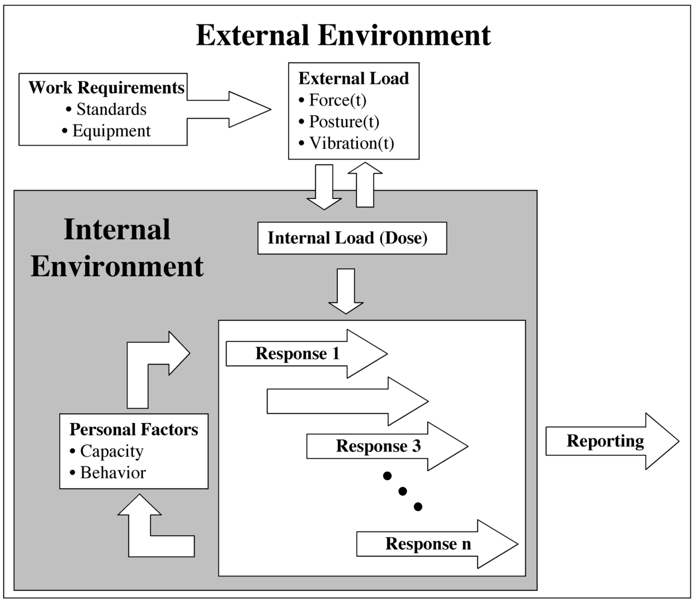

Figure 1. Conceptual Model of the relationship between external physical and social factors and internal responses (1).

Manifestations

Although vibration and related performance/health effects are included in this model, other investigators have treated them separately. Even the current ISO, ANSI and ACGIH (2, 3, 4) standards do not consider ergonomic stresses. It can be argued that HAVS is a subset of WMSDs. Firstly, there are overlaps between symptoms of HAVS and WMSDs. Secondly, hand-arm vibration is inherently linked to ergonomic stresses. Vibration exposure results from gripping something that shakes. Gripping requires force and may be performed for large portions of the work shift. In addition it may be combined with stressful postures, contact stresses and low temperatures. And thirdly, there may be interactions between vibration and ergonomic risk factors. Vibration affects how we hold and use tools and may result in exerting more force than is necessary (5).

According to the 1986 Stockholm Workshop HAVS includes vascular, sensorineural or musculoskeletal disturbances (6). There is evidence that some of these conditions are unique to vibration exposure, notable examples include circulatory impairments and certain nerve conditions described by Lundborg et al. (7), Brammer et al. (8) and Bovenzi (9). Other outcomes may be associated with ergonomics or vibration; an example of this is seen with carpal tunnel syndrome or CTS. Sensorineural effects of carpal tunnel syndrome are consistent with the Stockholm 1986 classification of HAVS, e.g., numbness, tingling, reduced tactility, and reduced dexterity (6). Nerve conduction tests are generally regarded as the definitive test of CTS; however, abnormal conduction findings are not always associated with symptoms.

Homan et al. (10) examined 822 workers using the same protocol for each, i.e., health/symptoms history, physical examination and electrodiagnosis. The results shown in Figure 2 display a conspicuous lack of overlap between the three health metrics. Of the 822 subjects 37% reported symptoms consistent with carpal tunnel syndrome; 20%

had physical findings consistent with CTS; and 17% had electrical findings consistent with CTS, specifically a median-ulnar sensory latency in excess of 0.5ms. While a total of 54% met at least one criterion for CTS, only 3% met all three criteria and 4-11% met any two criteria for CTS. The results leave a great deal of latitude for investigators and clinicians to interpret the health status of these workers.

In many cases WMSDs and HAVS have similar manifestations and may in fact involve similar mechanisms. Significant associations have been reported between CTS and vibration alone, ergonomic factors alone, and vibration and ergonomic factors together. Chatterjee et al. (11) reported elevated CTS associated with vibration exposures. Bovenzi et al. (12) reported significantly elevated CTS among forestry workers who used chain saws with respect to a control population of maintenance workers not exposed to vibration. Cannon et al. (13) reported significant associations with the use of vibrating tools and repetitive hand work with the former being the most important. Silverstein et al. (14) found significant associations with repetition and force to be the most significant factors, but indicated that vibration might contribute above and beyond force and repetition. Wieslander et al. (15) concluded that vibrating tools, repetitive wrist movements and possibly work causing heavy loads on the wrist all are important in the development of carpal tunnel syndrome.

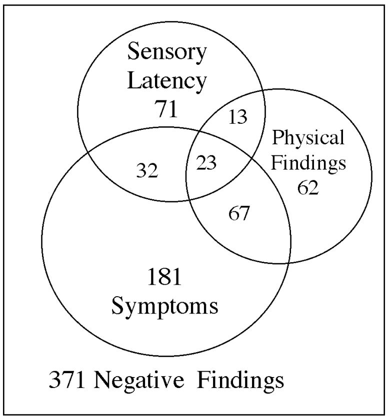

Figure 2. Prevalence of carpal tunnel syndrome symptoms, physical findings and nerve conduction findings among 822 workers (10).

Before engaging in debate over which is the most important, vibration or ergonomics, the circumstances of these studies should be considered. Chatterjee (11) apparently considered only vibration as an exposure variable; at least specific study controls for ergonomic factors were not reported. Cannon et al. (13), Wieslander et al. (15) and Bovenzi et al. (12) performed case-control studies on populations of convenience, so their findings were limited by the domain of work exposures at their respective study sites. The Silverstein study (14) was specifically designed to look at a range of repetition and force; vibration was only considered as a covariate in the analysis after the study was completed. Given the statistical power and size of these studies, it is difficult to show significance between multiple exposures and health outcomes. Vibration is inherently linked to ergonomic stresses. Special efforts are required for controlled observations to evaluate these relationships.

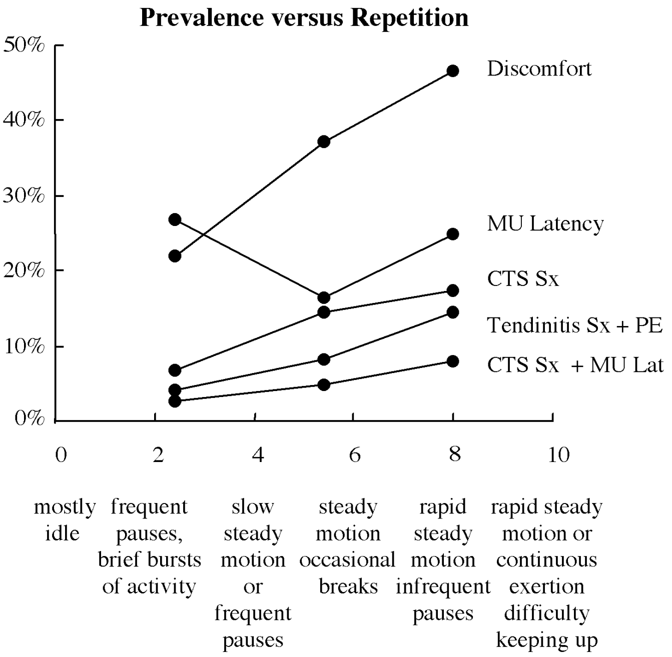

Figure 3. Prevalence of non-specific discomfort, CTS symptoms, CTS symptoms plus median–ulnar nerve sensory latency, tendinitis symptoms and physical findings, and median minus ulnar never sensory latencies among 352 industrial workers (17, 18).

Prevalence Patterns

There is a growing body of literature that supports an exposure-response relationship between ergonomic factors and WMSDs. This literature was recently reviewed and summarized by the National Institute for Occupational Safety and Health (16). Most of the controlled studies hitherfore have compared only two groups - those with high exposure and those with low exposure. While these studies provide important insight into the cause and control of WMSDs, they are not sufficient to establish safe exposure limits. Another limitation with previous studies is a lack of consistency in how the ergonomic stresses are characterized. It can reasonably be argued that an assembly line job, which requires rapid and forceful exertions, is more stressful than an inspector, which requires only occasional use of the hands; however, this characterization of exposure is not easily generalised to other situations. A ratio or absolute scale, which can be used to easily measure these stresses, is needed for comparison and integration of study findings.

Towards this end, Latko et al. (17) proposed a system in which repetition, force, contact stress, and posture are rated on a scale of 0 to 10. (see Figure 3) The scale for rating repetition or ”activity” contains verbal anchor points at two unit increments. Zero corresponds to the condition where the workers’ hands are completely idle. Ten corresponds to the hands moving as fast as possible with no breaks and difficulty keeping up. Similar scales were developed to rate other ergonomic stresses.

These rating scales were used to study the relationship between non-specific discomfort, tendinitis and carpal tunnel syndrome, CTS, and three levels of hand activity. Potential study jobs were rated independently by a team of 4-6 people masked to the health status of the workers. The ratings were then discussed until raters attained consensus, which was defined as + or –0.5 points on the 10 point scale. Similar ratings were performed for other ergonomic stresses, e.g., force, contact and posture stress. Three groups of low, medium and high activity jobs were selected at each of three factories. Mean values of activity of 2.4, 5.4 and 8.0 corresponded with low, medium and high activity levels. Other ergonomic and personal factors were treated as covariates.

Independent health assessments then were performed on 352 workers by a medical team masked to the exposure status of the workers. The evaluation included a health and symptom history, a physical examination and an electrodiagnostic evaluation. The results summarized in Figure 3 exhibit an exposure-response relationship. It can be seen that non-specific discomfort is the most prevalent finding, ranging from a prevalence of 20% for jobs with an average repetition rating of 2.4 to a high of 50% for jobs with a rating of 8. The prevalence of CTS based only on symptoms range from 7% to 17%; hand and wrist tendinitis from 4% to 14%; and CTS based on both median minus ulnar nerve sensory latency and symptoms from 3% to 8%. The only health metric that was not significant was electrodiagnostic findings irrespective of symptoms. No other ergonomic factor was significant. Overall this study supports a strong exposure-response relationship between repetition and health comfort/health outcomes. Several interesting questions arise from this study. One, what is an acceptable level of exposure? With chemical agents we set the safe exposure limit where it will protect most or all of the workers. If that were done here it would have a profound impact on production rates. It is doubtful that it would be accepted by industry or by many workers.

A second question pertains to the response variable and the criteria for determining safe work limits. Many clinicians in the United States prefer objective measures, such as electrodiagnosis, yet by itself, it was the only factor not significantly related to repetition or for that matter other symptoms. These findings suggest that symptoms should work as well as the more sophisticated tests for epidemiological studies concerned with finding safe exposure limits. From a workers standpoint, pain is an important variable in its own right. It is well established that low back pain can be a disabling condition.

A third question is concerned with other ergonomic stresses besides repetition. The study was specifically structured to look at repetition. Consequently the statistical power was greatest for this factor. Other factors, such as force, contact stress and posture tended to be confounded across repetition groups. Studies need to be designed with sufficient statistical power to critically examine other ergonomic factors also are important. As a practical matter, however, it is harder to isolate some factors than others and the sample size required for looking a multiple factors in the same study would be quite high. It is becoming increasingly difficult to find stable work populations with consistent exposure histories for these types of studies.

Pathogenesis

It is likely that there are many common elements in the pathogenesis of HAVS and other WMSD. Armstrong et al. (19) found significant thickening of the epinerium and endoproliferation of the smooth muscle in the arterioles in post mortem studies of the carpal tunnel contents. These vascular changes are very similar to those reported by

Taylor in patients with VWF (personal communication). A common element in both studies is mechanical trauma.

The tissues inside the carpal tunnel are subjected to compression traction and forces from adjacent tendons and to fluid pressures from certain wrist postures. Fluid pressure increases with increasing flexion or extension and with increasing forearm supination and pronation (20, 21). These pressures are equivalent to what would be produced on the feet when standing in a pool half a meter deep.

Depending on the posture of the wrist, there are also mechanical contact stresses acting between the finger flexor tendons and the flexor retinaculum or the carpal bones (19, 22). These stresses are the equivalent to what would be experienced if someone were to step on your toe. These stresses are great enough to interfere with biological processes in tendons, tendon sheaths and nerves and are likely to account for changes in the median nerve inside the carpal tunnel described above (19, 22).

Exposures

Reynolds et al. (23) reported hand-arm vibration exposure times for workers using chipping hammers in a foundry totalling three to three and a half hours per day. Chipping hammer amplitudes exceeded ANSI (3) for even brief exposures. Muscle, tendon or nerve symptoms among these chipping hammer users likely would be diagnosed as HAVS due to the conspicuous vibration exposures. The vibration, however, is also accompanied by prolonged and forceful gripping of the tool. To illustrate this, a chipping hammer job was simulated in our laboratory. The tool was operated against a casting, then moved to a second location and the process was repeated. The tool run and move times were approximately two seconds each. The tool was supported by a spring so only a small amount of effort was required to stabilize it when it was not running. The job required steady or near continuous activity and would be scored between six and eight on the repetition scale by Latko (17). Thus, there would be an elevated risk of WMSDs based on repetition alone.

Figure 4 shows the tool vibration and right hand finger flexor surface RMS-EMG for a simulation of two and a half work cycles. The mean RMS-EMG value is approximately 45% MVC. Recommended exertion limits for preventing fatigue range from 0-15% MVC for sustained exertions (24, 25, 26) and 17-21% for intermittent work (27, 28). The average force of exertion to use the tool is high enough to result in significant fatigue.

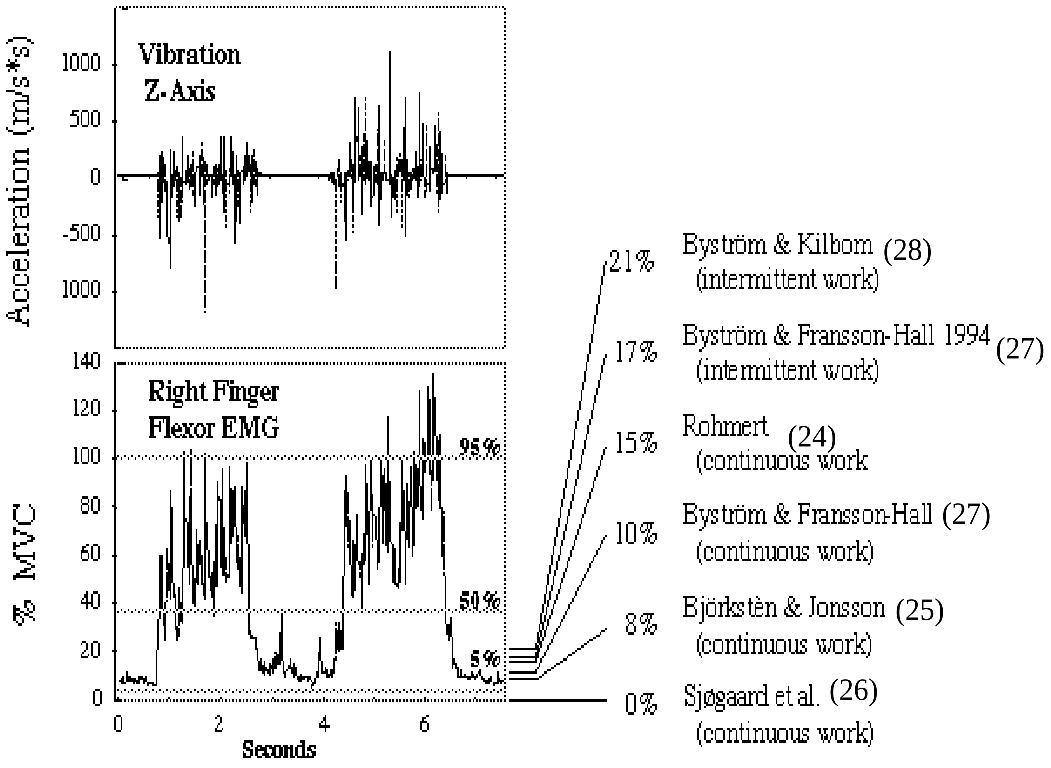

Figure 4. Vibration and Surface EMG recording for simulated chipping hammer job.

It can be seen that the highest EMG values occur when the tool is running and the user is also exposed to vibration. Figure 5 shows an amplitude probability curve for the chipping job. The mode at 6% corresponds to holding the tool and no vibration exposure; the mode at 51% corresponds to operating the tool and vibration exposure. Not only is vibration exposure associated with exertion, it is associated with the most forceful exertions.

Use of the chipping hammer involves high vibration and ergonomic exposures. Both factors should be considered when treating workers with musculoskeletal impairments and in studies of WMSDs.

In addition to vibrating, tools may ”jerk” as they start and stop. Armstrong et al. (29) conducted a study of reaction forces associated with small in-line powered screwdrivers. Reaction forces were first measured at the handle for several widely used tools. Subjects were then exposed to comparable torque profiles while recording surface hand/wrist flexor EMGs. Peak wrist extensor EMGs exceeded 80% of maximum strength to resist torques of 2.5 Nm; reducing the torque build-up time from 450 ms to 50 ms had a comparable effect on EMG as increasing torque from 1.25 to 2.5 Nm. Similar effects were observed for the EMG immediately before the tool was activated. The effects of ”jerk” may easily be confused with those of vibration and repetitive gripping.

It has been suggested that contact between tools and the base of the palm may contribute to carpal tunnel syndrome (30). Contact stresses on the base of the palm are related to force and the area of contact and result in elevated pressure in the carpal tunnel (31). Percussion or pressure on the base of the palm is often used as a diagnostic test of carpal tunnel syndrome. Workers often press on bucking bars and rivet guns with the base of their palms.

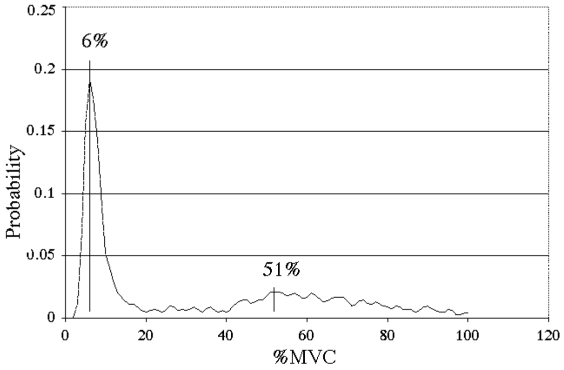

Figure 5. Amplitude probability distribution with one mode at 6% MVC from holding the tool and one mode at 51% MVC from operating the tool.

Another factor of WMSDs is posture. While there is a paucity of epidemiological data on posture and WMSDs, which led NIOSH to equivocate on the contribution of posture, the contribution of posture is supported by laboratory studies and models described above. Posture stresses result when the wrist is flexed or deviated from a neutral posture. Forced flexion is widely used as a provocative test for CTS (22). In numerous psychophysical tests, subjects consistently prefer to work with neutral wrist postures (32). Posture is relatively easy to control via the location and orientation of the work and the selection of the tool. Even in the absence of proof, it is hard to think of a compelling reason for requiring work with acutely flexed or deviated wrist postures when posture can be controlled by re-orienting work surfaces or selecting an alternative shaped tool.

There is a tendency to blame tools and vibration for WMSDs in manufacturing jobs, but the tool is only one component of a complex system. Liftshitz (33) analysed the work activities in the chassis department of an auto assembly plant in which the total incidence of non-specific, tendon and nerve disorders reported was 48.5 cases/200,000. Tool use ranged from only 0-19% of the time, with a median value of 4%; the rest of time was spent holding tools, getting parts or assembling.

Summary

Vibration exposure is inevitably accompanied by one or more physical stresses. It is essential that studies of vibration disorders and future vibration standards also consider ergonomic stresses. Failure to find significant ergonomic factors is often a result of confounding and statistical power. Finally, both vibration and physical work stresses should be considered in the management of workers with upper limb disorders.

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Aspects on hand-arm vibration

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Introduction

There have always been a lot of problems concerning hand-arm vibrations. First of all the attempt to measure the correct amount of acceleration or vibration velocity and then quantify the exposure-response in comparison with the risk of damage. I will give a short revue on the subject of measurements.

Sensor

The type of sensors that have been used for a number of years are sensors that converts mechanical energy to electrical energy. Normally people have preferred accelerometers instead of vibration velocity sensors for hand-arm vibration measurements. There are two different types of accelerometers in connection with hand-arm vibrations:

- Piezoresistive
- Piezoelectrical

The piezoelectric sensor is designed with a crystal of ceramic material which generates a charge when a force is applied to the crystal. The charge is proportional to the acceleration. The first piezoelectrical accelerometers were of compression type. This type of accelerometer produced undesired signals from base bending and temperature transients. A very serious drawback of the compression design is that they do not mechanically isolate the piezoelectric element from non-vibration-related forces. The newer designs were therefore piezoelectric elements which were exposed to shear forces instead of compression forces, see Figure 1 and 2.

The next step for sensor design was to produce accelerometers with built-in amplification and/or accelerometers using constant current supply, in general named ICP- accelerometers.

Mounting

More than 20 years ago there were much research and investigations carried out in the world on how to correctly measure the vibrations transmitted to the hands from a vibrating tool. A main question was:

- How to get the sensor to measure exactly what is transmitted to the hand.

At that time almost all measurements on handheld tools should be done in three directions. The sensors had to be very small and lightweight. The sensitivity was therefore very low. Low sensitive accelerometers may cause more problems with external noise and environmental factors.

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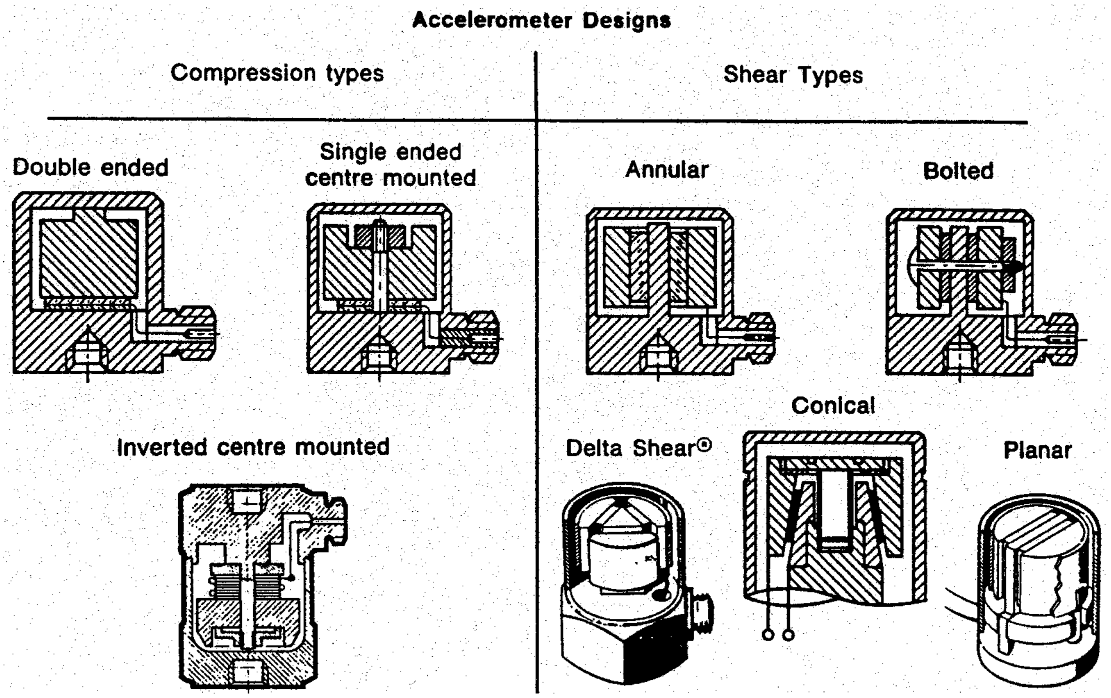

Figure 1. Older and newer types of piezoelectrical accelerometers, compression and shear types.

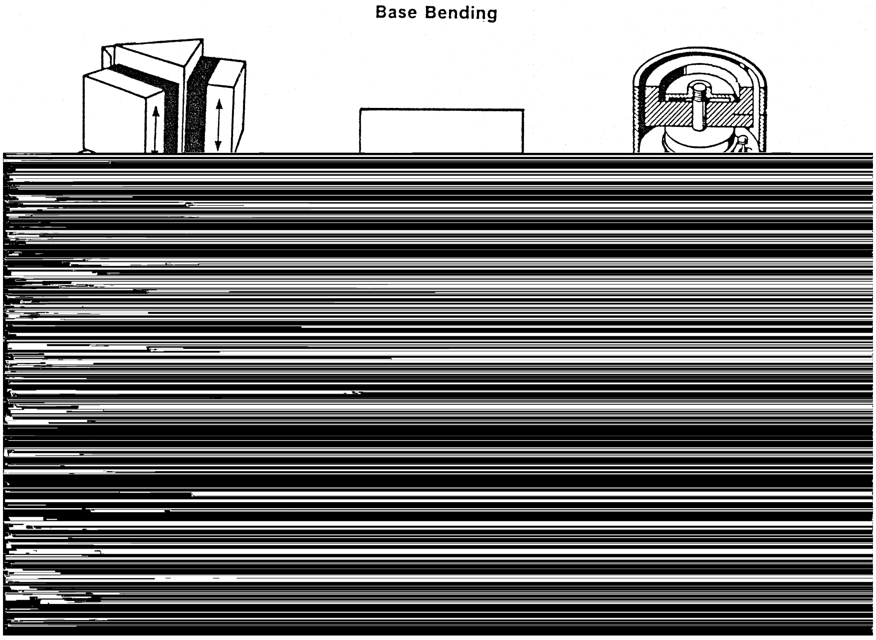

Figure 2. Sensitivity of shear and compression type accelerometer to base bending.

One of the investigations in Sweden pointed out a very small sensor device which should be located between the handle of the machine and the hand. The sensor device included a triaxial (3 x 0,5 grams) accelerometer array. The triaxial accelerometer array was glued to a rather small curved steel plate that was adopted to the handle bar radius. The array was glued to the steel plate. When measuring with this device the triaxial accelerometer array was meant to be placed between the fingers in the middle of the hand.

Two important questions are: How much does the device in fact disturb the normal hand-force and use of the machine? How much will any temperature changes and movements of the cable to the accelerometer influence the signal? In fact nobody knows, therefore the people working with the ISO standardisation choose another way.

In the ISO standard 5349 the measuring directions are given, see Figure 3.

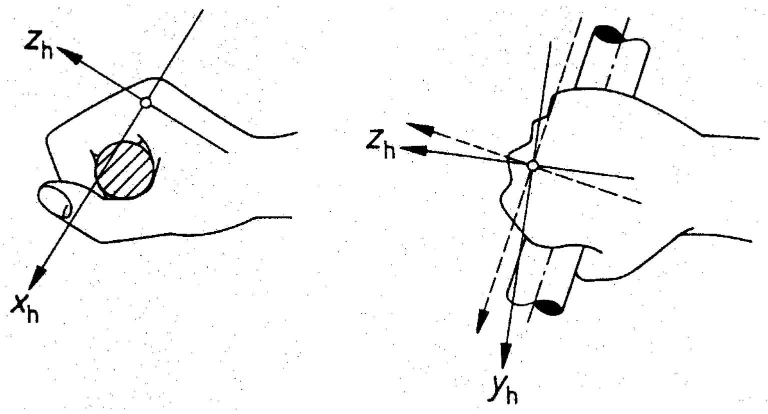

Figure 3. Measuring axis.

In practice a lot of hand-arm measurements on vibrating machine are done with the accelerometers mounted upon the handle, covered by rubber, with a tiny tubeclamp. During the 80´s there were possibilities to use a new device, the Laser Doppler Vibrometer was constructed. With this kind of instrument you were able to make measurements both on the machine, the machine tool and on the outside of the vibrating hand without any additional mass or local stiffness. The Laser Doppler Vibrometer (LDV) do not have any cross axis sensitivity. Most accelerometers have about 5%. But as always there are limitations. The first instruments were rather heavy and big. The laser beam needed to have a reflecting surface and during the measurement the machine needed to be quite still in the axis you wanted to measure. The operator was therefore limited in his use of the machine. If the working operation of the machine caused dust flows, it could disturb the laser beam. In order to get a good signal the distance to the subject should be rather short.

Today there are other possibilities to use very small sized chip. With this kind of chips you are able to measure two directions and in the frequency range 1 - 1500 Hz and have a sensitivity of 300 mV/g, see Figure 4 and 5.

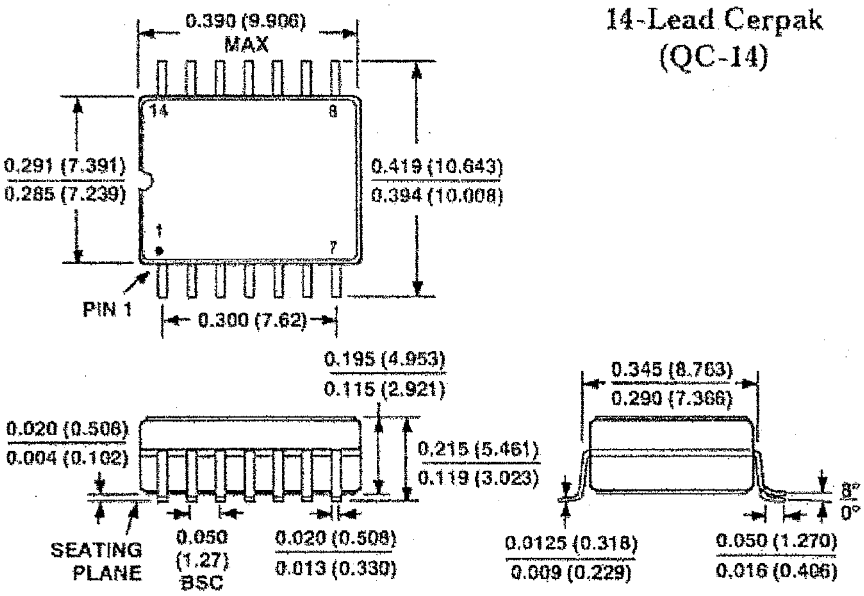

Figure 4. Geometric dimensions of a 2 direction accelerometer chip. Dimensions shown in inches and (mm).

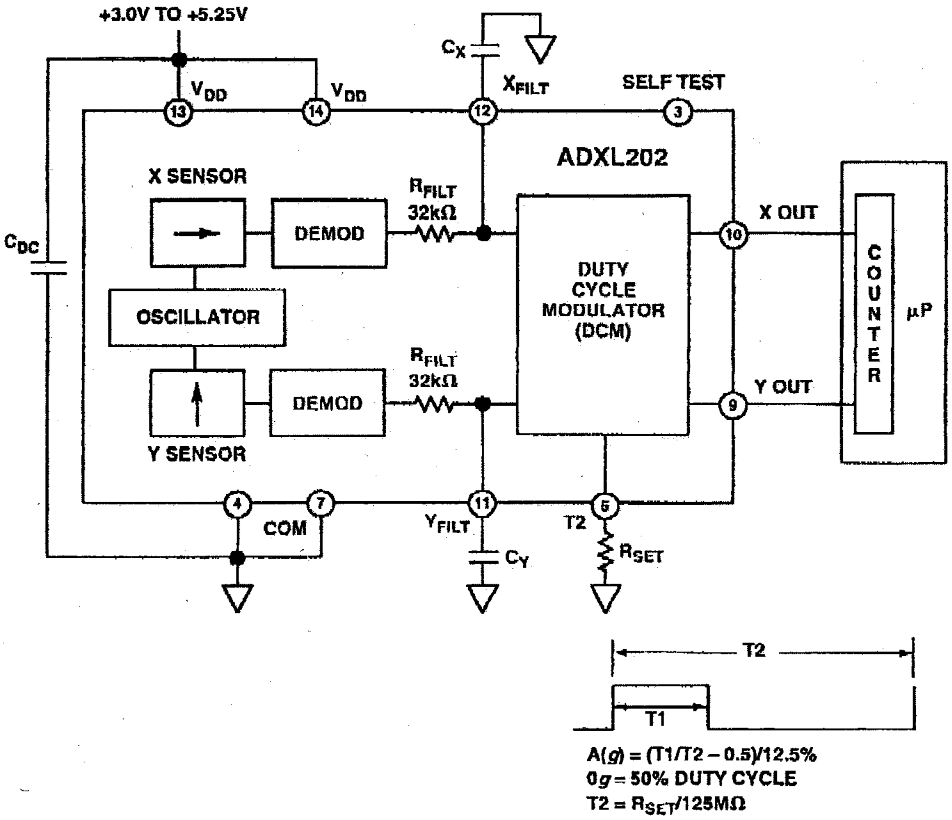

Figure 5. Functional block diagram, accelerometer chip.

Signal conditioning

Signal conditioning is mainly an optimisation of the frequency content and the amplitude of the signals. A usual trap you may fall in is that a low-pass filtered signal from an overloaded amplifier seems to be very nice and correct.

In the 60´s most instruments had a total dynamic range of about 50 dB. I order to get relevant measurements you very often needed to use the whole range. The instrumentation of today normally have a dynamic range of more than 80 dB so many times you are not aware of problems you may have. Sometimes you are analysing the amplified noise floor. If you then do present the acceleration signals as integrated velocity the results in 1/3-octave bands at low frequencies will decrease very smooth with increasing frequency, 5 - 12.5 Hz, see Figure 6. The high levels at 40 Hz and the rather high level at 20 Hz might indicate a bad conditioned hand tool, 40 blows/second. The result at high frequencies is probably influenced by the mounting frequency-resonance of the sensor.

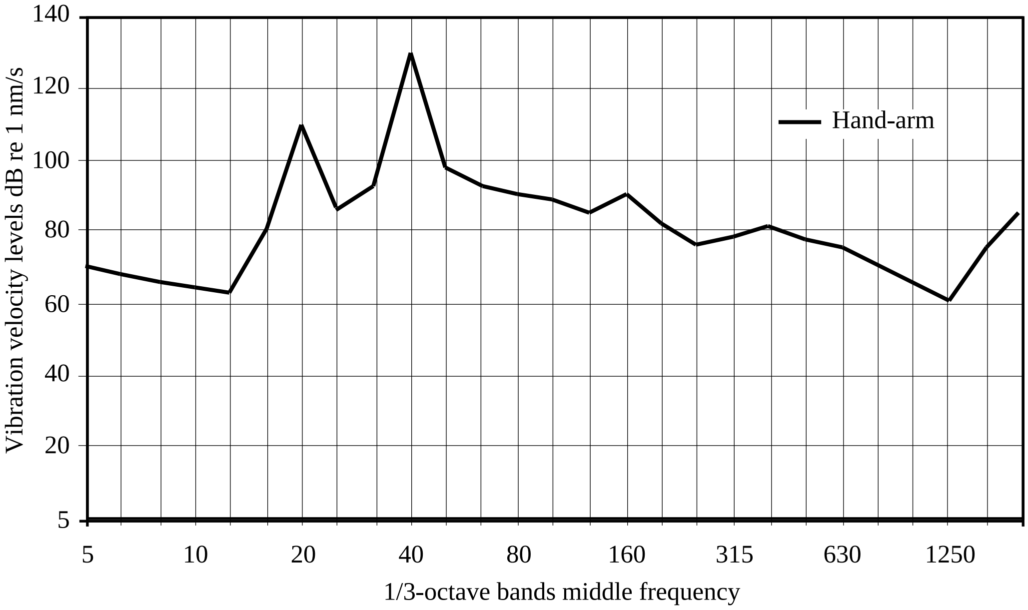

Figure 6. Vibrating handle, RMS.

If you desire to measure vibration on any kind of hammer-machines you will have a problem with the accelerometer. The signal spikes will normally have a huge amplitude at high frequencies above 1500 Hz. Both the accelerometer and the charge amplifier could be overloaded. In order to get a more adapted signal range for hand-arm vibration measurements you need to use a mechanical filter between the machine and the accelerometer.

In Figure 7 the results measured with both accelerometer on the handle and with LDV on a bone in the hand are shown. The results might indicate that the vibration energy in the frequency range above 100 Hz is absorbed by the hand.

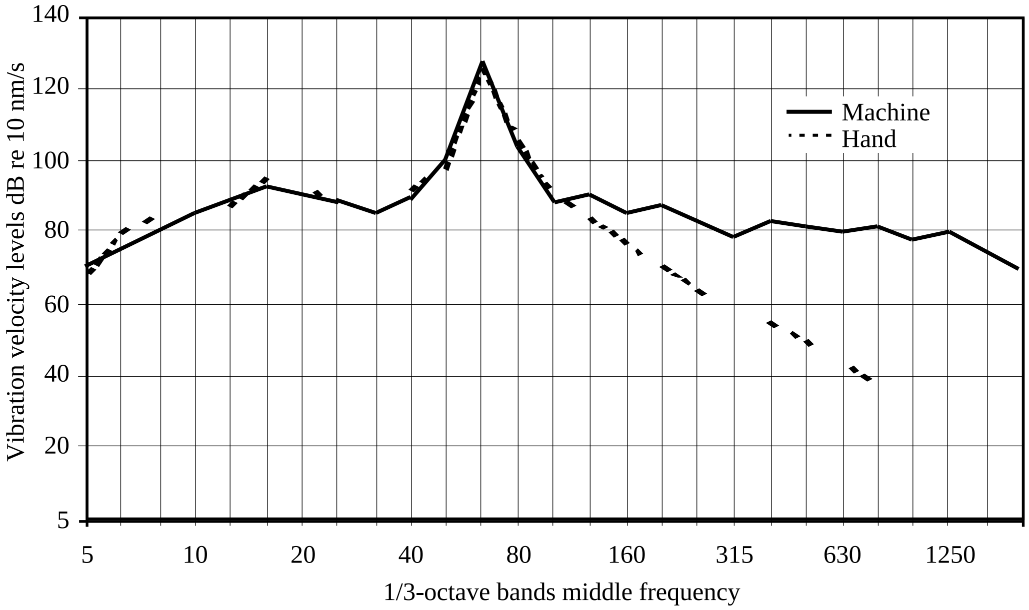

Figure 7. Results measured with accelerometer and laser doppler vibrometer.

Operation condition

The ISO-standard group 8662 say that the measurements on machines should be done with a group of professional operators and the working task should be as normal as possible. My opinion is that this is very important because the difference in measurement results between an inexperienced operator and a professional could be in the range of 2 - 3 times or 6 - 10 dB.

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The vibration pattern of pneumatic hammers

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Introduction

Pneumatic powered hammers are still routinely used in Italy in a wide spectrum of working environments ranging from road construction to mining. Indeed, it is not uncommon to find workers, whose unique source of occupational exposure to hand-transmitted vibration is a tool of this kind, particularly in the mining sector where much use is made of rock drilling hammers.

Rock drilling hammers are known to have a preferential vibration axis along the direction of percussion. Given that the current version of ISO standard 5349 (1) recommends the use of the largest of the three axial acceleration values, one might resort to measuring just the vertical acceleration. Although the draft revision ISO/CD 5349-1 (2) advocates the use of the weighted acceleration total value a_{hv} as an indicator of potential hazard, again this is quantity presumably dominated by the vertical acceleration, in which case a single axis measurement is allowed. On the other hand, studies of several biodynamical quantities such as impedance, apparent mass and absorbed power of the hand-arm system (3) all indicate a large dependance on vibration axis.

In this paper we aim at providing a characterisation of the basic vibrational pattern of rock drilling hammers as complete as possible, including an analysis of the vibration on each individual axis. These tools have traditionally been regarded as good candidates to test the effects on the hand and arm of long-term exposure to large levels (several tens to a few hundred ms^{-2}) of acceleration both at medium (30 – 60 Hz) and at high (> 250 Hz) frequencies. Several low-vibration (”ergonomic”) hammer models have been developed in recent years. They incorporate vibration dampers in the form of metal springs which significantly alter the vibration pattern. It is important to assess the quantitative impact of these devices. Finally, daily energy-equivalent acceleration values A(8) of involved subjects are calculated and compared to existing limits and action levels.

Similar work is in progress for other hand-held tools (angle grinders, chipping hammers, impact drills) commonly found in this same work area. All the results will be combined in a forthcoming paper with the outcome of a medical survey in an effort to improve the accuracy of existing correlations between long-term exposure to vibration and vascular/musculo–skeletal pathologies of the hand-arm system.

Methods

The r.m.s. accelerations of 28 pneumatic rock drilling hammers of 9 different models have been measured along each axis of two cartesian basicentric reference frames, one for each hand. Axes are oriented according to the ISO standard 8662-3 (4). Table 1 summarizes the characteristics of the hammers in the sample, including the

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manufacturer’s declared noise levels and accelerations. Hammers whose name includes a final S incorporate a sound-reduction device. Different versions with and without sound-proofing have been joined in the same category as they are equivalent from a vibratory standpoint. Hammers whose name includes a final E have both noise and vibration reduction devices.

Our sample of 28 hammers represents approximately 50% of the total population of 59 hammers in use at the end of 1997 in the quarries of Tivoli/Guidonia, the largest travertine production area in Italy.

Table 1. Summary of hammer characteristics and declared values.

Name and Type	Mass (Kg)	f_p (Hz)	L_{aeq} (dBA)	a ms^{-2}	Power (kW)
Atlas Copco BBD 15 E	15.5	42	97±4	3.5±2.5	13.2
Atlas Copco RH 572 E	22.8	34	100±4	3.0±2.3	22.2
Atlas Copco BBD 12 T(S)	11.1-12.1	42-43	97±4	17.5±8.5	14.4
Atlas Copco RH 571 L(S)					
Atlas Copco RH 571 3L					
Atlas Copco RH 571 5L(S)	17.8-18.9	33-35	97±4	3.5±2.5	23.4
Boehler BH 11					
Daap PK 140 L	14.0	41			
Sclaverano SG 16					

Travertine is a comparatively soft stone, which limits drilling times to less than 60 seconds, the hole depth would otherwise exceed the length of the hammer spike. Typical measurement durations have therefore been in the of order 30-45 seconds. All hammers have been measured in situ, while operated by those same workers with everyday experience in their use. Two measurements have been taken on each of the handles, resulting in a redundant measurement of acceleration along the handle longitudinal axis.

The field equipment used includes two Brüel & Kjær accelerometers type 4374 mounted on a Brüel & Kjær adaptor type UA0894, and a four-channel digital recorder Sony PC204A. Off-line analysis has been performed with a real time dual channel frequency analyser Brüel & Kjær type 2144 providing a frequency range extending up to 11.2 kHz.

Results

Table 2 displays axial weighted accelerations, the acceleration total value, and A-weighted noise equivalent levels at the operator’s ear. If two or more hammers of the same model have been measured, the values of axial acceleration displayed are linear averages, and the acceleration total value is the root-sum-of-squares of these three axial averages. The noise equivalent levels of Atlas Copco RH 571L(S) and RH 571 5L(S) have been jointly analysed according to the presence/absence of sound-proofing.

Table 2. Results.

Name and Type	a_x (ms^{-2})	a_y (ms^{-2})	a_z (ms^{-2})	a (ms^{-2})	L_{Aeq} dB(A)
Atlas Copco BBD 15 E	3.23	3.32	5.13	6.91	102.5
Atlas Copco RH 572 E	4.37	3.41	7.63	9.43	102.8
Atlas Copco BBD 12 T(S)	8.68	8.39	16.42	20.38	105.7
Atlas Copco RH 571 L(S)	10.02	7.83	24.71	27.79	108.5 (no sil)
Atlas Copco RH 571 3L	6.99	4.34	19.79	21.43	104.4
Atlas Copco RH 571 5L(S)	9.81	7.59	25.05	27.95	100.3 (sil)
Boehler BH 11	6.79	7.47	18.72	21.27	108.8
Daap PK 140 L	8.45	5.99	22.77	25.01	110.3
Sclaverano SG 16	4.98	3.74	20.19	21.12	104.5

Discussion

Axisymmetry & vertical prominence

No statistically significant deviation from left/right symmetry has been found using a matched pair *t* test (5). Fore-aft acceleration is however higher than left-to-right acceleration by about 25%. This inequality is statistically significant ($p < 0.05$, same test), providing evidence for deviations from axisymmetry. It is unclear whether this is intrinsic to the tools, or if it depends on the operational setup. Defining the average horizontal acceleration as $a_h = (a_x^2 + a_y^2)^{1/2}$, this is smaller than the vertical acceleration by a factor of about 3 in traditional hammers, by a factor of 1.5-2 in ergonomic hammers. This translates into average ratios of acceleration total value to strongest-axis acceleration of 1.12 and 1.30 respectively, in excellent agreement with the value of 1.2 quoted in (2), as well as with previous more general results on hand-held vibrating tools (6). If one or two axis measurements are taken, we recommend that use is made of these two values to calculate the acceleration total value from a_z.

Ergonomicity

Because of the way rock drilling hammers operate, which imply a large, mostly vertical acceleration at the percussion frequency, and because of the ISO/CD 5349-1 weighting curve, which is so strongly biased in favour of low frequencies, the weighted acceleration total value is dominated by the peak in a_z at the percussion frequency. The overall vibration reduction is therefore determined by the damping that can be attained therein. The effectiveness of vibration dampers can be gauged from Figure 1, which displays the ratio of $a_k(f)$ of an ergonomic (Atlas Copco RH 572E) to a non-ergonomic hammer (Atlas Copco RH571 5LS). Vertical damping is much more pronounced at all frequencies, as required and expected. There is a mechanical resonance at $f \approx 8$ Hz, the proper frequency of the springs mounted below the handle. The vertical acceleration is always lowered, and more than halved at the percussion frequency. Vibration reduction along the X and Y axes are more limited, but by no means negligible, as they are largest around the resonance frequency. Additional resonances appear to be present around 100 Hz and 500 Hz in both the X and Y axis response, but their impact on the acceleration total value is marginal.

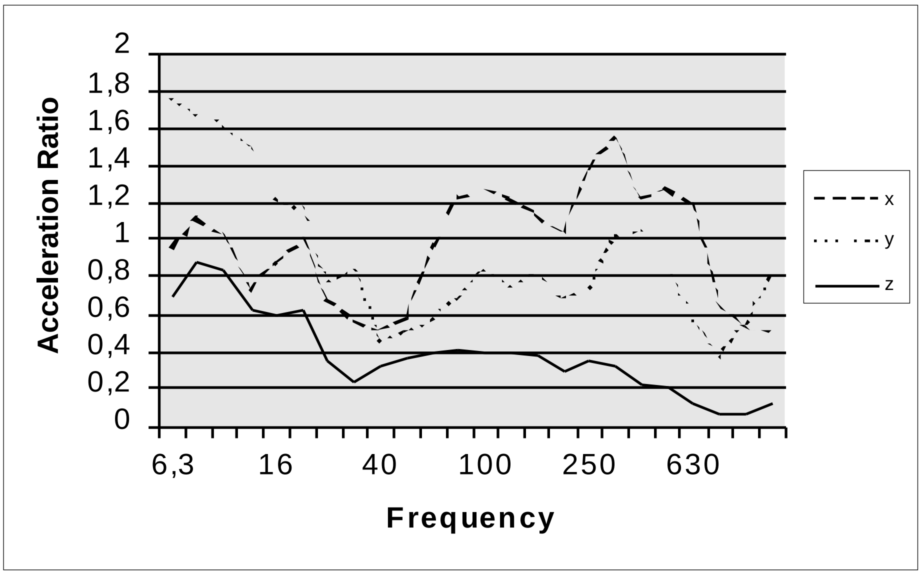

Figure 1. Ratio of acceleration spectra of ergonomic to non-ergonomic hammers.

Correlations with intrinsic properties

A study of 9 hammers of the same model (Atlas Copco BBD 15E) does not reveal any significant difference between young (age ≤ 2 years) and old (age > 2 years) tools. The group comparison *t* test (5) has been used. Spectra are displayed in Figure 2. The observed scatter ($\sigma = 1.6\ ms^{-2}$) can be attributed in part to different operators and their drilling ”style” (posture, push force, grip force); unfortunately neither the push force nor the grip force have been measured. Additional scatter is probably introduced by the poor association between nominal age and actual use. It is reassuring though, that a measurement of acceleration on a brand new hammer (thick line, Figure 2) presents a spectrum, and an acceleration total value just at the lower edge of the set, although still somewhat larger than that declared by the manufacturer (see below).

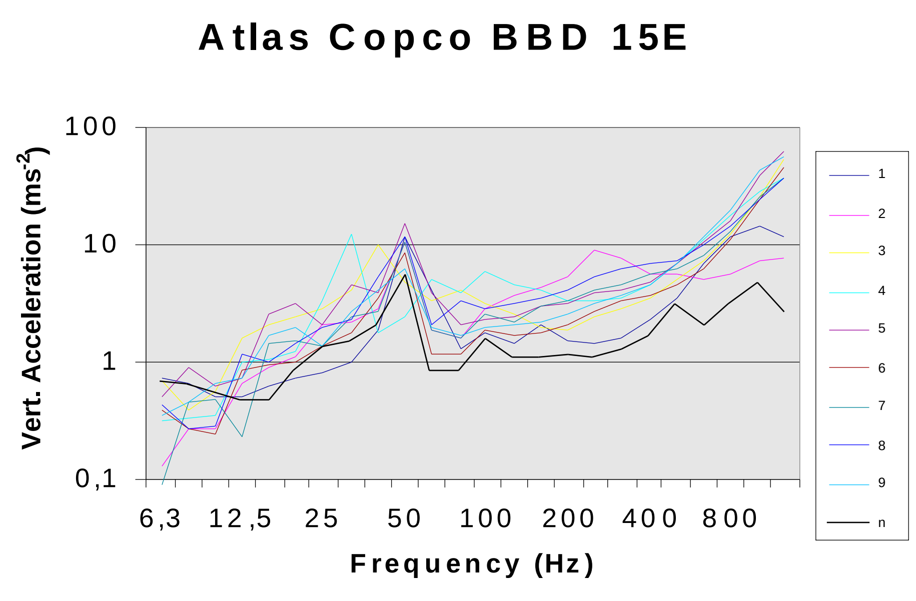

Figure 2. Acceleration spectra of Atlas Copco BBD 15E hammers.

Separate analyses of light (m ≤ 20 Kg) and heavy (m > 20 Kg) traditional hammers do not provide significant statistical evidence for differences between these two groups.

There is, however, a tendency of light hammers to have accelerations at the low end of the range.

The peak frequency is consistently shifted in ”light” hammers (Atlas Copco BBD 15E, BBD 12T) to values larger than the nominal percussion frequency indicated by the manufacturer. This is presumably due to the use of higher than recommended air pressures (usually 6 bar), in order to speed up drilling operations. The data are consistent with declared values in ”heavy” hammers. Since available power is a linear function of air pressure (7), the observed peak frequency shift also implies a 10-15% increase in acceleration.

Comparison with previous studies

Our results have been compared to those of previous measurements (8) on a limited common sample of three hammers (Table 3). Values of a_x are not shown in ref. (8), so they have been calculated using the appropriate a_x/a_y ratio found in this work. Because different tools, different operators and different experimental setups were employed, differences of order 50% are not unexpected, so an overall good agreement can be claimed.

Table 3. Comparison with previous measurements.

	Weighted axial acceleration					
	Ref. (8)			This paper		
Model	a_x ms^{-2}	a_y ms^{-2}	a_z ms^{-2}	a_x ms^{-2}	a_y ms^{-2}	a_z ms^{-2}
Atlas BBD 15 E	4.51	3.35	3.58	3.23	3.32	5.13
Atlas RH 572 E	6.16	4.99	7.44	4.37	3.41	7.63
Atlas BBD 12 T	4.90	3.95	14.55	8.68	8.39	16.42

Noise

Correlation of acceleration total values with A-weighted noise levels is remarkably good, particularly if we consider that noise is mostly of aerodynamic nature, as it is generated by the compressed air exhaust system, while vibration is due to the mechanical motion of the hammer piston. On top of that, acceleration and noise weighting curves have very dissimilar shapes. Noise spectra clearly show the peak associated with the percussion frequency, as well as a second peak at the 1st harmonic; there is a mid-frequency shallow section, followed by a new rise at high frequency. Apart from the peak at the 1st harmonic, this is strongly reminiscent of acceleration spectra. Sound-proofing devices provide a reduction of 8-10 dBA. Manufacturer declared noise levels closely match the lower envelope of measured values, in line with expectations.

Manufacturer declared values

Manufacturer declared acceleration values tend to be substantially lower than measured values, in line with studies of other hand-held tools (9). This is not unexpected, given the idealised conditions which characterise standard tests. Measurements taken on brand new hammers close the gap somewhat, but do not entirely reconcile field with laboratory results.

Daily energy equivalent acceleration values

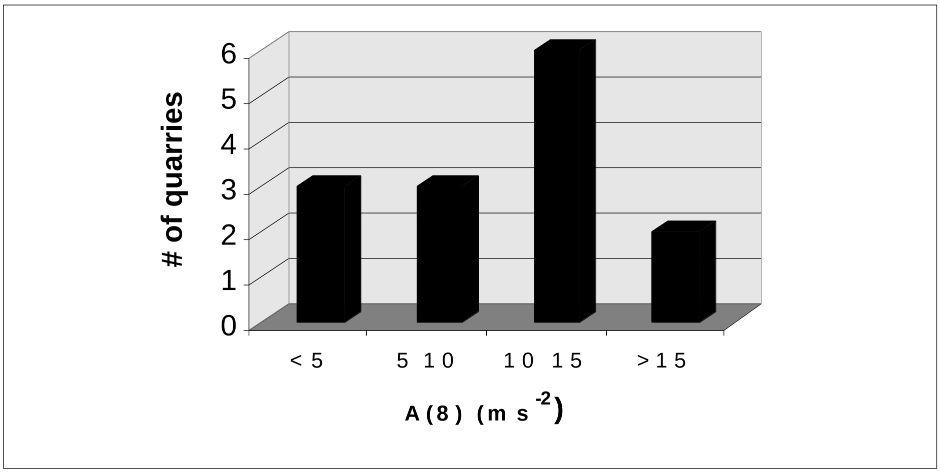

Figure 3. Histogram of daily energy-equivalent A(8) values.

In order to calculate daily energy-equivalent values, all hammer accelerations and associated exposure times have to be known for each exposed subject.

If the acceleration of a given hammer has been measured, that value has always been used. If that was not the case, but hammer(s) of the same model have been measured in the same quarry, their average acceleration total value (see, Results) has been used. Otherwise, the overall average acceleration value for that hammer has been adopted.

Employer declared values and employees self declared values are both viable options to estimate exposure times. Because of the effect of exposure time on daily energy-equivalent acceleration values A(8), the former understandably tend to underestimate, the latter possibly to overestimate real values. Our calculations are based on employer declared working times (40-210 minutes per day).

A sensible mean value can be calculated assuming that each subject has identical exposure times to all the hammers he has access to. In this case, all workers operating in a given quarry have identical exposures. An upper limit to A(8) can also be computed, assuming that work is entirely performed using the highest-acceleration tool. This is hardly a real possibility, since operators usually favour lighter models, as they are easier to move around and use, and these tend to have accelerations at the lower end of the range (see, section “Correlations with intrinsic properties”).

Table 4 shows that, in spite of the wide availability of ”ergonomic” hammers, there are no situations where only low-vibration hammers are used, resulting in daily energy equivalent acceleration values A(8) ranging from 4.7 up to 18 ms^{-2}, mostly in the range 6 to 14 ms^{-2} . These calculated values are all largely in excess of both current (e.g. 2.8 ms^{-2}, (10)) and proposed (2.5 ms^{-2}, (11)) action levels. ISO/CD 5349-1 does not recommend a daily exposure limit, rather a lifetime dose below which the incidence of Raynaud’s syndrome is predicted to be below 10%. Given typical working lives of 15 to 20 years, extrapolation of Figure B.1 of ISO/CD 5349-1 implies limit values of 1.5 to 2 ms^{-2}, 3 to 9 times lower than the values of A(8) shown in Table 4. The much lower acceleration values which characterise ergonomic hammers suggest that if traditional hammers were entirely replaced by ergonomic models, much smaller exposures might be achieved. An idealised situation has been investigated, where work is accomplished using Atlas Copco BBD 15 E for 2/3 of the time, Atlas Copco RH 572E 1/3 of the time. For a total daily drilling time of N hours, we get A(8) ≈ 2.8 $N^{1/2}$ ms^{-2}. Assuming N = 2, a value which is seldom exceeded in practice, we get A(8) ≈ 3.9 ms^{-2}, not far from recommended limits. It has to be stressed, however, that unless exposure times are significantly shortened, professional use of existing rock drilling hammers always results in values of A(8) above the action levels.

Table 4. Energy-equivalent acceleration values.

Quarry	Exposure Time (minutes)	A(8) ms^{-2}	A(8) Upper Limit ms^{-2}
1	120	12.15	13.93
2	150	17.12	17.29
3	15	4.70	5.05
4	180	13.15	17.12
5	112	7.99	10.38
6	90	12.48	12.48
7	210	17.82	23.99
8	40	3.19	8.02
9	60	4.79	6.55
10	120	10.37	14.46
11	60	10.26	11.81
12	120	7.92	9.38
13	80	7.40	9.87
14	60	12.32	14.31

Conclusions

The vibrational pattern of pneumatic hammers shows the expected prominence of vertical motions, but not the expected axisymmetry. There appears to be a good correlation with noise levels. Light hammers and heavy hammers do not show statistically significant differences; the former however tend to be at the low end of the acceleration range. There is no evidence of age being a factor, although brand new hammers do vibrate less than used hammers. Hammers with spring damping of vertical motions (i.e. ergonomic hammers) have much lower vertical and consequently lower acceleration total values. The peak frequency of light hammers is higher than expected based on construction data; vibration levels are always somewhat larger than declared. Daily energy equivalent acceleration values are widely in excess of currently recommended international action values. These might be approached if traditional hammers were fully replaced by ergonomic models.

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The influence of shock-type vibration compared with non-impulsive vibration on the absorption of vibration energy in the human hand

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Introduction

Risk assessment for hand-transmitted vibration is in most countries based on the International Standard ISO 5349 (6). The measurements of vibration according to the standard are expressed in terms of the frequency weighted acceleration, measured on the vibrating surface which is in contact with the hand, the frequency and the exposure time. The standard applies to periodic and random, or non-periodic vibration. Provisionally, this standard may also be applied to repeated shock-type excitation. The knowledge of the effect of shock-type excitation is, however, limited.

Shock-type vibration is often generated by different kinds of percussive tools (chipping hammers, impact wrenches, impact drills, concrete breakers) and is characterised by repetitive impacts, usually with low levels of acceleration at low frequencies and high levels of acceleration at higher frequencies. Each stroke generates an initial transient with very high peak acceleration.

In the international literature there have been discussions as to whether these shock-type excitations of vibration contribute to a higher risk of vibration injury compared with non-impulsive vibration, i.e. harmonic vibration. According to several authors, shock-type vibration might have an underestimated influence on the human and therefore produces a higher prevalence of vascular disorders than non-impulsive vibration (for ref. see (3)). Shock-type vibration has also been associated with effects on the locomotor apparatus of the hand-arm system, especially located at the wrist and elbow (4). Acute effects, such as decreased vibrotactile thresholds due to shock-type vibration, have also been shown to differ from non-impulsive vibration exposures (for ref. see (3)). On the contrary, studies have also been presented where no differences were found between shock-type and non-impulsive vibration.

The assessment problems concerning shock-type vibration exposure have also been emphasized in some studies (9, 11). Proposals for the measurement of transferred force as a basis of assessment of the effect of shock vibration on the hand and arm have also been discussed (7, 10).

A possible method of measuring the influence of shock-type vibration on humans could be to determine the quantity of the energy transmitted to and absorbed by the hand (2). The assumption is that a higher quantity of absorbed energy per unit time (power) represents an increased risk of vibration injury or reduction in comfort. The quantity of absorbed energy is not only influenced by vibration intensity but also by several other factors, such as frequency, transmission direction, grip and feed forces, hand-arm postures, and individual factors (1).

The purpose of the present investigation is to compare the influence of shock-type vibration compared with non-impulsive vibration on the absorption of vibration energy in the human hand and on the grip and feed forces applied by the subjects.

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Methods

The technique used to determine the quantity of absorbed energy in the hand-arm system was based on measurements made as close as possible to the surface of the hand, of vibration force, velocity, and the phase between these parameters. These were obtained by using a specially-designed handle (2) mounted on an electrodynamic shaker. The grip and feed forces applied by the subject to the handle were measured simultaneously.

The vibrations which affect the subjects through the handle were measured and recorded from one hand-held chipping hammer under practical working conditions. From the signals recorded, one typical stroke was chosen. Using a computer program, a random non-impulsive vibration signal was created. The created signal consists of added sinusoidal signals of different frequencies together with a random component. Both the shock-type and the non-impulsive signals had almost the same frequency spectrum. Due to limitations in the shaker the frequency range used was 4 to 2500 Hz.

The study was carried out on 10 healthy right-handed subjects and two different frequency weighted acceleration levels were used. Every subject participated in four experiments and each exposure took about 12 minutes to conduct. In order to investigate the influence of studied variables on the absorbed vibration energy and grip and feed forces, analyses of variance for repeated measurements were carried out.

Results

In Table 1 the mean value and standard deviation of the total quantity of absorbed energy within one-third octave bands with centre frequencies from 6.3 to 2000 Hz are presented. In the table the energy absorption is presented in three ways, for the whole experimental time of twelve minutes, for the first six minutes and for the last six minutes.

Table 1. The average and standard deviation for the energy absorption of the two different stimuli and the two vibration levels presented in three parts, the whole period of twelve minutes, the first and the final six minutes of the exposure time. The standard deviation is presented in parenthesis.

Acceleration (m/s^2)	3		9	
Exposure	Non-impulsive	Shock	Non-impulsive	Shock
(0-12 min)				
Energy absorption (Nm/s)	0.0597 (0.0097)	0.0660 (0.0154)	0.4964 (0.1920)	0.5362 (0.1844)
(0-6 min)				
Energy absorption (Nm/s)	0.0587 (0.0094)	0.0656 (0.0173)	0.4873 (0.1954)	0.5158 (0.1702)
(6-12 min)				
Energy absorption (Nm/s)	0.0607 (0.0103)	0.0664 (0.0136)	0.5054 (0.1915)	0.5565 (0.2027)

Acceleration has a significant influence on the absorption of vibration energy in the hand. During the experiment the absorption increases and is higher during the final six minute period. The statistical analysis also shows that the absorbed energy is higher during exposure to shock-type vibration compared with non-impulsive vibration exposure.

Table 2 shows the mean and standard deviation value for grip and feed forces over the whole experimental time, and also divided into the first and the second halves of the experiment.

Table 2. The average and standard deviation for the grip and feed forces of the two different stimuli and the two vibration levels presented in three parts, the whole period of twelve minutes, the first and the final six minutes of the exposure time. The standard deviation is presented in parenthesis.

Acceleration (m/s^2) Exposure	3 Non-impulsive	 Shock	9 Non-impulsive	 Shock
(0-12 min)				
Grip forces (N)	12.4 (6.3)	13.8 (3.7)	14.0 (4.7)	16.0 (7.0)
Feed forces (N)	13.8 (5.2)	16.5 (3.0)	20.9 (5.8)	23.9 (5.6)
(0-6 min)				
Grip forces(N)	14.5 (6.3)	16.5 (3.8)	16.4 (4.8)	19.1 (7.7)
Feed forces (N)	15.8 (5.1)	18.7 (3.1)	24.4 (6.0)	26.7 (5.9)
(6-12 min)				
Grip forces (N)	10.3 (6.3)	11.0 (3.6)	11.5 (4.6)	12.8 (6.3)
Feed forces (N)	11.7 (5.4)	14.5 (3.0)	17.5 (5.7)	21.1 (5.4)

Statistical analysis shows that the vibration level has a significant influence on the grip and feed forces and that the forces increase when the vibration level increases. Moreover, the analysis show that both the grip and feed forces decrease over the experimental time. Furthermore, the analysis also shows that the grip and feed forces are higher for shock-type vibrations compared with non-impulsive vibrations.

Discussion

The outcome of the present study shows that the vibration level and frequency of the vibration stimuli have a strong influence on the magnitude of the quantity of absorbed energy. The reason for this is probably changes in the dynamic mass of the hand-arm system. When the stimulus amplitude increases, a major part of the hand-arm system is in consequence mechanically activated. The energy-consuming part, i.e. damping mechanisms, of the system therefore increases and leads to the possibility of more energy dissipation. These results are also in accordance with earlier studies (for ref. see (3)).

The results also show that the grip and feed forces increase when the vibration level increases. The difference between the two types of acceleration used were for the grip and feed force about 10 to 15% and 40 to 50%, respectively. One possible explanation could be the so-called tonic vibration reflex (TVR). It is known that TVR leads to an increased contraction of the muscles when the hand-arm system is exposed to vibration. It has also been found that this reflex is related to the acceleration level (5).

The total quantity of absorbed mechanical energy in the human hand and arm is dependent upon whether the exposure is of shock-type or non-impulsive type. This could be concluded since the experimental conditions were controlled, i.e. the frequency weighted acceleration was the same for both types of exposures and almost all of the absorbed energy is related to the fundamental operational frequency. The difference in absorption between the two vibration exposures was about 10%. With regard to the unsubstantiated premise that a higher quantity of absorbed energy represents an increased risk of vibration injury, one could therefore conclude that shock-type vibrations increase the risk of vibration injuries compared to non-impact vibrations. Since the hand forces were also higher during exposure to shock-type vibration compared with non-impulsive vibration, it could be speculated whether observed differences in the absorption are due to the changes in the hand forces.

The grip and feed forces decrease over experimental time presumably due to muscle fatigue. Changes in the grip and feed forces have in earlier investigations been shown to a large extent to contribute to the absorption of energy, mostly due to changes in the transmission of vibration (1). Since the hand forces, in this investigation, decreased with time one would expect that the quantity of absorbed energy also should decrease. However, the results show that the absorbed energy significantly increases with the exposure time. The hand forces decrease about 20 to 30% while the energy absorption increases by 5 to 10%. Since the reduction of the forces will increase the peripheral circulation (8) it can be speculated whether the increased volume of viscous material, i.e. blood, could explain the increased absorption of energy.

Conclusions

It could be concluded that the vibration response characteristics of the hand and arm differ, depending upon whether the exposure is of shock or non-impulsive type. Whenever possible, a tool that requires low grip and feed forces should be used as well as tools that do not generate shock-type excitation. This can be helpful in choosing the proper tool for the job. Moreover, it could be concluded that the international standard ISO 5349 should in future only be used provisionally for evaluation of shock-type vibration until more knowledge is available. Considering the present results, further research appears necessary within this field to clarify the influence of shock-type vibrations on the hand-arm system.

Acknowledgement

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Energy flow in Human-Tool-Base System (HTBS) and its experimental verification

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Introduction

The main aim of our investigations was to describe theoretically the energy flow in a Human-Tool-Base System (HTBS) and its application to optimisation of designs of power hand-held tools. The energy flow has also been applied to an energetic assessment of vibration generated by power tools which are transmitted to a man-operator. The author of this paper began to solve these problems many years ago. The subject matter of the paper is directly connected with the work of Work Group no. 3, ISO TC108/SC4 whose task is the elaboration of an ISO standard for the energy assessment of vibrations transmitted to a man-operator from power hand-held tools. Since 1996 the author has co-operated with this WG and has exchanged papers.

An analysis of the biomechanical HTB System in the energy flow domain has required elaborating theoretical foundations of this physical phenomenon. Publications (2) and (5) were the first devoted to the energy flow phenomenon in a HTB System. In the prepublication (4) and the publications (5, 7) the theoretical foundations of the energy flow in mechanical and biomechanical HTB Systems are presented. The problem was realised by the author as his own investigations concerned with a habilitation dissertation entitled: "Optimisation of energy flow in Human-Tool-Base System (HTBS)", which was also printed in March, 1998 (7). The habilitation dissertation also contains results of experimental investigations of the energy flow in real HTB Systems. In this paper part of the investigation results are presented.

Theoretical and experimental investigations of the energy flow in HTB Systems have been carried out with the use of MP pneumatic chipping hammers equipped with MS13A compressed-air engine and WOSSO anti-vibration subsystem for protection of the man-operator against vibrations.

Methods

A) Methods used in analytical investigations of the energy flow in MTB System

In analytical investigations of the energy flow in a HTB System the First Principle of Energy Flow in Mechanical System (FPoEFiMS) elaborated by the author has been applied (4, 5, 7). The FPoEFiMS correctly defines the relation between fundamental energy fluxes which are flowing through a system, subsystem, element, and degree of freedom.

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The fundamental fluxes are the following: the flux of input energy, the flux of energy output, the flux of reflected energy (stored or accumulated) which equals the sum of kinetic and potential energy and the flux of total lost energy.

The principle of energy flow in a mechanical system has been defined in words (5, 7):

The change of input energy to a mechanical system net (taking into account the change of energy losses) equals to the sum of changes of reflected energy (accumulated or stored) in the system and output energy from the system.

The Principle of Energy Flow in a Mechanical System has the following formula in mathematical notation:

$$\Delta E_{in} - \Delta E_{lo} = \Delta E_{st} + \Delta E_{ou} \qquad (1)$$

where:

- $\Delta E_{in} = L_{e\,f\,in}$ - the change of input energy - equivalent to the work of external forces acting on mechanical system at input,
- $\Delta E_{lo} = \Delta E_{in\,lo} + L_{f\,s\,m\,r}$ - the change of loss energy equivalent to the sum of change of internal lost energy into the system and work of forces of system motion resistance,
- $\Delta E_{st} = \Delta\,(T + U)$ - the change of energy stored or accumulated in a system equal to change of system internal energy, which has been called **reflected energy in a mechanical system,**
- $\Delta E_{ou} = L_{ou}$ - the change of output energy equivalent work of external forces at output of mechanical system.

The FPoEFiMS or a biomechanical system can be presented graphically, as shown in Figure 1.

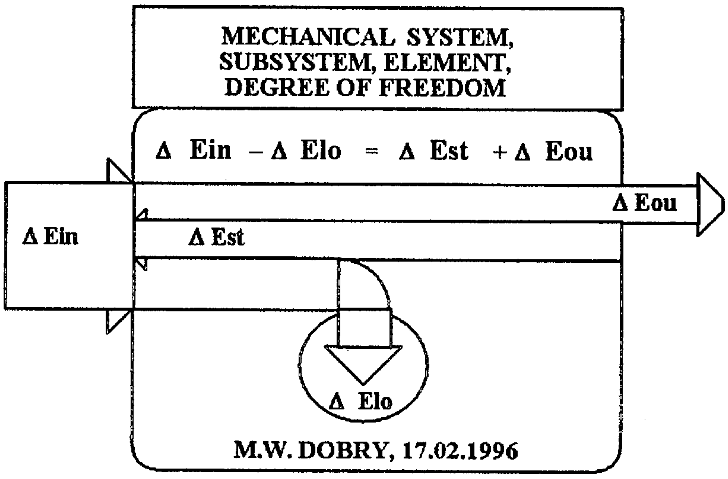


Figure 1. Graphic interpretation of Principle of Energy Flow in Mechanical System (PoEFiMS) and universal model of energy flow in mechanical systems, their subsystems, elements and in derees of freedom (4, 5, 7).

Figure 1 shows fluxes of input, output, lost and reflected energy in a mechanical system in a form of graphic strips of width proportional to the value of energy of particular fluxes. Full width of the strip at input is an input energy to the mechanical system derived from external forces, which equals the sum of widths of all other strips - energy fluxes.

The introduced FPoEFiMS enables the effective analysis of energy flow. In equation (1) the loss energy is not usually known and other energies can be identified in an active identification experiment, i.e. by the monitoring of input energy to the system, output energy from the system and reflected energy by measurement of vibration parameters such as acceleration, velocity and displacement.

The FPoEFiMS enables the calculation of energy flow in the HTB investigated structure. The dynamic structure of the HTB System is presented in Figure 2. This drawing also presents a model of energy flow in HTB System with the use of original graphic signs, the meaning of which is shown in the legend in this figure.

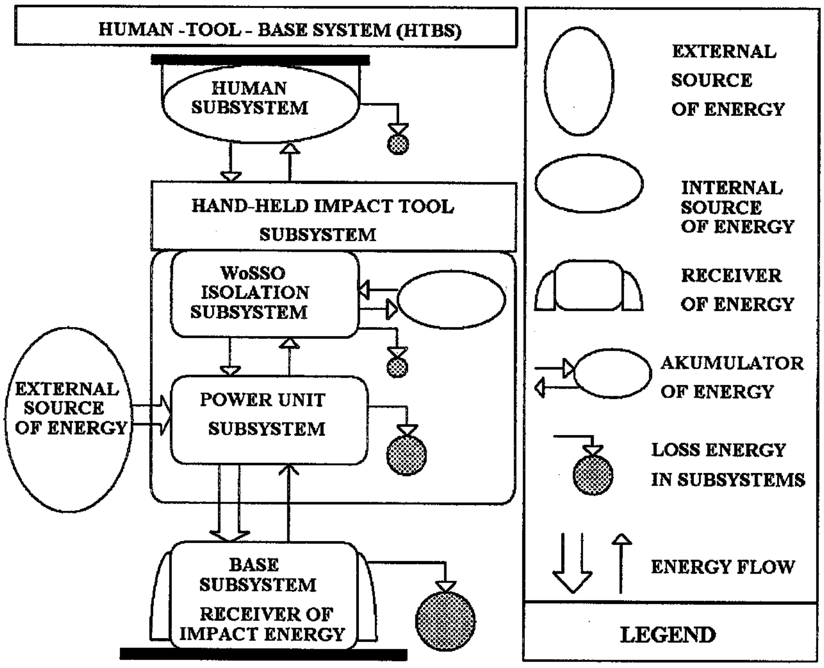


Figure 2. Dynamic structure of Human - Tool - Base System (HTBS) and energy flow model into the HTB System (2, 5, 7).

The defined dynamic structure of HTB System contains the following subsystems: a man-operator, a power hand-held tools and a base on which the tool acts.

Between these subsystems energetic interactions take place which are shown by arrows. The energy flow model describes the energy flow from its supply sources to receiving places in the system and losses in the flow.

Every subsystem contains elements. The calculation of energy fluxes through subsystems first needs the calculation of energy flow through all elements. The symbolically presented structure in the energy flow model is exactly connected with a dynamic model of the HTB System. It means that every subsystem also has its dynamic model. Elaborating the energy flow model was possible thanks to a dynamic model of the HTB System which is presented in the author’s doctoral dissertation (1).

For analytical investigations of energy flow in HTB Systems special computer programs have been elaborated using the MATLAB/simulink program. The results of these investigations are presented in the next chapter.

B) Methods used in experimental verifications of energy flow in the HTB Systems.
Experimental investigations of energy flow in the HTB Systems have included measurements of interaction forces between a man-operator and a tool simultaneously with measurements of vibration accelerations at a handle on a laboratory stand in the Laboratory of Dynamics and Ergonomics of Man-Tool Systems (3). The signals of these physical values were recorded using a multichanel digital recorder. Investigations were carried out with the use of three man-operators and mounted tools in an integrated handle of the test stand.

During experimental investigations three MP pneumatic chipping hammers were used, containing the same MS13A type of compressed-air engine, which were signed in the following way: MS13A+WoSSO - investigated model, MP - first prototype and MPM - second prototype (modernised MP prototype).

A hydraulic impact energy meter was used as the base which has received shocks of work tools.

Recorded signals have been used for calculating of energy doses transmitted to a man-operator or the handle of the stand. Another computer program was elaborated for the calculation of these energy doses. The results of these investigations are presented in the next chapter.

Results

Data obtained from simulations of HTB System dynamics in the form of accelerations, velocities and displacements for all degrees of freedom have allowed the calculation of the input energy distribution in all dynamic structures. It is illustrated in Figure 3. The input energy was calculated on the basis of measurements during investigations of pressure of supply air, its cubic flow intensity, temperature, atmospheric pressure in lab (3, 5, 7). The input energy flux is divided into three fundamental fluxes:

1. energy flux transferred to a beater of compressed-air engine,
2. energy flux transferred to a body of compressed-air engine and
3. energy flux of losses. The variable in time energy transferred to the body of the engine excites its motion and in this way flows directly to a man-operator in case the hand-held tools are without a protection subsytem.

The introduced subsystem of WoSSO isolation into the investigated subsystem of the hand-held impact tools protects a man-operator against transmission of vibration energy. The dynamic interaction of WoSSO subsystem on a man-operator was reduced to minimum in the transformation process of the kinetic energy of the engine body to potential energy of the WoSSO subsystem.

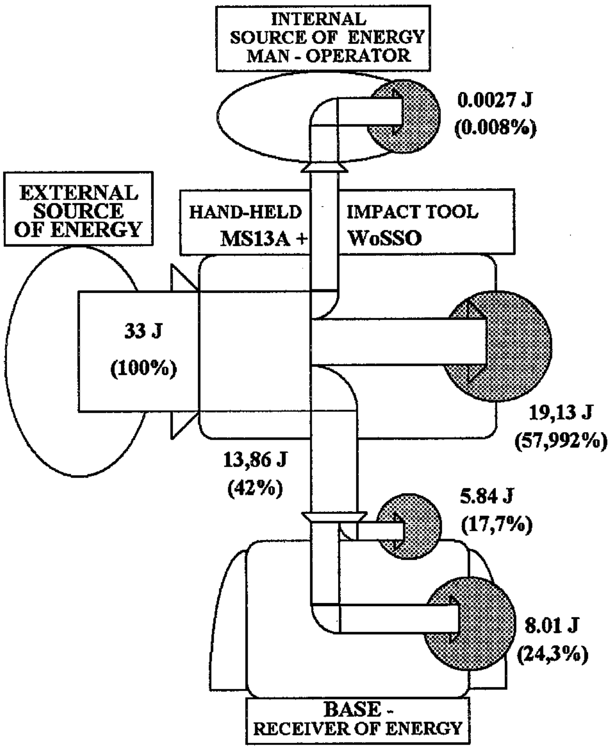


Figure 3. Energy flow in Human-Tool-Base System (HTBS) for vibration-safe and ergonomic pneumatic MP chipping hammer (test model) with WoSSO anti-energy subsystem during one T work period.

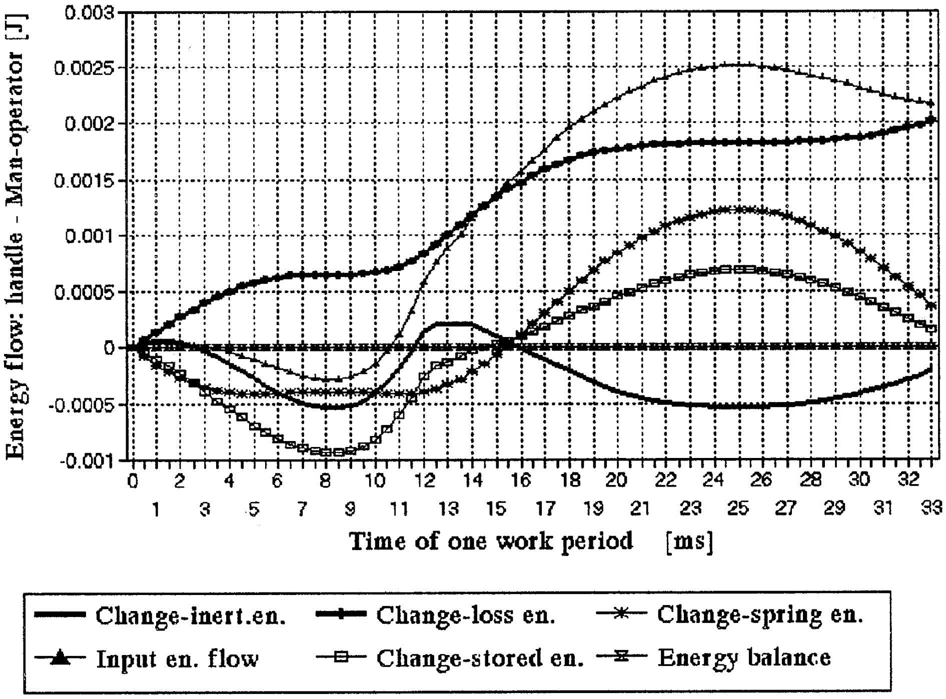


Figure 4. Energy flow during one T work cycle for the palm-handle of a pneumatic hand-held impact tool (MS13A+WoSSO model) with pressure realised by a man-operator through the WoSSO vibroisolation system (5, 7).

Figure 4 illustrates this state in which energy flows (doses) are shown for all kinds of energy and energy balance in a contact point between the man-operator and the tool (on the handle of the tool). For comparison of energy flows of all kinds before the WoSSO isolation subsystem, energy flows to the body of engine are also shown in Figure 5. The energy flow in dynamic structure of the base obtained in the computer simulation is shown in Figure 6.

The results of experimental energy measurements on the laboratory stand are shown in Figure 7. This figure presents the average powers in W, which were calculated as a ratio of energy doses in J flowed to the man-operator to time of expositions in seconds. The time of energy flow analysis in this case was 125 ms.

Discussion

A) Discussion for the analytic investigations

The results of the analytic investigations allow analysis of the energy flow in HTB System for every moment of time "t" in dynamic structure of the investigated system. The presented figures show how much energy in J flows into the investigated system, how it is divided into overcoming of inertia forces, of spring forces and how much energy is lost generally into overcoming resistant forces of motion. in conversion of the energy into heat etc. in every ms of duration of one T work period of the hand-held tool. In the described case T, the work period of the tool was 33 ms (30 Hz of work frequency).

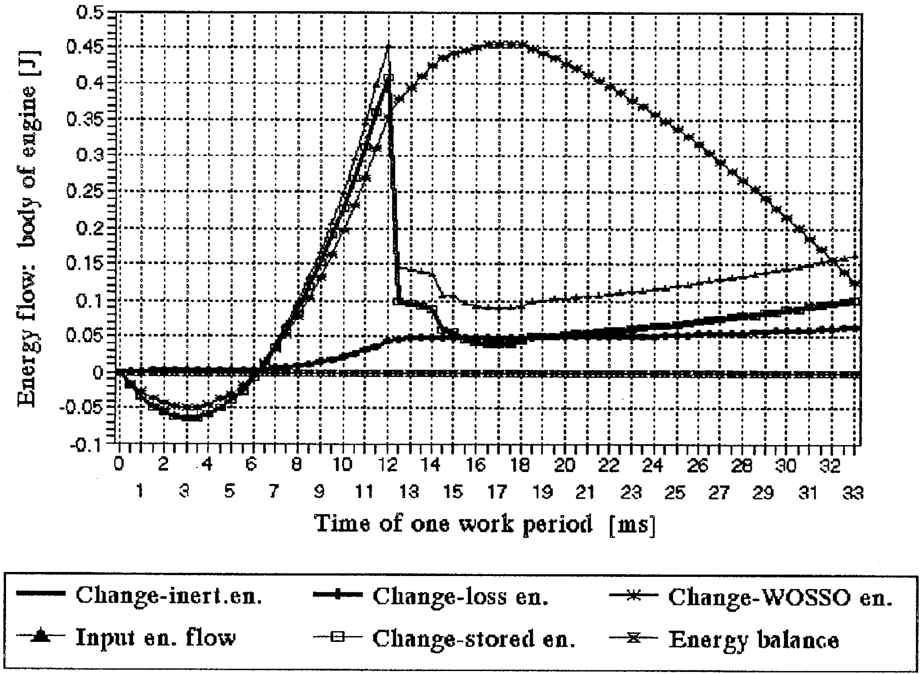


Figure 5. Energy flow during one T work cycle for the body of the compressed-air engine of the hand-held impact tool (MS13A+WoSSO model) with pressure realised by a man-operator through the WoSSO isolation subsystem (5, 7).

The energy flow for the palm-handle shown in Figure 4 gives the answer that the dose of energy which flows into this degree of freedom equals 0.0027 J during one T work period of the tool. In the same time a dose of 33 J flows into the HTB System. These data make possible the calculation of a global coefficient of the energy isolation efficiency of WoSSO subsystem. Its value equals 0.008%. It means that a man-operator is protected very effectively, in this case, against vibration energy transmitted from a hand-held tool. A difference between the value of input energy to this degree of freedom at the end of the T work period and the loss value of energy means that the HTB System is still in transitional process.

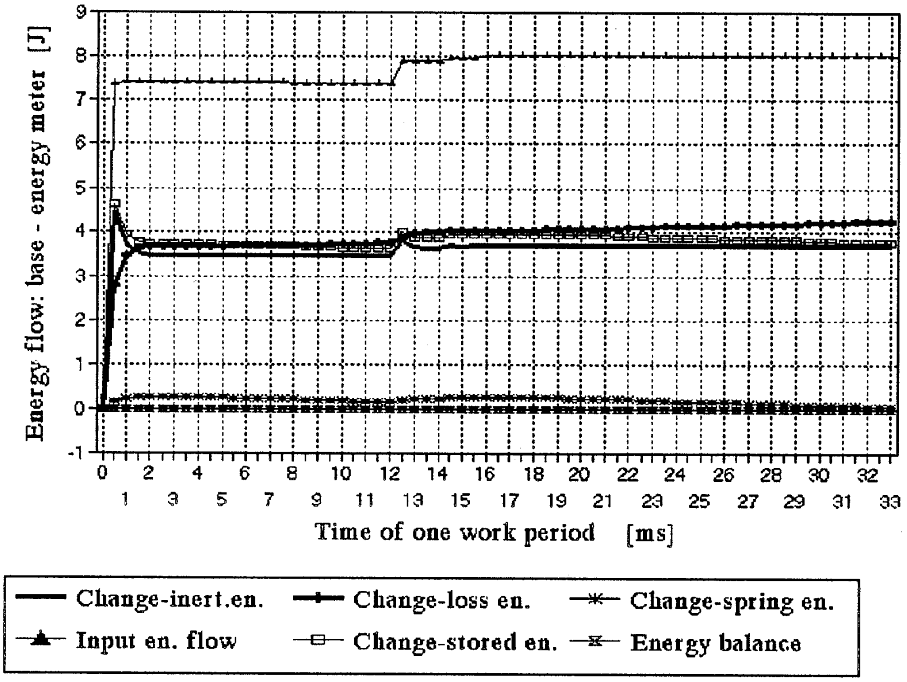


Figure 6. Energy flow to the base subsystem (shock energy meter) and its transformation during one T work cycle, coming from a pneumatic hand-held impact tool (MS13A+WoSSO model) with pressure realised by a man-operator through the WoSSO isolation subsystem (5, 7).

The dose of energy which flows into the base equals 13.86 J (see Figure 3). A calculated global coefficient of a use energy efficiency for the output of the engine equals 42%. It means that the efficiency of the energy transformation from compressed air to the kinetic energy of the beater, which is transferred to the work tool, is small. Energy investigations have also proved that a large amount of energy was lost during transformations of energy to the base by the work tool in the shock process. It follows that simulated shock energy values on the base (input energy into the base) are only 8 .01 J (24.3%) (Figure 6). This value of energy is less than value of the output energy from the compressed-air engine of the tool. These losses of energy are connected with a dissipation of energy inside the work tool material and in plastic deformations on the plane of an anvil of the shock energy meter. It also follows that the analysis of the energy flow makes possible an assessment of technology process in the base and an assessment of the dose of energy transferred to the dynamic structure of the base.

B) Discussion for experimental investigations

The obtained results of average powers directed to the man-operator have confirmed the correctness of the elaborated theoretical model of the HTB System. The model of energy flow in the HTB System was also confirmed. The average power directed to the man-operator equalled the analytical investigations 0.0835 W and 0.0956 W for experimental investigations (man-operator no. 3 - Figure 7) for thermal constant conditions of measurements.

The measurement of average power at the point of contact between the man-operator and the WoSSO isolation subsystem verifies the full model HTB System correctness. The energy flow through this point depends on all dynamic phenomena at all other points.

The analysis of experimental results also shows that the value of the average power transmitted to a man-operator differs insignificantly from the value of the power transmitted to the stand handle. It confirms a good similarity between dynamic parameters of the stand handle and dynamic properties of man-operators.

This fact only makes possible investigations of hand-held tools in the laboratory stand without taking part of man-operators, as is required by ISO 8662 Standard. The elaborated method of energy flow enables continuation of an optimisation of the theoretical model for obtaining its better compatibility with the real structure of the investigated HTB System.

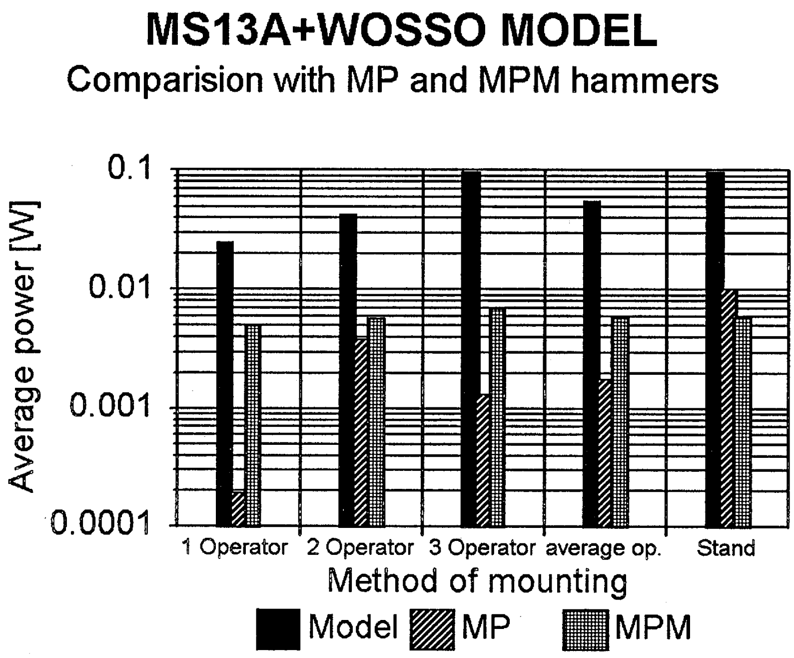


Figure 7. Results of measurements of the average power directed to three man-operators and to the integrated handle of stand for MS13A+WoSSO investigated model of hammer with WoSSO anti-vibration subsystem, MP pneumatic hammer and MPM prototype (modernised) of pneumatic hammer after exploitation investigations in industry (7).

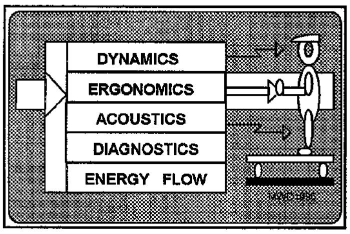
The experimental investigations proved that the measurement of the energy dose at the point of contact of the man-operator with the power tools makes possible a distinguishing of the technical state of the tool and its assessment. Investigated pneumatic hammers have exemplified objects with different dynamic parameters. It follows from intentional optimisation works which have been made in accordance with preparation of these tools to production. The intentional changes of the tool parameters have influenced considerable improvement of energy parameters. The energy dose (power) transmitted to the man-operator was reduced over ten times in the case of MP and MPM chipping hammers compered with the first investigated model (MS13A+WoSSO). This property means that energy parameters can be used to assess the technical state of hand-held tools and to assess of the risk of the vibration exposition for a man-operator from these hand-held tools.

Conclusions

The analysis of results of the theoretical and experimental investigations of the energy flow in the HTB System makes it possible to formulate the following conclusions:

1. The elaborated theoretical foundations of the energy flow method and computer simulation programs for the HTB System enable analytical investigations of energy flow and distributions of power in the system. The First Principle of Energy Flow in Mechanical System was applied in the theoretical foundation, which describes in clear-cut way the energy flow at all levels of HTB System.
2. The application of the FPoEFiMS to the biomechanical HTB system enables analysis of energy flow as the instantaneous phenomenon in all dynamic structures of the HTB System at all its levels.
3. The input energy to the HTB System in the power tool subsystem is divided into three fundamental fluxes directed to the base, to the man-operator and to the global energy lost flux.
4. The analysis of energy flow in the HTB System enables its optimisation and effective protection of the man-operator against the vibration energy transmitted from hand-held tools.
5. The experimental investigations proved the correctness of the elaborated model of energy flow in the HTB System and the model of dynamic structure the system.
6. The experimental investigations of the MS13A+WoSSO model of pneumatic hammer, MP and MPM prototypes proved a big progress in the reduction of the energy flow from the tools to the man-operators. It proved the efficiency of the energy optimisation made in the HTB System.
7. The results of the presented investigations enable elaboration of a project of energy standard for the assessment of vibrations transmitted to the man-operator from power hand-held tools.
8. The dose of energy in J or average power in W which is transmitted to a man-operator can be assumed to be a criterion value to the ISO energy standard (6). For these values an acceptable limit can be determined, as the energy dose in J or average power in W for 8 hours of work directed to the man-operator from power tools (6, 7).
9. Investigations of energy flow in the HTB System also enable objective assessment of hand-held tools with shock interactions on the base and on the man-operator. The elaborated computer program makes possible investigations of energy flow in Human-Tool-Base System for all types of hand-held tools and exciting forces (also impulsive), taking into account a transfer process of engines supplying the HTB Systems.

The energy investigations of the HTB System will be continued by the author in Laboratory of Dynamics and Ergonomics of Man-Tool Systems.



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Energy transmission to the human hand-arm system from different vibration exposures

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Introduction

The International Standard ISO 5349 gives guidelines for the risk assessment of hand-transmitted vibration (6). The standard specifies general methods for measuring and reporting hand-transmitted vibration exposure. Since several investigations show results that disagree with the risk predicted by the exposure-response relationship in the ISO 5349, the validity of the relationship has been questioned (3).

The absorption of vibration energy in the human hand and arm has been claimed to correlate better with vibration injury than the currently used measurements of the frequency weighted acceleration (2, 7). The assumption is that a higher quantity of absorbed energy per unit time (power) represents an increased risk of vibration injury or reduction in comfort. The quantification of the energy absorption is based on measurements of vibration force, velocity and phase between these parameters as closely as possible to the surface of the hand. Calculations of the cross-spectrum between the force and the velocity signal are thereafter used to determine the quantity of absorbed energy in the hand-arm system (2). The real-component from the cross-spectrum reflects the absorbed energy per unit time.

A great number of reports can be found where the transmission of vibration to the hand and arm has been studied (for a review see 10). These studies do not give any description of the distribution of the vibration energy to different parts of the hand and arm since only the amplitude of skin movements are measured. The determination of the energy transmission requires simultaneous vibration measurements for determination of the phase shift between the excitation point and the test point of the hand-arm system. Moreover, it has also been discussed in the literature if the vibration response of the human hand depends on whether the signal is a discrete frequency signal or a signal consisting of several frequencies (1, 5). However, the investigations have produced conflicting results.

The aim of the present study, which has been reported in more detail in the International Archives of Occupational and Environmental Health, was therefore to see how the energy transmission changes along the hand and arm and to compare the energy transmission for two different kinds of vibration exposure, i.e. random and sinusoidal.

Methods

The transmission of absorbed energy to different parts of the hand-arm system was determined by simultaneous measurements on the contact surface of the hand and at the actual part of the hand-arm system. At the contact surface measurements were made of the force, the velocity, and the phase between these parameters. At the surface of the hand-arm system measurements were made of the transmitted velocity as well as the

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phase between the transmitted velocity and the velocity on the contact surface of the hand.

These measurements were obtained by using a specially designed handle developed in an earlier study (9). The velocity signal could be registered on the test points at the hand and arm with a laser velocity-transducer.

Ten healthy subjects with no previous work exposure to vibration participated. The transmission of energy was measured at three test points which were located at the knuckle, wrist and elbow. The grip and feed forces were held constant at 40 N. On three experiment occasions the subjects were exposed to vibration with different frequency contents (three different frequencies for each occasion and location). The exposures were random (within the frequency-range 20 to 5000 Hz) and sinusoidal vibration (20, 40, 80, 160, 320, 630, 1250 and 1600 Hz). The vibrations have a frequency weighted acceleration of 3 m/s^2. The order of the exposures was determined through so-called counter balancing (4).

The calculations of the energy transmission have been carried out with the software Labview (National Instruments) which determined the cross-spectrum between the force and velocity signals from the handle. Since the cross-spectrum is complex, the real component reflects the energy absorption in the hand and arm. The calculations also included subtraction of the additional dynamic force produced by the handle itself. The energy transmission functions were thereafter calculated. The statistical analysis of the data is based on analyses of variances for repeated measurements (8). The probability level accepted for statistical significance was $\alpha=0.05$.

Results

The results in Figure 1 show that most energy is transmitted to the hand, thereafter the wrist and the elbow respectively. For the measurement point at the hand there is an indication of a resonance frequency area (40 to 100 Hz) where the transferred energy is amplified. The energy transmission to the knuckle of the hand increases with frequency and reaches a maximum at 63 Hz. For the wrist the transmission has a maximum at 25 Hz and for the elbow the highest transmission was found at 20 Hz. For all three points the transmission decreases for frequencies above each maximum.

From the results of the average energy transmission functions for sinusoidal vibration exposure at different frequencies in Figure 2 it can be seen that the energy transmission to the hand increases with frequency and reaches a maximum at 80 Hz. The transmission to the wrist and elbow decreases with frequency to a minimum at 160 Hz. Thereafter the transmission increases and reaches a maximum at 320 Hz and 630 Hz respectively. At frequencies higher than the respective maximum the transmitted energy decreases for all measurement points.

The statistical analyses for both the random and sinusoidal exposures show significant differences in the energy transmission between the three locations. An interaction was found between the energy transmission and frequency and also between the excitation frequency and the measurement point.

The results show significant differences in the energy transmission between the random and sinusoidal vibration. Furthermore, an interaction between the two types of exposure and location was found. An interaction between exposure types and the exposure frequency was also found.

For both random and sinusoidal vibration exposures no significant differences between the sexes was shown.

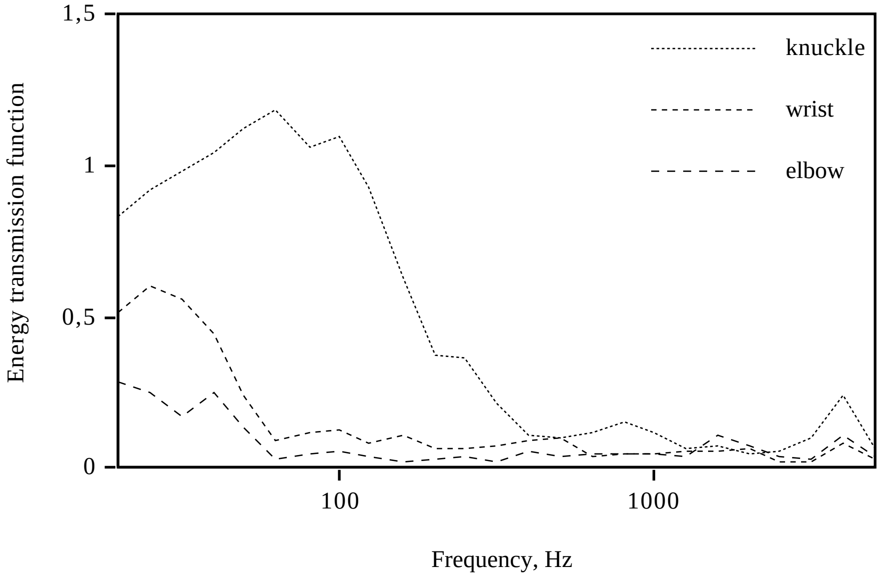

Figure 1. The average of the energy transmission during random vibration exposure for the test subjects as a function of the frequency (one-third octave bands) and for the three test points.

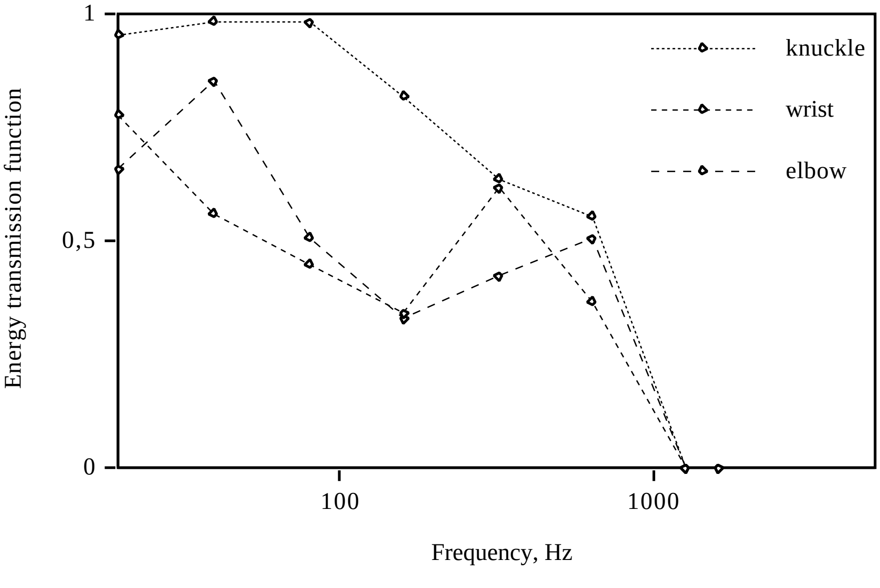

Figure 2. The average of the energy transmission during sinusoidal exposure at eight frequencies for the ten subjects as a function of the frequency (one-third octave bands) and for the three test points. The dots show the excitation frequencies.

Discussion

The results of this study show that the energy transmission to different parts of the hand and arm decrease with distance from the source. The absorption is, however, dependent on the nature of the exposure, i.e. random or sinusoidal vibration. For random exposure, about 50% of the energy has been absorbed before it reaches the knuckle, 85% before the wrist and about 90% before the elbow. The corresponding absorption during sinusoidal exposure are 40%, 60% and 60%.

The results also show that the energy transmission is dependent on the frequency. From the transmission curve for the random vibration exposure, it could be concluded that for frequencies above 400 Hz, almost all of the energy is absorbed before the knuckle of the hand. For frequencies above 60 Hz the absorption takes place in the hand. No frequency dependence could be seen between the wrist and the elbow. The results also show an amplification of the energy transmission in the frequency area to the knuckle of the hand in the frequency area around 100 Hz. This peak in transmission is probably due to the resonant area of skin at the knuckle.

For the sinusoidal exposure, the frequency dependence of the energy transmission is not clear. Even high frequencies are transmitted to the measurement point at the elbow.

The comparison between the exposures shows that sinusoidal excitation leads to a higher transmission of energy than random vibration exposure, especially at higher frequencies. A possible explanation could be that during the experiment the velocity spectrum on the handle had a constant level within each 1/3-octave band. This means that the energy content in the vibration signal was quite different since the sinusoidal signal is more or less concentrated to one infinite frequency while the random vibration is spread all over the 1/3-octave band. For instance, if the sinusoidal signal at 1000 Hz has a bandwidth of 1 Hz, the corresponding random vibration signal at the same frequency and bandwidth will have a velocity level that is more then 20 times lower. This could of course lead to differences in the vibration response of the hand and arm. Moreover, it is also reasonable to assume that these high levels could more easily cause resonance in different parts in the hand and arm.

From earlier transmission investigations sets of measured data from comparable measurements points have been selected. These curves are summarised in Figure 3 as a function of the frequency for each measurement point. For comparison, a corresponding graph from this study obtained during random vibration exposure has been inserted in the figure, one for each measurement point.

As can be seen, the magnitude of the energy transmission for the knuckle shows very good agreement with other authors’ work. No pronounced differencies between the studies at higher frequencies is shown. The energy transmission to the wrist shows good agreement with earlier studies up to about 200 Hz, thereafter the transmission of vibration decreases with frequency while the energy transmission shows a plateau. The elbow shows the same pattern as the wrist.

Conclusions

The observed differences between the transmission data from the random and sinusoidal excitation imply that more studies in this area are necessary. Furthermore, the absorption of vibration energy at higher frequencies also indicates that more studies are of importance. This will not only give an opportunity for obtaining more knowledge about the human hand-arm system, but could also be very useful in the setting of future standards.

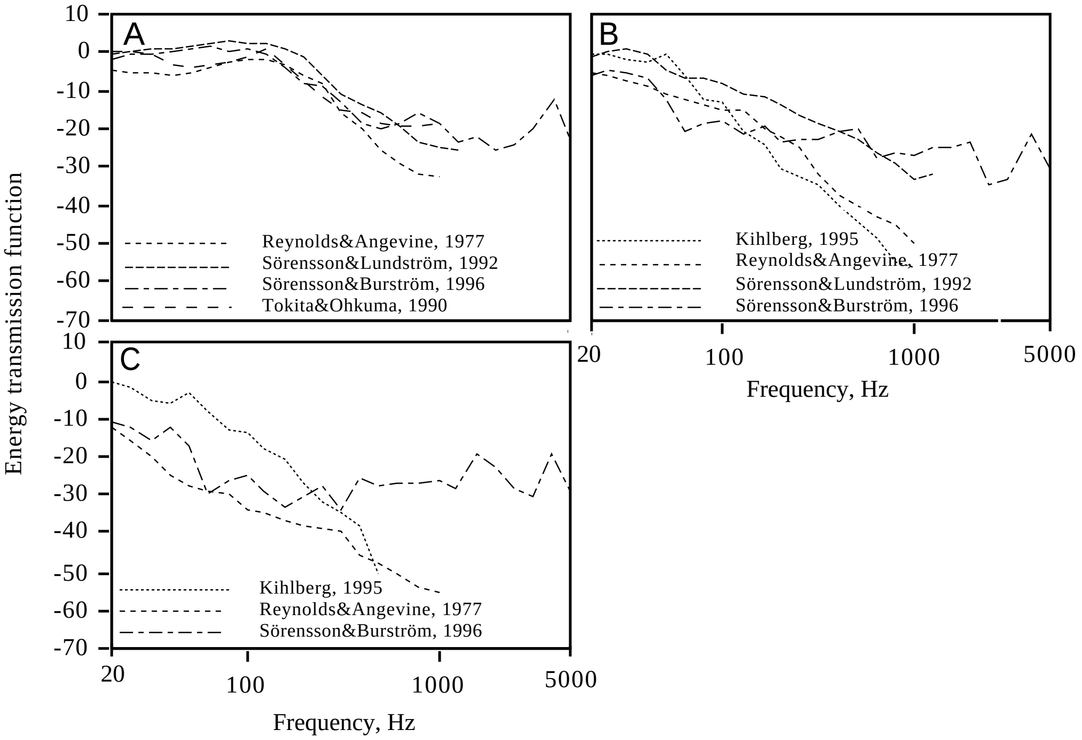

Figure 3. Comparison of the energy transmission function with some other comparable studies for the test points, A on the knuckle, B at the wrist and C at the elbow.

Acknowledgement

Financial support by the Swedish Work Environment Fund is gratefully acknowledged.

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Reproducibility and value of hand-arm vibration measurements using the ISO 5349 method and compared to a recently developed method.

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Introduction

Repeatability and reproducibility of hand-arm vibration measurements are two major problems in assessing the risk of a certain pathology due to exposure to these hand-arm vibrations (1).

Dose-response relationship as well as other suggested limit values are based on measurements dictated by the ISO 5349 standard method (2) (3). Yet a lot of critical remarks about this sort of measurement technique have been found in literature, especially concerning reproducibility (2) (4) (5).

To illustrate this we carried out 5 measurements on a chain saw, strictly following the method described in the ISO 5349 standard. The lowest value we obtained was 2.6 m/s^2, the highest was 8.4 m/s^2. These values are situated in too wide a range and in order to evaluate the risk of an exposure using a dose-response relationship, it is very difficult to rely on these results.

We faced the same problem for a hand mower, with a root-mean-square acceleration range from 3.6 to 7.8 m/s^2. In this latter case results were situated in a different axis (x-axis and y-axis).

In order to try and solve this problem the "Directoraat-Generaal van de Arbeid" (Labour Directorate-General) of the Netherlands conceived an alternative method (Publication S58-8). The aim of this method is to get a representative and reproducible picture of workers' daily exposure to vibration (5). This method is based on the ISO 5349 standard but is more elaborate. Up to now, however, it has not been evaluated in practice.

The aim of our study was to assess the reproducibility of this new method and to compare it to the ISO 5349 standard.

Methods

The method described in publication S58-8 is based on a number of measurements of the same tool in various situations.

For each tool at least 4 different measurement situations have to be set. For example, concerning a chain saw: different persons, various working postures, different kinds of wood and tree-trunks with different diameters.

In each situation 4 measurements of the vectorsum of the frequency-weighted root-mean-square accelerations in the 3 axes described in ISO 5349 must be made:

$$a_{eqh} = [\, a^2_{wx} + a^2_{wy} + a^2_{wz}]^{1/2}$$

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where a_{eqh}: vectorsum of the frequency-weighted root-mean-square accelerations and $a^2_{wx/y/z}$: frequency-weighted root-mean-square accelerations respectively, x, y and z axis.

If the highest value is one and a half times higher than the lowest one, 4 extra measurements have to be carried out.

On some occasions extra situations must be found: if the highest result of the 4 situations exceeds 20% but does not exceed 50% of the lowest result, 2 extra situations have to be found. If the highest value of the 4 situations reaches more than 50% of the lowest, 4 extra situations must be found or the tool's task has to be split up into two separate tasks.

1 work cycle must be completed and the duration of one measurement must be at least one minute. If the duration of a complete cycle is less than 1 minute, one has to measure more cycle up to a total time of 1 minute.

If during a measurement more than 20% of the time no exposure to vibration occurred, the measured root-mean-square acceleration has to be corrected with a factor calculated using the following formula:

$$a_{eqhc} = a_{eqh} \cdot [\ T_m/T_b\ ]^{1/2}$$

where a_{eqhc} : corrected vectorsum, a_{eqh} : measured vectorsum of the frequency-weighted root-mean-square accelerations, T_m : measurement duration, T_b: time with exposure to vibration.

The resulting value for each situation is calculated using the root-mean-square of all the measurements in that particular situation (Figure 1).

sit.1 sit.2 sit.3 sit.4

a_{c1} a_{c2} a_{c3} a_{c4} (m/s^2)

↘ ↓ ↓ ↙

$a_{sit1} = \left[\ (a^2_{c1} + a^2_{c2} + a^2_{c3} + a^2_{c4})\ /4\ \right]^{1/2}$ a_{sit2} a_{sit3} a_{sit4}

↘ ↓ ↓ ↙

$a_{tool} = \left[\ (a^2_{sit1} + a^2_{sit2} + a^2_{sit3} + a^2_{sit4})/4\ \right]^{1/2}$ (m/s^2)

Figure 1. Scheme showing the final result for one tool, built up out of a number of measurements in different situations (here an example for 4 measurements and 4 situations, if no extensions needed)

A Brüel & Kjær Human-Vibration Unit type 2522 (module BZ 7105), connected to the Sound Level Meter 2231 in addition with a hand-adapter UA 0891 (+3 accelerometers 4374) was used to measure hand-arm vibration during working conditions on the field.

4 forestry tools (2 chain saws, 1 two stroke engine leaf blower and 1 two stroke engine hand mower) were measured for 4 or 5 times on different occasions according to both the ISO 5349 standard method and the alternative method conceived by the "Directoraat-Generaal van de Arbeid" of the Netherlands (publication S58-8).

The reproducibility of these methods was evaluated by repeating the two measurement methods for 4 or 5 times on the same tool and by calculating the variation coefficient of the different acceleration values for each tool.

A second way to evaluate the reproducibility was the use of the AFNOR standard NF E 90-322. In order to be acceptable according to this latter standard, vibration measurements must meet the following criterion (1):

$$20 \log \left[a_{max} \ / \ a_{min} \right] \ \leq \ 3 \text{ dB}$$

where a_{max} : highest acceleration value for a tool in a measurement series
a_{min} : lowest acceleration value for a tool in a measurement series.

Results

The variation coefficients are listed in Table 1.

Table 1.Variation coefficients (in %) as calculated for the ISO 5349 method and the publication S58-8 method.

Tool	ISO 5349	S58-8
1	59.0	8.1
2	30.0	13.3
3	30.4	7.8
4	13.4	4.2

The results of the evaluation of the reproducibility according to the AFNOR standard NF E 90-322 are listed in Table 2.

Table 2.Results of the calculation of $20 \log \left[a_{max} \ / \ a_{min} \right]$ for the ISO 5349 method and for the publication S58-8 method (in dB).

Tool	ISO 5349	S58-8
1	10.1	1.6
2	6.1	2.3
3	6.7	1.6
4	2.6	0.8

The results of this calculation must be equal to or lower than 3 dB.

Discussion

The lower the variation coefficient, the more consistent and the more reproducible the measurement procedure tends to be.

The variation coefficients resulting from the ISO 5349 method are very high and this method therefore can not claim reproducible results.

The variation coefficients resulting from the S58-8 method are much lower and this method tends to have a good reproducibility.

This conclusion is confirmed by the results found using the AFNOR standard NF E 90-322. Except for tool 4, all results of ISO 5349 are higher than 3 dB and therefore have no acceptable reproducibility.

On the contrary, all values obtained from the S58-8 method are under 3 dB.

Conclusions

The S58-8 method was much more reproducible than the ISO 5349 one and it had an acceptable reproducibility meeting the AFNOR standard.

The ISO 5349 method's reproducibility in measurement of hand-arm vibration was poor and hence not acceptable.

Therefore, and especially when measurements are used for scientific research and to allow comparison of vibration levels of machines or exposure of workers to this vibration, we recommend the ISO standard to be adapted to this use. The method drawn up by order of the "Directoraat-Generaal van de Arbeid" of the Netherlands (S58-8) seems to be a suitable adjustment to it.

There also should be a reasonable doubt about the ISO 5349's capability of assessing dose-response relationship, as the specific doses are based on almost non-reproducible measurements.

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Automatic test stand for the measurement of the vibration emission of hand held machines

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Introduction

It was the essential goal of a research project (1) of the Federal Institute for Occupational Safety and Health to create an automated test stand for vibrational and other investigations of vibrating hand machines. For this, requirements for the test stand were to be derived on the basis of current knowledge and practical demands of prototype testing. A test stand for selected groups of machines was to be build up as an example. A particular emphasis for the development and the realisation of a suitable hand-arm model, was that it has to serve in the test stand as a link between the test stand and the machine under test, and must simulate the vibrational characteristics of the human hand-arm system as exactly as possible.

With the use of these test stands in the development, optimisation and testing of hand held machines it is possible to reduce the expenditure by automation of whole test procedures. Also, it is possible to avoid the vibration exposure (as well as other work-related exposures, e.g. from dust and noise) for the operating subjects. Furthermore a better reproduction in comparison with measurements at manual controlled tools can be achieved at the test stand. In addition to this, a better comparability of the vibration emission of different machines is possible by reduction of deviations and measuring uncertainties.

State of the hand-arm modelling and the realisation in test stands

The vibrational behaviour of the human hand-arm system has been investigated since the beginning of hand-arm vibration research. The general methodology of these investigations is based on the measurement of the mechanical driving point impedance of the hand-arm system (2) or other system parameters, which are convertable into impedance (admittance, dynamic mass amongst others). After the evaluation of the impedance a process of system modelling and parameter identification follows. From the obtained impedance curves a theoretical (mechanical) model and a comparison model are derived: measurement of human impedance in magnitude and phase is mathematically approximated as exactly as possible with this model.

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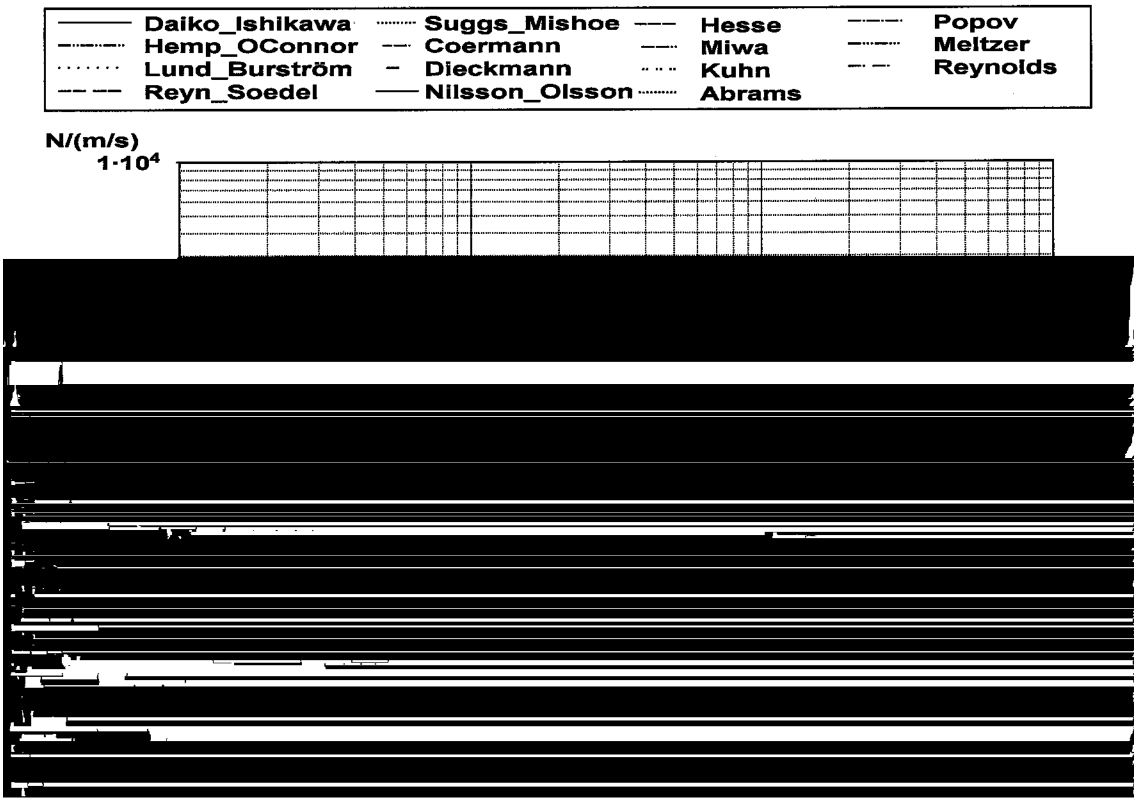


Figure 1. Impedance curves of different researchers.

The models to be found in the literature vary between spring-mass-damper systems with one degree of freedom (3) to non-linear four-masses models with consideration of the gripping force (4). Certain characteristics of the hand-arm system are not considered in the modelling because of the complexity of the system. So, all authors assumed a almost linear behaviour and a completely decoupled system. Likewise, the active behaviour of the hand-arm system (e.g. physiological functions, regulations, steering against the affecting forces and others) can not be considered at present. In the international literature relatively little information can be found about realised test stands with the special purpose of the measurement of hand-arm vibration. The published results (5), (6) show clearly that test stand measurements have better reproducibility and fewer measurement deviations in comparison with measurements with operating persons.

Experience indicates that only simple hand-arm models have the possibility of constructive realisation. Therefore a simple spring-mass-damper model with one or a maximum of two degrees of freedom should be used for the development and optimisation of the test stand. The individual elements of the models should be made of customary components. Preferably elastomer elements, in which the spring and the damping are integrated into one component, should be used.

The choice of a model is dependent on the decision for a mean impedance curve (7). The approach to these impedance curves can be successful only in a narrowly limited frequency range because of the simplicity of the modelling. This approach must be acceptable especially in the area of the beat frequencies of the machines.

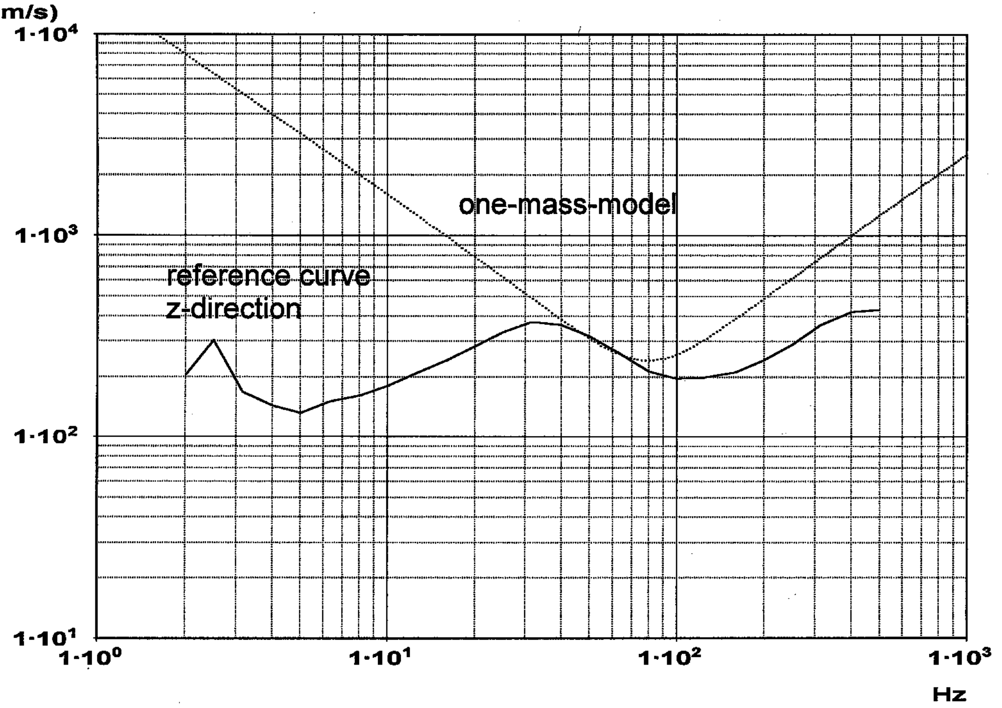


Figure 2. Comparison of an one-mass-model impedance curve and a reference curve; z-direction.

Selection of test machines for the development of the test stand

Selection criteria are, for instance, the kind of powering, dimensions and masses (8, 9) as well as possibilities for easy application in the test stand. Because of the relatively high vibration exposure and to include several different types of machines in the investigations, a preselection was made for percussive machines and herewith for electric hammer drills, impact hammers and percussion drills. The working principles of grinders, nailing guns, sand rammers and saws are so specific that at reasonable expense extra test stands must be developed. Needle scalers and riveting hammers are very similar to the selected types of machines, so that transferability of knowledge in the investigations for these machines can be assumed.

The decision for the test machines, based on a survey of all essential manufacturers and dealers of drilling hammers, impact hammers and electric percussion drills, was carried out for the German market with regard to the technical parameters of the suggested machines. The final decision for the test machines was made on the basis of the results of this survey (Table 1).

Table 1. Technical data of the selected machines.

Type of machine	Manufacturer	Mass (kg)	Beat frequency (Hz)	Rotation frequency (Hz)	Declared vibration value (m/s^2)
Hammer drill, PBH 160 R	Bosch	2	0 - 80	0 - 18.3	9
Hammer drill, BH 45 EK	Elu	6.2	16.7 - 43.3	1.75 - 4.6	8.6
Electric percussion drill, DSceu 638 Ki	Fein	2	0 - 600	0 - 30	8
Impact hammer, PB 14 D	Atlas Copco	14	26.7	-	7
Hammer drill, BHS 25	Smalcalda	5	50	16	-

Quality of the adjustment of the hand-arm model to the hand-arm system and judgement of the test stand

For the judgement of the test stand it is assumed that the measurements according to the valid measurement regulations (e.g. in (10)) at the test stand should show comparable results with those while the machines are operated by persons when the boundary conditions are the same. Accordingly, it is possible to use the r.m.s. value of the frequency weighted acceleration $a_{h.w}$ for the z-direction and the vector sum VB as a criterion for the judgement of the test stand. If these parameters are of equal amounts for measurements at the test stand and for measurements with operating persons, one can also assume a similar vibrational behaviour of the investigated machine. For the judgement of the test stand it is assumed likewise, that similar vibrational behaviour causes similar frequency spectra (one-third octave spectra) for the measurements at the test stand and with operating persons.

Because of the impossible identity between the simplified hand-arm models in the test stand and the human hand-arm system, deviations are not to be avoided between the measurements at the test stand and with operating persons.

The measurements of vibration at the handles of hand held percussive machines are influenced by two groups of factors (11):

- The first group contains errors of the measuring technology and the measuring process and especially influences the precision and reproducibility of the measurements. In particular, the choice of accelerometers and their mounting on the machines belong to this problem.
- The second group includes factors which influence the magnitude of the acceleration without an incorrect measurement (e.g. variations of the machine parameters, mode of operation of the user) and thus influence the comparability of the measurements.

Information about the amounts of these measurement uncertainties can be found in the literature, e.g. from (12) and (13). From these the conclusion can be drawn that a difference of the frequency weighted r.m.s. accelerations in the primary direction for several users of the machines of 3 dB must be judged as being of sufficient agreement of the results. Deviations in the order of up to about 5-6 dB are quiet possible. For the judgement of the quality of the adjustment of the hand-arm models to the human hand-arm system, a criterion of 3 dB for the r.m.s. acceleration $a_{h.w}$ in z-direction and the vector sum VB, as well as a criterion of 6 dB for the r.m.s. acceleration $a_{h,w}$ in x- and y-direction, was used. Because of the more complicated treatment of measurement deviations of one-third octave spectra, the range between maximum and minimum of the measurements with operating persons was used as the criterion.

Evaluation of the test stand

The preconditions for reliable and exact vibration measurements are a hand-arm model tuned at the working conditions of the machines used and a rigid and non-reactively designed test stand. With this test stand and the applied hand-arm model, it was realised for a relatively large field of applications for electrically and pneumatically driven (maybe also for combustion-powered) percussive or non-percussive hand machines with a mass until 20 kg. It is necessary that the machines work along the machine axis.

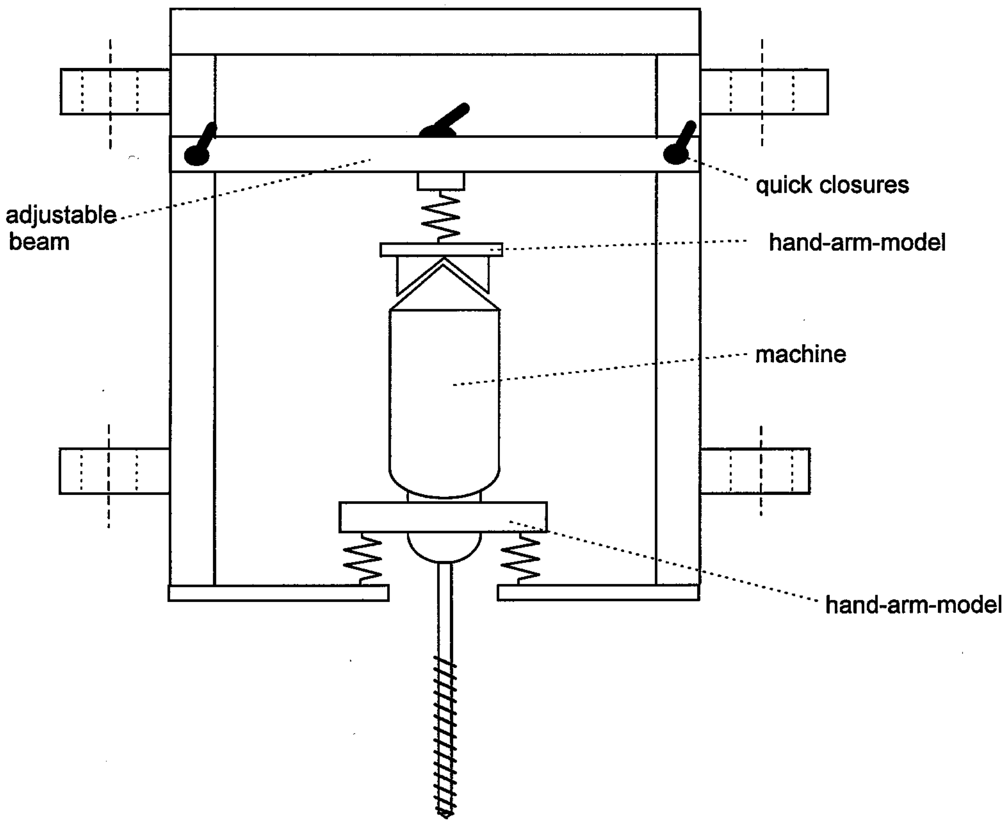


Figure 3. Principle of construction of the device for holding the machines with hand-arm systems.

The test stand may be turned very quickly from the vertical to the horizontal direction. By the applicated construction for connecting the machines with the test stand machines of different sizes may be used, just as different grip sizes and forms. It is possible that extreme grip sizes and forms need a new adaption. Work safety and accident protection were taken in account.

Comparing measurements test stand - operating persons

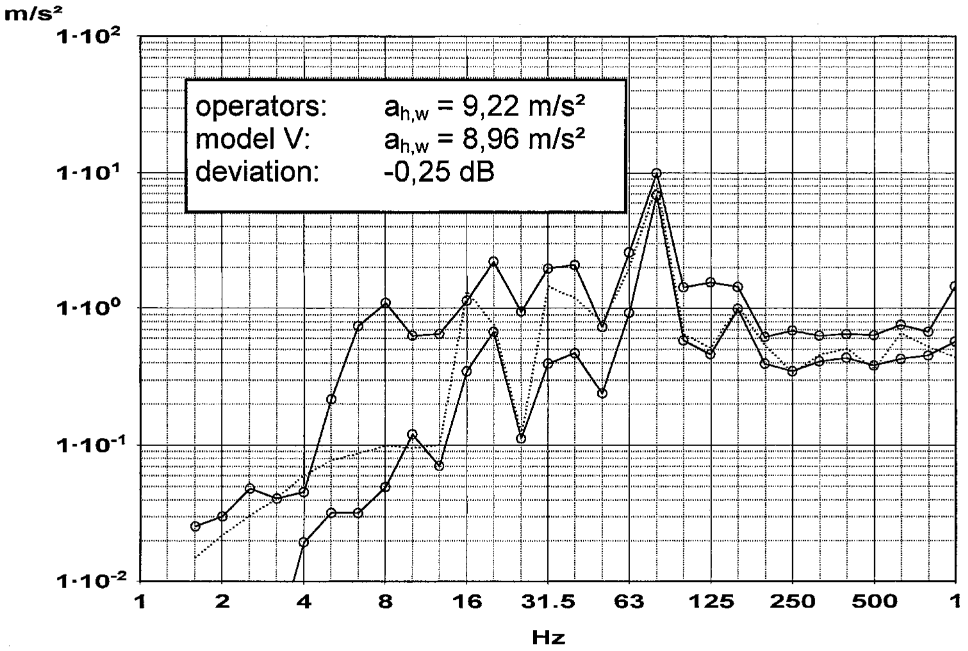
For this comparison vibration measurements were carried out at all selected machines, both in vertical as well as in horizontal working directions. The pushing force was held constantly at 100 N. For the electric percussion drill and the hammer drill the diameter of the drills was varied in two levels. Concrete blocks of type B 35 and dimensions of 800 x 500 x 200 mm were used. The impact hammer was only measured in vertical working direction acting on an absorber.

The measurements were carried out with 5 operating persons per machine and with 5 single measurements per person. The number of measurements was equal at the test stand. Before the measurements the machines operated for several minutes to warm up. Each drill-hole was pre-drilled before the measurement with a depth of about 15 mm. The minimum measuring duration was 30 s, the longest 120 s. The measuring duration of the impact hammer was 60 s.

One-third octave spectra in all three orthogonal directions were used as measuring parameters. The r.m.s. accelerations $a_{h,w}$ and the vector sum VB were calculated from these spectra. Figure 4 shows a measurement result as an example.

The values measured at the test stand are very good reproducible after a longer time and also after repeated changing of the test stand.

The deviation of the measured values is lower by using the test stand as by using test persons.



machine: Bosch PBH 160 R working direction: horizontal

model: model V z-direction F_A: 100 N drill: 16 mm

.... one-third octave spectra at the test stand

_______ reference curves (range of measurements with operating persons)

Figure 4. Comparison of $a_{h,w}$-values and one-third octave spectra for the test stand and for test persons.

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Vibration-induced white fingers: knowledge deficits

G. Gemne

Introduction

Despite eight decades of more or less intense research on the hazards of vibration, starting with the famous report (19) from a study of Italian marble quarry workers using pneumatic chisel hammers, there are still many gaps in our knowledge about white fingers. I will bring up the most important issues, those which are essential for prevention. Everything we do has a single goal, explicit or implicit: to look for data that allow us to carry out relevant preventive work. What does this require?

It is very much a question of thinking in terms of bias-free epidemiology. This is a concise way of saying that studies on the relationship between the incidence or prevalence of a disorder and the occurrence of certain working environment factors should be designed so that possible sources of error will not mar the results.

To be able to take appropriate measures in the working environment, we have to know the quantitative relationships between hand-arm vibration exposure and the disorders we want to prevent. Quantitative relationships concern both intensity of exposure, the characteristics of vibration, and the duration of exposure. Associated with this is the matter of how much it means that exposure is intermittent, so that the anatomical structures and physiological functions involved can recover during the breaks. Therefore, the relevant parameter is what we can call "effective exposure".

There is no sense in changing the working environment to prevent a disorder, if we are not certain that there is a disorder in the first place. It is therefore imperative that the diagnostic methods we use be valid. So far, we have to rely on the anamnesis to decide whether or not there is a typical disorder, but we would like to have objective ways of settling this matter. Thus, what we want is reliable objective methods for laboratory diagnostics with the purpose of assessing both the presence of abnormal symptoms and the etiology of the white fingers. This requires confidence concerning what is to be regarded as normal, which is a matter for epidemiology.

What changes should we make in the working environment? The answer to that question depends not only on correct information on the causative exposure but also on what we know about the physiological mechanisms behind the development of the disorder.

Among other matters that we need to learn more about, either for preventive or therapeutic purposes, is the role played by exposure to cold and the use of nicotine for the development of white fingers. This is also true for the influence of metabolites and other substances, such as nitric oxide, that accumulate in the vascular system during a white finger attack. Finally, an effective medical treatment without unwanted side effects is still lacking.

The quantitative relationships between exposure and disorder

We are still uncertain concerning the degree and type of relationship between exposure and white fingers with respect to vibration intensity, type of vibration, and duration. We

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do have indications that strong transients may make white fingers develop faster (7, 9, 21, 22). But for the most common types of vibration (for instance, from chain saws and chisel hammers) we are still in the dark concerning what parameters we should pay most attention to. It is reasonable, for instance, that discontinuous exposure that goes on in intervals rather than being continuous should be less harmful.

Add to this the chronic uncertainty concerning the magnitude of the exposure in the past. The tools used in the past, during the often long period when the disorder developed, were often different from those in use now, and the same goes for the work processes. It is therefore of little avail to rely on measurements made on today’s tools employed in present work processes. Even if measurements were indeed made in the past (which is often not the case), they are less reliable in many instances, since the measurement technology was not so developed, and there was a lack of standardisation. One has to recall that the first ISO guidelines for the assessment of hand-arm vibration exposure only came in 1986, whereas most of the studies that have been used in attempts to formulate a quantitative relationship were carried out long before that.

In the "risk prediction model" (4, 5, 6) published as an appendix to the current standard (18), the effect variable is the latency of white fingers in some occupational groups working with vibrating tools. As has been pointed out in surveys of the model, (14, 16, 17) this choice is unfortunate and makes the relationship uncertain. White fingers is a slowly developing disorder, and it is very difficult to recall the time when the symptoms first appeared. Furthermore, the very choice of latency leads to an automatic overestimation of the "risk", because the statistical influence on the model of those many workers who did not develop white fingers at all is not taken into account.

The exposure variable is the average acceleration of one single tool characteristic for each group and used in continuous work for at least four hours daily. However, the model does not specify whether the duration of daily exposure includes shorter and longer periods during which the tool has not actually been in use on the material. In other words: intermittency of exposure has not been taken into account. This is an important point of interest. We don’t know whether, and to what extent, shorter or longer breaks in the exposure allow recovery of the mechanisms that have been disturbed by vibration – but on physiological grounds we can assume that they are indeed beneficial.

Before we can be certain that a change in the working environment in the form of reduced exposure is relevant, we obviously need new models for individual tools and work processes.

There are a few promising attempts to formulate such models. An example is the study by Bovenzi and collaborators (3), who reported that the prevalence of white fingers in forestry workers increased almost linearly with either the number of years of exposure or the daily 8-hour energy-equivalent frequency-weighted acceleration according to the British standard 6842. The observed risk was lower than the one predicted by the model in the appendix to ISO 5349. The authors concluded that the findings instead tended to support the exposure levels proposed by the EU directive for physical agents.

Studies carried out with the purpose of establishing quantitative relationships have to be epidemiologically efficient. This requirement, unfortunately, amounts to making longitudinal studies, for the total exposure up to the time of symptom onset cannot be assessed correctly without continuous monitoring. Longitudinal investigations are best made on a fairly large number of subjects (preferably those who have just started their working career after vocational training) without previous exposure to vibration. This group must then be followed for a sufficiently long time, which would mean four to five years. During this time, the monitoring of exposure must be carried out in a way that assesses the effective exposure, and therefore time studies must be made continuously.

Diagnostic methods

It is in line with what has just been said that epidemiological studies aiming to arrive at quantitative relationships cannot be reliable without valid diagnostic methods. In older studies, we cannot be sure that the diagnosis was correct because we do not know whether the diagnostic criteria were to the point. Typical vibration-induced white fingers have often been confused – by the examining doctor as well as by the subjects themselves – with the constitutional tendency in many people to feel cold in the fingers, sometimes also in the toes. In particular, what has not always been stringently taken into account is that the whitening of the skin should appear in patches corresponding to the areas that have received the strongest vibration exposure. The type of blanching thus should not be of the diffuse pallor over the whole hand that characterises cases of general reduction of the finger blood flow in response to environmental cold.

As regards objective laboratory methods, so far we have no way of making an etiologic diagnosis. No method can answer the question, "Has the vasospastic phenomenon been caused by vibration, and by no other factor?". There are several alternative explanations, and we still have to rely on what the patient tells us about his symptoms. To make the matter still more complicated, we cannot even be sure that there is what can be called a disease at all, since we don’t know enough about the limits of normality for each subject that we examine. What we do know is that the interindividual variation in sensitivity is very large, which explains that so many (indeed most) members of an occupational group do not contract white fingers. The so-called cold provocation methods that use immersion of the hands in cold water and the recording of finger skin temperature during the recovery phase suffer from lack of sufficient specificity and sensitivity, and their positive and negative predictive values are low. We clearly need standardisation of these methods, and it is comforting that efforts to this are in progress within the ISO (12).

Fortunately, we have another laboratory method that can confirm the presence of abnormal vasospasm with some certainty, namely the recording of finger systolic blood pressure when the fingers have been cooled to low temperatures (20). Studies carried out so far (2) have indicated that pressures below 60 % of the original values are likely to reflect the presence of abnormally strong vasoconstriction. A drawback with this method, however, is that the reaction of the vessels to cold seems to be rather dependent on climatic conditions as well as on environmental temperature in the laboratory. This makes some clinicians abstain from using the method, especially during warmer seasons. It is also desirable to make efforts to consolidate the usefulness and interpretative power of this method by making further epidemiological studies on occupational groups and relevant fractions of the general population.

Pathophysiological mechanisms

The pathophysiological mechanisms behind the appearance of white fingers must be given further attention because of their relevance for what changes we ought to make in the working environment. We have long assumed that the basis for the symptoms is an overactivity of the sympathetic part of the autonomic nervous system. This is considered to result in an abnormally strong vasoconstriction of the digital arteries, those that carry blood along the two sides of the fingers from the palmar arches to the periphery. There is good reason to believe that this is what happens in many cases. However, since it is not uncommon for a white patch to be localised proximal to an unaffected skin area with normal hue, an involvement also of smaller vessels seems to be necessary to bring about such a distribution (15).

According to a second theory, for which there is also valid evidence (1, 11), a secondary sympathetic overactivity may develop in strongly vibration-exposed subjects because of a relative reduction in parasympathetic activity.

Recently obtained evidence points to a further mechanism resulting from a lesion localised in the wall of the vessels involved. Disturbances in adrenergic receptor activity of the smooth muscle cells of the vessel wall have been implicated by experiments by Ekenvall and collaborators (8) on with vibration exposure and white fingers. The results indicated that finger cooling affects alpha-2 receptors more than alpha-1 receptors to produce an increase in vasoconstriction triggered by norepinephrine. Consequently, substances inhibiting the constrictive alpha-2 receptors might be of therapeutic value.

Still another clue to the existence of a local lesion comes from experiments with iontophoresis of sodium nitroprusside and metacholine into the finger skin of chain sawyers (15). The results of this study suggested that endothelial damage and disturbance of the functions of the endothelium-derived relaxing factor (EDRF), may be responsible for abnormally strong vasoconstriction in vibration-exposed persons with white fingers.

What may be the consequences of these various mechanistic explanations? If sympathetic overactivity is all-important, we should, of course, make every effort to rid the working environment of factors that increase the level of activity in that part of the autonomic nervous system. This amounts to eliminating stressful factors, and among those we have to count not only psychological factors like tight time-schedules and excess physical loading, including hard manual work and low temperatures as well as strong noise. But if a local lesion is responsible for the disorder, vibration exposure of the hand should be reduced as much as possible even necessitating, in some cases, avoidance of work processes where hand-held tools are used and switching to automated work.

Both pathophysiological processes (sympathetic overactivity, and a lesion to the vessel wall) are likely to be at play in the development of white fingers. To be on the safe side, therefore, both types of preventive measures should be used. It is a regrettable fact that neither approach has been carried very far, and the raising of employers' consciousness about these matters should be given high priority.

Additional gaps in our knowledge

There are also other matters that we should try to learn more about, for preventive as well as therapeutic purposes. Take, for instance, the rather straight forward idea that exposure to cold and the use of nicotine contribute to the development of white fingers, not only to the triggering of the symptoms. However, we do not know the answer to this question (a great pity because both factors are so common in vibration-exposed occupational groups), and further epidemiological work must be carried out. This is, however, a very difficult matter considering the complexity of peripheral vasoregulatory mechanisms and the need for accurate control of the exposure variables.

Another essential gap in our knowledge concerns the influence of metabolites and other substances accumulating in the vascular system during a white finger attack. We can be sure that they are of great potential importance both for the development of symptoms and for therapy. The role of nitric oxide (NO), for instance, is largely unmapped in the context of white fingers. We only know that NO and the substances with which it interacts participate strongly in the complex vasoregulatory mechanisms in response to cold. Further research into these matters should therefore be given high priority.

Finally, in the absence so far of effective medical treatment without unwanted side effects, a flicker of hope may be contained in a recent report with seemingly paradoxical results. In an experiment by Falkenbach and collaborators (10) on former forestry workers with white fingers, rewarming of the hand after cooling was faster when the feet were immersed in cold water than when the feet were immersed in warm water. It was therefore suggested that (as the authors expressed it) "a deliberate training of the systemic counter-reaction may prove beneficial for patients with vibration-induced white fingers".

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Finger systolic blood pressure during cooling in VWF; value of different diagnostic categories for a routine test method

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Introduction

Vibration-induced white finger (VWF) is a secondary type of Raynaud's phenomenon (RP) caused by exposure to hand-arm vibration. A medical interview is widely accepted as the best available method of diagnosing RP and VWF. However, an objective test is desirable to confirm or support the anamnestic diagnosis of RP. Measurement of finger systolic blood pressure (FSP) during finger cooling has been reported to be a valuable test (7-9). However these results were obtained in scientific investigations of small groups. The aim of the present study was to evaluate further the value of different diagnostic categories for the FSP cooling test used as a routine method during several years in a large number of men with VWF.

Methods

The present study included all subjects with suspected VWF who were referred for a cold provocation test at the Department of Clinical Physiology and Nuclear Medicine, Aarhus University Hospital, during an 7-year period from 1991 to 1997. The anamnestic diagnosis of RP was obtained by a medical interview performed by the author of the present study and was regarded as a method of reference. RP was defined as cold provoked episodes of well-demarcated distal blanching in one or more fingers. VWF was defined as RP with the first appearance after the start of professional exposure to hand-arm vibration and no other probable causes of RP. VWF was currently active if episodes had been noticed during the last two years (9-10). Six of a total of 103 referred men were treated with vasodilating medicine and were investigated separately. The remaining 97 men were the main group of subjects. They were divided by medical interview into 81 men with currently active VWF and 16 vibration exposed men without RP. The severity of the disease was classified by the Stockholm Workshop scale (4). The stage of VWF was in median 2 (0-3) for each hand, with no hands in stage 1 or in stage 4. Most subjects were in stage 2 for at least one hand and only a few hands were in stage 3. A group of 20 men without finger symptoms and who had never worked with vibrating hand tools served as a control group (9).

Diagnosis of RP was performed by our introduced cold provocation test measuring FSP by cuff and strain gauge technique during combined body and finger cooling (7-8). Body cooling was performed by a cooling blanket of 10-12°C from 15 minutes before the first measurement of FSP. FSP was measured after thermostating of the middle phalanx during 5 minutes ischemia. FSP% was FSP measured at 15, 10 and 6°C in percentage of FSP at 30°C, corrected for changes in FSP of an ipsilateral non-cooled symptomless reference finger (usually the thumb). Only the lowest FSP% in a subject

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was used for comparison. An attack of RP with digital arterial closure as defined by Lewis (6) was verified by the presence of a zero pressure, FSP(0), in the cooled finger (7). A negative FSP(0) test was FSP% above zero. A positive FSP(A) was an abnormal cold response, its FSP% being below the lower normal 95% confidence limit that was 58% for the most exaggerated cold response (9). The lower normal range of FSP% was 60%. A negative FSP(A) test was FSP% $\geq$ 58%. The diagnostic value of a test was described by its nosographic values and its predictive values. The nosographic sensitivity was the fraction of positive tests in the group with VWF. The nosographic specificity was the fraction of negative tests in the vibration exposed group without RP. The predictive value of a positive test was the fraction of true positive tests in the group with a positive test. The predictive value of a negative test was the fraction of true negative tests in the group with a negative test. The prevalence of VWF was the fraction of vibration exposed men that had currently active VWF. The predictive values of a test, but not its nosographic values, depend on the value of the VWF prevalence. The systolic blood pressure gradient from the upper arm to the finger, SPG, was measured at thermo-neutral conditions to detect organic obliterations. It was measured on all 10 fingers in each subject. The upper normal range of SPG was 40 mm Hg (9).

Statistical evaluation was made by non-parametric statistics with a significance limit of 0.05. Values are given as numbers, fractions or median (range).

Results

SPG was normal in all 1030 fingers of 103 vibration exposed subjects including all 87 men with VWF. In the separate group treated with vasodilating medicine all six men had RP and a normal SPG. Their cold response was 52% (33-62) with one normal and 5 abnormal FSP(A) tests. The results of FSP% in the main group of 97 vibration exposed men are given in Table 1. It shows that a true positive FSP(0) test was obtained in 70 out of 81 men and a true positive FSP(A) test was found in 80. One false positive FSP(A) test but no false positive FSP(0) tests were found in 16 men. FSP% was 0 (0-71) in 81 men with VWF and 73 (42-97) in 16 vibration exposed men without RP. The diagnostic value of the FSP cooling tests is given in Table 2. The nosographic sensitivity and the predictive value of a negative test were significantly higher in FSP(A) than in FSP(0) ($p<0.05$). Table 3 gives some theoretical examples of predictive values of the FSP cooling tests calculated for different values of VWF% in 100 vibration exposed men, presuming the same sensitivity and specificity as found in the present study.

Table 1. Results of the cold provocation test. FSP% classified in 81 men with VWF and 16 vibration exposed men without RP. Values are given as number of tests (n) and as FSP% median (range).

Group of	FSP% = 0		0<FSP%<58		FSP% $\geq$ 58	
subjects	n	FSP%	n	FSP%	n	FSP%
with VWF	70	0 (0-0)	10	23 (14-48)	1	71
without RP	0	0	1	42	15	74 (63-97)

Table 2. The diagnostic value of the FSP cooling tests in 97 vibration exposed men. The prevalence of VWF was 83.5%. Values are given as percent.

Diagnostic value	FSP(A) test	FSP(0) test
Nosographic sensitivity	99*	86
Nosographic specificity	94	100
Predictive value of a positive test	99	100
Predictive value of a negative test	94*	64

* Different from same value of the FSP(0) test ($p<0.05$).

Table 3. The predictive value of the FSP cooling tests at different prevalences of VWF theoretical examples. The sensitivityand specificity found in the present study were used. Values are given as percent.

VWF%	A positive test		A negative test	
in 100 men	FSP(A)	FSP(0)	FSP(A)	FSP(0)
80	99	100	96*	64
20	80	100	100	97
10	65*	100	100	98
5	46*	100	100	99
1	14*	100	100	100

* Different from same value of FSP(0) test ($p<0.05$)

Discussion

All fingers of 103 subjects had a normal SPG before finger cooling. This indicates that all men with VWF had a vasospastic type of RP without detectable organic obstructions in the arteries leading to and through the fingers. Thus no subclinical cases of arterial obstructions were revealed by SPG that was in agreement with the clinical inspection of the fingers. Contradictory to this finding, an increased SPG has been shown in severely affected men in other studies (3, 8-9). This has been explained by an insufficient termostating at the time of measurement (3) but may also be caused by differences in the investigated materials. Arteriographic findings have demonstrated an equal frequency of arterial obliterations of hands and fingers in subjects with VWF and age-matched, non-exposed, hard manual workers without RP (12). This result seems to support the present finding of a normal SPG. It has to be underlined that a truely increased SPG will reflect radiologically very serious obliterations in the arterial system. It is suggested that SPG measurement could be reserved for severely affected subjects in stage 3 and all in stage 4. An abnormal SPG pattern of the fingers may help to elucidate the possibility of competing secondary causes of RP. Men in stage 4 should always be screened for other causes of RP than exposure to hand-arm vibration.

The results of the separate group indicate that the FSP(A) test can support the anamnestic diagnosis of RP even during treatment with vasodilating medicine but that a provocation and detection of an attack is less expectable. This finding has to be taken into consideration in legal questions concerning compensation for VWF. If the detection of an attack is needed to obtain compensation, the consequence may be that the cold provocation test has to be performed after the treatment with vasodilating medicine has stopped. However, discontinued treatment may not be medically justified if the medicine is given for the treatment of hypertension or heart disease.

The predictive value of a positive FSP(0) test was 100% and the predictive value of a negative FSP(0) test was 64%. The objective detection of an attack of RP is of diagnostic importance in individual cases. Furthermore, an economical compensation may only be obtained if an attack of RP has been detected by a doctor. A visual observation of cold provoked white finger or the finding of a positive FSP(0) but not a positive FSP(A) fulfils this condition in Denmark. A positive FSP(A) test supported the anamnestic diagnosis of RP but did not verify an attack of RP if the FSP% was above zero. It may be of guidance when used as a screening test. However, the diagnostic support of a positive FSP(A) test was strongly reduced in other studies because of a low FSP(A) specificity of about 60% in combination with VWF prevalences below 35% (9-10). The theoretical examples given in the present study show that even a specificity of 94% as found in the present study gives a very low predictive value of a positive test in materials with a prevalence of VWF below 10%. Such low prevalence rates are not unusual in selected branches. In such branches the FSP(A) test is only of little help in the screening for RP. The predictive value of a positive FSP(0) test was independent of the VWF% as no false positive tests were found. In another study it was found that all men with a positive FSP(0) test in combination with a negative interview showed an attack of white finger in a following hand cooling test or had a positive history of RP with the last attack more than two years before the interview (10). Therefore it seems fair to assume that a positive FSP(0) test is a true result and that subclinical RP exists and can be provoked by cooling tests. The large gap in FSP% between zero and the lower normal limit of 58% makes it possible to detect an abnormal response to cold in a subjects without RP or in a subject with a false negative FSP(0) test (9). A negative FSP(0) or FSP(A) never excludes the presence of RP but makes the diagnosis of RP very unprobable if the prevalence of VWF is low.

In the present study the FSP(0) test had an acceptable sensitivity of 86% which was a similar size to that found in scientific studies of smaller groups of subjects (1-2, 8-10). Other investigators have used modified versions of the present cooling test and obtained lower sensitivities of the FSP(0) test (3, 11). This may be due to differences in the investigated subjects, the applied temperatures, the prewarming procedures or the omission of body cooling. The FSP(A) test of the present study had a sensitivity of 99% which was the same size as the values found in some other studies (2, 9-10) but higher than the 74% found in a large sample of 111 men with VWF (3). All these studies used almost the same discrimination limit of 58-60%. The FSP(A) of the present study had a specificity of 94% in vibration exposed men, which was in accordance with the values of other studies (2-3, 5). The discrimination level of FSP(A) was 89% in a single study which gave acceptable nosographic values in the vibration-exposed groups but a specificity of only 95% in the non-exposed control group (5).

The advantages of the FSP% cooling test are a standardised cooling procedure, acceptable nosographic values, a verification of RP by a positive FSP(0) test, and a reliable measure of the cold-induced arterial tone that makes it suitable for follow-up studies. The disadvantages are a expensive equipment, a demand for experienced investigators, and the testing of commonly only one or a few fingers. This makes the method most suitable for investigations in specialised laboratories.

Conclusions

The FSP cooling test had acceptable diagnostic values when used as a routine method in a specialised laboratory. A positive FSP(A) test made RP highly probable if the VWF% was high but not very probable if the VWF% was low. The FSP(A) test may be of help in the discrimination between groups of subjects. A positive FSP(0) test verified an attack of RP. The FSP(0) test had a lower nosographic sensitivity than the FSP(A) test. A negative FSP(0) or FSP(A) test did not exclude RP. VWF was considered to be a vasospastic type of RP as the SPG was normal in subjects with VWF.

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Assessment of peripheral circulation under impulsive vibration or variation of temperature using the thermal diffusion method

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Introduction

In the assessment of peripheral circulation, it is necessary to monitor peripheral circulatory movement of fingers exposed to hand-arm vibration including impulsive vibration. During vibration exposure it is important to know whether signals from the sensor may be disturbed by vibration. The plethysmography and clearance methods show problems in continuity, while the laser Doppler method is limited, not only from the aspect that an absolute value is difficult to determine, but also that it cannot be used on the side exposed to stimuli (1). We have explored the effects of impulsive vibration on peripheral circulation using the thermal diffusion method with a Peltier stack (2).

The cold water-immersion test may lead to early diagnosis of peripheral circulatory disorders including vibration-induced white finger (VWF). Although peripheral circulation is actually examined using skin temperature at the fingertip because of its non-invasive and continuous measurement for finger skin circulation, the value obtained by such indirect measurement as skin temperature seems unlikely to reflect peripheral circulation with accuracy. Therefore, we used the thermal diffusion method with a thermal clearance curve to monitor circulatory changes at a variety of temperatures as a measure for direct observation of peripheral circulation.

Subjects and Methods

1) *Measurement of peripheral circulation*

The characteristics of measurement for peripheral circulation and its related indices are summarised in Table 1. Various methods have been developed for measuring blood flow which have been widely used in various clinical fields: the thermal diffusion method, clearance methods using hydrogen gas or ^{133}Xe, the plethysmography method, the laser Doppler method, and so on. However, the method must be selected according to the application as each method has its own merits and demerits (1, 2). Skin temperature and the volume of the pulse wave at the fingertip can be measured non-invasively and continuously. Although these can be measured on the side exposed to stimuli, there are limitations in the assessment of blood flow or quantitative measurement.

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a) Measurement of blood flow using a Peltier stack

Measurement by the thermal diffusion method can be carried out continuously on the side exposed to stimuli and absolute values can be determined by the clearance method using hydrogen gas, etc. Some use the classical type using a temperature-controlled thermocouple (3-5), and the others use a Peltier stack, a method begun by Carter in the neurosurgical field in the 1980's (6-8).

Table 1. Characteristics of peripheral circulatory measurement.

Measurement	Invasion	Continuity	Assessment of absolute value	Observation of blood flow	Object or site	Use under temperature condition	Use in exposed side under handgrip	Use under impulsiveness
Skin temperature	no	good	possible	impossible	human, animal surface of organ	possible	possible	possible
Volume pulse wave	no	good	possible	impossible	human, animal finger, etc.	possible	impossible	possible
Plethysmograph	pressure	poor	possible	possible	human, animal finger, etc.	possible	impossible	possible
Clearance method (^{l33}Xe,H$_2$)	severe	poor	possible	possible	animal, human many organs	possible	impossible	impossible
Thermal diffusion using classical thermocouple	no	good	impossible	possible	human, animal surface of organ	impossible	possible	possible
Thermal diffusion using a Peltier stack	no	good	possible	possible	human, animal surface of organ	impossible	possible	possible
Thermal diffusion using a thermal clearance curve	no	poor	possible	possible	human, animal surface of organ	possible	possible	possible
Laser Doppler flowmetry	no	good	impossible	possible	human, animal surface of organ	possible	impossible	impossible

The measuring principle of the thermal diffusion method is that the thermal conductivity of tissue such as skin responds simultaneously to changes in blood flow. Therefore, this measurement method is based on the precise monitoring of thermal conductivity. A temperature-controlled-type blood flow meter, in which a classical thermocouple is used, is currently on the market (5). In this classical system, current is changed to regulate the temperature difference of the thermocouple. The changes of blood flow are measured through changes in the current. The response is insufficient for increases in blood flow beyond a certain blood flow level and the determination of absolute values is limited because the actual values are different when estimated at two different times. Therefore, the absolute value cannot be estimated in this classical method.

On the other hand, current is fixed in the method using a Peltier stack, and blood flow is evaluated from the temperature difference of two gold plates (V), when blood flow exists and the temperature difference (V_0) when there is no blood flow. The difference between V and V_0 (V_0-V) corresponds to the absolute value of the clearance method. This result is proved by the theoretical equation derived from Fourier's law of thermal conduction.

b) Measurement of blood flow using a thermal clearance curve

The method using a Peltier stack was affected by large or rapid changes of the environmental temperature such as cold water immersion, because the sudden change of environmental temperature induces a change of the thermal conductivity, which resulted in an inconstant baseline (1). It is impossible to assess finger blood flow quantitatively with the laser Doppler method, which provides us with insufficient data. Therefore, we must develop a new method for monitoring finger blood flow quantitatively under various temperature conditions. The improved method was hardly affected by environmental temperature by using thermal clearance. To remove the effect of the environmental temperature change, the baseline is corrected before each measurement using a thermal clearance curve (1). This can be measured almost every minute, though it cannot be measured continuously. The flow probe is larger in size than the probes using a Peltier stack because the probe for thermal clearance curve utilises heat insulation by air, it can be attached to the finger.

2) *Effects of impulsive vibration on finger blood flow*

a) Subjects

Six healthy male Japanese office workers with no history of vibration exposure (mean age SD 53.2 ± 7.0 years) were studied. The ambient temperature was 23° ± 1°C. Subjects were instructed to remain inactive and were prohibited from smoking or drinking for at least 30 minutes before the exposure to following two vibrations: vibrations extracted from chain saw and pneumatic nailer. Finger skin temperature was measured on the right side of the right third finger by a thermistor D111 (Takara, Tokyo, Japan). Finger blood flow was measured by the thermal diffusion method using a Peltier stack. The probe was placed on the back of the middle phalanx of the third finger of the right hand. The subjects had been well informed of the protocol and had given their informed consent before the experiment.

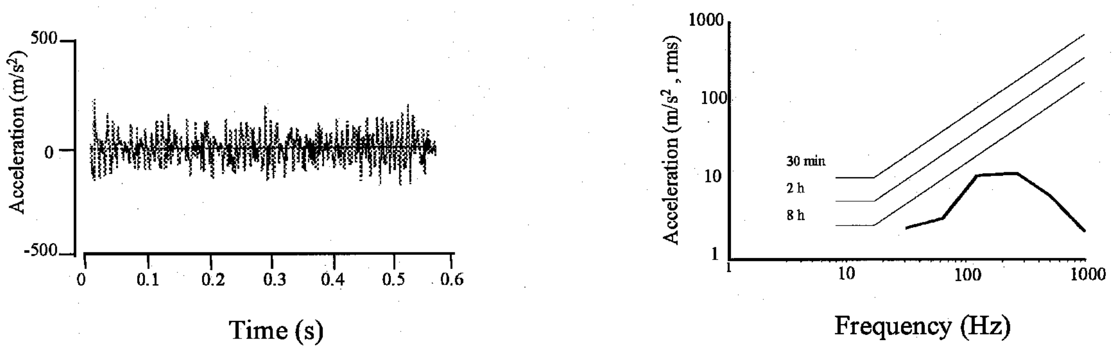
b) Vibration exposure

Each subject was seated on a chair with his right hand extended downwards and placed on the handle of the vibration apparatus. When the finger blood flow level was stable the subject started gripping the handle. The subject was instructed to grip the handle with a steady force of 50 N, which was monitored by an instrumentation amplifier WGA-710A-3 (Kyowa, Choufu, Japan), using a miniature load cell LM-20KA (Kyowa) as a sensor. One minute after the start of grasping, the hand was exposed for 5 minutes to a vibration in the X-axis according to an ISO 5349 (9). Finger blood flow of the subject who was instructed to continue grasping after cessation of vibration exposure was monitored for another 2 minutes.

Vibration acceleration signals measured on two different hand-tools under practical working conditions were chosen for stimulation. The stimulated signals were only modified in order that the frequency-weighted acceleration a_{xhw} was at the same level

(6.3 m/s^2) for the hand-tools used. The two vibrations produced by the chain saw and pneumatic nailer differed in terms of impulsiveness. The crest factor of the unweighted acceleration from the chain saw and pneumatic nailer were 2.2 and 9.5. The acceleration time histories and frequency spectra of the stimulated vibrations, which were measured by the real-time frequency analyser 2123 (Bruel & Kjar, Narum, Denmark) added to a charge amplifier 2635 (Bruel & Kjar) and an accelerometer 8309 (Bruel & Kjar) are shown in Figure 1. The apparatus for reproduction of vibration consisted of an electromagnetic shaker (IMV, Tokyo, Japan) coupled to a power amplifier VA-ST (IMV, Tokyo, Japan), spectrum shaker 5612 (Bruel & Kjar), cassette data recorder RD-130T PCM (TEAK, Tokyo, Japan), and an acrylic vibration exposure device with a column handle (40 mm diameter) fixed to the vibrating plate of the shaker.

(a) Chain-saw



(b) Pneumatic nailer

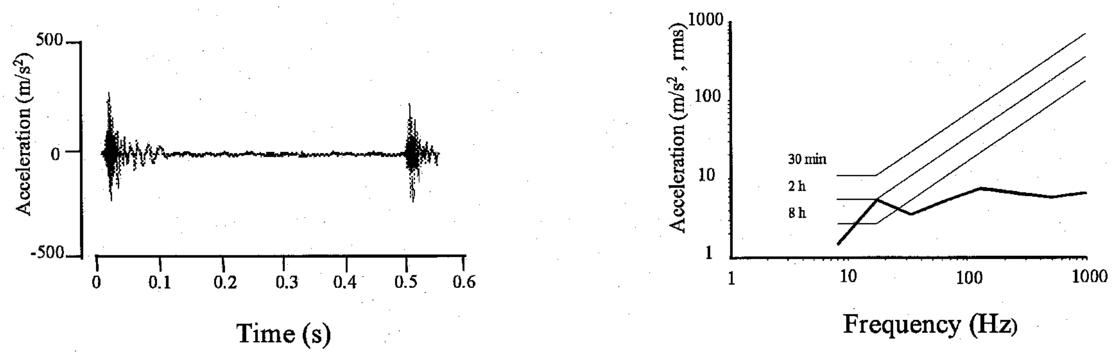


Figure 1. The acceleration-time histories and frequency spectra of the stimulated vibrations, produced by (a) chain saw and (b) pneumatic nailer. The proposal action levels corresponding to 8, 2, 0.5 h exposure are also shown.

3) *Effects of cold water immersion on finger blood flow*

a) Subjects

The chain saw workers with VWF were selected from a group of workers who annually received special medical examinations for vibratory tool users. Responses to detailed questionnaires confirmed that the white finger was induced by vibration exposure in each case. The workers with VWF included 10 male chain saw workers, two of whom were in stage 1, seven in stage 2 and one in stage 3, based on the

Stockholm Workshop scale (10). For comparison we selected 10 male workers without VWF (stage 0), matched for age and duration of vibration exposure. The mean ages ±SD in workers with VWF and without VWF were 57.6 ± 4.2 and 58.7 ± 5.4 years, respectively. The mean vibration exposure duration ±SD in the workers with VWF and without VWF were 24.7 ± 6.1 and 25.5 ± 8.6 years, respectively. Student's t test did not reveal a statistically significant difference in age or vibration exposure duration between the chain saw workers with and without VWF. None of the subjects in either group had cardiac abnormalities, hypertension, diabetes, or peripheral neuritis, and none were receiving any medications.

The subjects, wearing light clothes, were examined in a sitting position with the arms held at the level of mid-sternum, without moving and after 30 minutes adaptation. The ambient temperature was 23° ± 1°C. They were prohibited from smoking or drinking for at least 30 minutes before the cold water immersion test. Finger blood flow was measured by the thermal diffusion method using a thermal clearance curve. The probe was placed on the back of the middle phalanx of the third finger of the right hand. The subjects had been well informed of the protocol and had given their informed consent before the experiment.

b) <u>Cold water immersion test</u>

Cold water immersion test was provided by immersing the hands up to the wrists in cold water at a temperature of 10°C for 10 minutes. The hands were then lightly dried and finger blood flow was monitored for another 10 minutes. Effects of cold water immersion on finger blood flow were assessed by the measurement just prior to the immersion (0 minutes), and 1, 2, 3, 5, 7.5 and 10 minutes after its start, and 1, 2, 3, 5, 7.5, and 10 minutes following the end of the immersion. The test was carried out in winter.

4) *Statistics*

In the first experiment, to test for the effects of vibration, the completely randomized block design using two-way analysis of variance (ANOVA) was used. The factors were vibration exposure, which was composed of two levels (chain saw and pneumatic nailer), and time course, which was composed of eight levels (0-7 minutes). The finger skin temperature and blood flow at each time point were compared to the initial value using a post-hoc Dunnett test. In the experiment examining the effects of cold water immersion an ANOVA with repeated measures was used. The finger blood flow at each time point was compared to the initial value using a post-hoc Dunnett test. All statistical tests were two-tailed. P values of less than 0.05 were considered statistically significant.

Results

1) *Vibration exposure*

The ANOVA did not show statistically significant change in either the main effect of time course or vibration exposure on finger skin temperature, as shown in Figure 3. Changes of finger blood flow produced by two vibrations in the healthy workers without history of vibration exposure are shown in Figure 2. The ANOVA revealed a statistically significant main effect of time course ($F(7, 75) = 3.53$, $p<0.01$) as well as a significant interaction between time course and vibration exposure (F(7, 75) = 4.99, $p<0.001$). The pneumatic nailer was seen to decrease finger blood flow at 4 and 5 minutes (both $p<0.01$) after exposure by the post-hoc Dunnett test, but the chain saw was not.

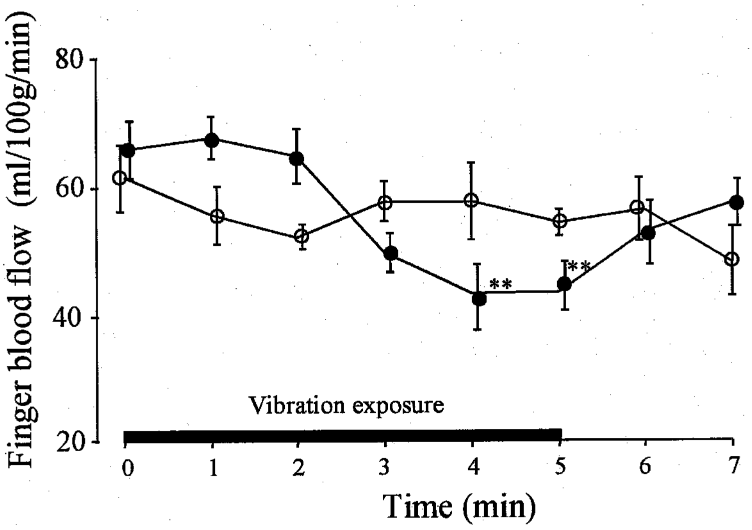


Figure 2. Effects of vibrations produced by chain-saw (O) and pneumatic nailer (●) on finger blood flow. Values represents mean standard errors. **$p<0.01$ as compared to the initial value.

2) *Cold water immersion test*

Changes of finger blood flow produced by cold water immersion in the VWF and control groups are shown in the absolute value of blood flow (Figure 3). The repeated measures ANOVA revealed statistically significant main effects of vibration exposure (F(12, 225) = 21.2, $p<0.001$) and groups (VWF and control) (F(1, 225) = 6.15, $p<0.05$) as well as a significant interaction between them (F(12, 225) = 18.4, $p<0.001$). Although the finger blood flow at 1 and 2 minutes after immersion in the control group decreased significantly (both $p<0.01$), those in VWF did not change as compared to the

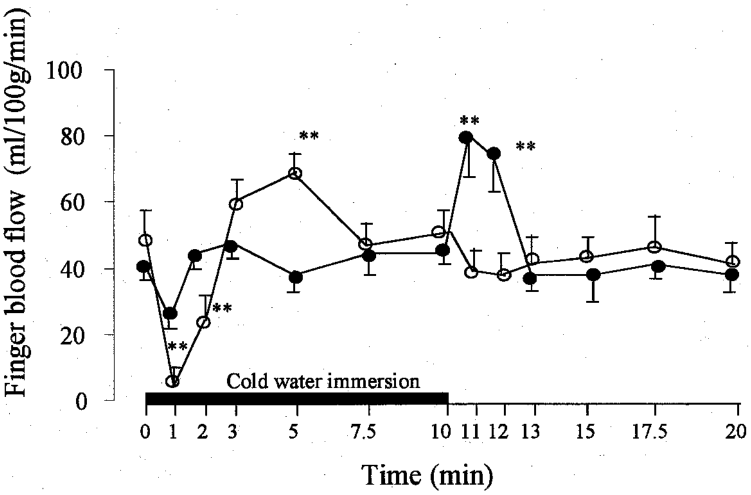


Figure 3. Effects of cold water immersion test on finger blood flow in the workers without VWF (O) and with VWF (●). Values represent mean standard errors. **$p<0.01$ as compared to the initial value.

initial value. The finger blood flow at 5 minutes after immersion in the control group increased significantly ($p<0.01$), but that in VWF group did not change. The finger blood flow at 11 and 12 minutes (both $p<0.01$) in the VWF increased significantly, but the increase was not observed in the control group.

Discussion

Whether the effect of impulsive vibration on human hand-arm is equal to that of non-impulsive vibration is questionable. The present standard using the frequency-weighted r. m. s. acceleration level (ISO-DIS 5349) (9) does not provide satisfactory evidence for the justification of the assessment for repetitive impulsive vibration. Epidemiological study examining the relationship between prevalence of VWF and vibration level suggests that the effects of impulsiveness are under-estimated (11). Yonekawa and his associates (12) have studied human perception to shock-type vibration, demonstrating that the r. m. s. values under-estimated the repeated shock-type vibration. Although the r. m. q. and the vibration dose value (V. D. V.) have been proposed by Griffin (13) for the measurement of the shock-type vibration, the effect of the impulsiveness on peripheral circulation has not been incorporated in the proposal. Indeed, little research has been performed to examine the effects of shock-type vibration on peripheral circulation. Schafer and his associates (14) have used finger skin temperature as an indicator of peripheral circulation, suggesting that it is justified to use the present standard. The present finding on finger skin temperature coincides well with the study performed by Schafer et al. (14) who report no different change of skin temperature produced by impulsive vibration from that by non-impulsive vibration. Although skin temperature may be considered as an indirect criterion of peripheral circulation, its measurement is not so sensitive as that of blood flow (1). The present results demonstrated that impulsive vibration with acrest factor of 9.5 affects finger circulation 4 minutes after the initiation of exposure. These data suggest that the evaluation of the impulsiveness using the frequency-weighted r. m. s. acceleration level (ISO-DIS 5349) (9) must be reconsidered. Future studies should clarify the relationship between impulsiveness level and responses of finger blood flow to work out the proposal for appropriate evaluation methods.

The vasoconstriction subsequent to the start of immersion was decreased in the workers with VWF. Such a poor response of peripheral circulation to cold water in workers with VWF seems similar to that of the sustained hand grip. We have previously demonstrated that the vasoconstrictive effect of hand grip is smaller for workers with VWF than for without VWF (1). The lack of a significant change in finger blood flow produced by hand grip, as well as cold water immersion in workers with VWF, may be explained by organic and functional changes in the peripheral blood vessels due to long term exposure to vibration. The organic changes seem to include the sclerosis of subcutaneous tissues and the resultant decrease in tissue compliance, as assumed by Stewart and Goda (15). Contrary to our findings, some researchers have found a decreased finger systolic blood pressure in workers with VWF using strain-gauge plethysmography with a digital cooling cuff (16, 17), considering an increased vasoconstriction to cold as its etiology (18, 19). In workers with VWF, however, a decrease in blood flow may precede finger blood pressure reduction observed during a cold provocation test (17). Thus, observation of finger circulatory movement using finger systolic blood pressure seems unlikely to reflect finger blood flow exactly. We assumed that a lack of an increase in finger blood flow at the middle period of the immersion schedule in workers with VWF was due to an attenuation of cold-induced vasodilation (CIVD). Cold-induced vasoconstriction is caused by augmented smooth muscle responsiveness to norepinephrine, whereas CIVD is caused by a cessation of transmitter release from adrenergic nerve endings (20). The CIVD is known as one type of reaction of skin vessels which show first a constriction when exposed to cold with a subsequent vascular relaxation following immediate vasoconstriction (21). The attenuated CIVD in workers with VWF has been reported by Magos and Okos, who measured finger blood flow indirectly. Hellstrom and Myhre, who measure finger skin temperature, do not recognise the diagnostic significance for VWF using CIVD (22). However, the attenuation is observed in patients with primary Raynaud's disease as well (23). Thus, an attenuated CIVD seems to be one of the important characteristics of VWF because our results are based on a sensitive and direct measurement for blood flow. This is supported also by the recent study by Kurozawa and Nasu (24) who examine peripheral circulatory change using laser-Doppler method. It is assumed that CIVD during cold exposure decreases excessive cooling of the extremities, thus preventing irreversible tissue damage caused by freezing (21). Taken together with the significance of CIVD, a functional disorder such as the attenuated CIVD in workers using vibratory tools, may lead to the development of VWF in an organic disorder in addition to the functional change.

It is impossible to observe finger systolic blood pressure using plethysmography continuously. A total decrease in finger blood flow during cold water immersion including the attenuated CIVD in workers with VWF might be monitored by the method of plethysmography which has detected a reduced finger systolic blood pressure as a characteristic of VWF workers.

Conclusion

The thermal diffusion method is very efficient in measuring peripheral circulation in fingers exposed to unstable conditions, e.g. impulsiveness and cold.

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Eight cases of HAV syndrome with arterial lesions of the lower extremities

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Introduction

HAV syndrome is composed of the following peripheral components: circulatory order to confirm the peripheral circulatory disturbances we have been actively trying to perform arteriography of the upper extremities and the total number has cumulated to 442 cases in our disturbances, sensory and motor disturbances, and musculo-skeletal disturbances. In department. As vibration-exposed workers advance in age it is not rare to find cases with stenotic or obstructive changes of the arteries in the lower extremities.

The purpose of this study is as follows: first, to examine the incidences of abnormal findings of the superficial arteries of the lower extremities by palpation, the second is to study the arteriographic findings of the upper and lower extremities in 3 cases with TAO (Thromboangiitis obliterans, Buerger’s disease), and the third is to study the arteriographic findings of the upper and lower extremities in 5 cases with ASO (arteriosclerosis obliterans).

Subjects and Methods

Workers who have used vibrating tools for a period of time in mining, forestry and several other industries in Hokkaido were examined at the Iwamizawa Rosai Hospital (Workmen’s Accident compensation Hospital of Iwamizawa).

Ninety-nine workers who had a detailed examination for vibration disease (VD, HAV syndrome) over a period of 3 years were investigated for work history, vibration exposure, smoking habit and the findings of the palpation of superficial arteries of the lower extremities (dorsalis pedis artery and posterior tibial artery).

A direct arteriography of the upper and lower extremities was carried out under general anaesthesia, when it was necessary, on workers who had been engaged in jobs using vibrating tools. After an intra-arterial administration of Tolazoline as a vasodilator, serial automated arteriograms were taken at three exposures per second following an intra-arterial administration of 60% Urographin (1, 2).

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Results

1. Pulsation of superficial arteries of the foot

Among 99 workers who had had the detailed examination for VD, 19 cases (19%) showed a defect or weakness of pulsation of the dorsalis pedis artery and/or posterior tibial artery (Table 1). The mean age with SD was 56±9 years and the exposure period to vibration was 19±9 (M±SD) years. The number of smokers was 66 and the smoking period was 17±2 (M±SD) years. The mean blood pressure was 134-81 mmHg. Eighty-one subjects complained of Raynaud's phenomenon. Among them, 56 were examined by arteriography of the upper extremities and, in some cases, when it was necessary, arteriography of the lower extremities was performed.

Table 1. Pulsation of tibial arteries in the detailed examination of vibration disease.

Experimental group (N)	Age (years)	Vibration exposure (years)	Smoking period	Syst. BP (mmHg)	Pulsation of the tibial artery			
					Anterior		Posterior	
					Lt	Rt	Lt	Rt
VD (73)	57±9	20±8	15±6	134±17	12*	12	12	12
Non VD (21)	53±8	19±11	20±11	135±21	6	6	6	5
Others (5)	50±6	14±7	19±5	132±26	1	1	1	1
Total (99)	56±9	19±9	17±2	134±18	19	19	19	18

*Numbers of cases with no or weak pulsation

2. Arteriographic findings of 3 VD cases with TAO

Three VD cases with TAO were all male and the mean age was 54.3 years (Figure 1, Table 2). All were smokers. The arteriographic findings are as follows:

Case 1. T.K., 55-year-old male

Right upper extremity

Obstruction of ulnar artery, common digital arteries, and proper digital arteries (II, III & IV)

Left upper extremity

Obst. of uln. a., and prop. digit. aa. (III, IV & V)

Lower extremities

Obst. of bilateral post. tibial and peroneal arteries at trifurcation

Rippling or corrugated appearance of lt. ant. tibial a.

Case 2. I.J., 43-year-old male

Right upper extremity

Obst.of uln. a., and obst. or tapering-off of prop. digit. aa. (II, III, IV & V)

Left upper extremity

Obst. of uln. a., and obst. of prop. digit. aa. (II, III & V)

Lower extremities

Tapering-off of bilat. ant. tibial arteries and delay of blood flow at the left dorsum of foot.

Case 3. Y.K., 65-year-old male

Right upper extremity

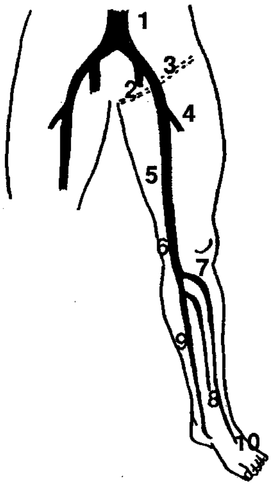
Obst. of uln. a., obst. of common digit. aa. and each prop. digit. a.

Left upper extremity

Obst. of uln. a., obst. of common digit. aa. and each prop. digit. a. at the origin

Lower extremities

Obst. of bilat ant. tibial arteries and coiling of rt. post. tibial a. with its stenosis (>75%)



1. Common iliac artery
2. Internal iliac artery
3. External iliac artery
4. Deep femoral artery
5. Superficial femoral artery
6. Popliteal artery
7. Anterior tibial artery
8. Peroneal artery
9. Posterior tibial artery
10. Dorsalis pedis artery

Figure 1. Arteries of the pelvis and the lower extremities.

An arteriography of the upper extremities revealed complete or 90% stenosis of the ulnar artery at the wrist in 2 cases, and obstructions of the common digital arteries and the proper digital arteries in all 3 cases. An arteriography of the lower extremities revealed delay of blood flow, tapering-off or obstruction of the anterior or posterior tibial artery at the lower leg, and a rippling or corrugated appearance in the tibial arteries in all 3 cases (Table 3).

Table 2. Background of subjects and circulatory disorders.

	Case (Age)	Occupation (Years)	B I	Raynauds' phenomenon		Pulsation of tibial arteries			
				R	L	R		L	
						Ant.	Post.	Ant.	Post.
	T.K. (55)	Mining (25)	450	II, III	II, III, IV	++	-	++	-
TAO	I.J. (43)	Mining (23)	115	II ~ V	II, III	-	++	-	++
	Y.K. (65)	Concrete industry (17)	660	II ~ V	II ~ V	-	-	-	-
	O.M. (49)	Mining (35)	-	I ~ V	I ~ V	+	+	-	+
	T.M. (55)	Construction industry (17)	700	II ~ V	II ~ V	-	+	+	+
ASO	Y.T. (58)	Mining (26)	190	I ~ V	I ~ V	-	-	-	-
	S.K. (61)	Mining (33)	2200	II ~ V	II ~ V	+	+	+	+
	H.H. 64)	Construction industry (27)	775	I ~ V	I ~ V	++	-	+	-

Note. I, II, III, IV, and V indicates finger number

Table 3. Summary of arteriographic findings of the upper and lower extremities.

Diagnosis	Upper extremities	Lower extremities
TAO (3 cases)	Type IV*	3 below knee lesions no high lesion
ASO (5 cases)	Type III**	2 below knee lesions 3 high lesions 1 75% stenosis of lt. ext. iliac a. 1 complete obst. of bl. superf. fem. a. 1 mild stenosis of lt. superf. fem. a.

* Type IV: Obst. at palm and forearm

** Type III: Obst. of proper digit. a. (Intact radial a., ulnar a. and common digit. aa.)

3. Arteriographic findings of 5 VD with ASO

Five VD cases with ASO were all male and the mean age was 57.4 years (Table 2). Four of them were smokers. The arteriographic findings are as follows:

Case 1. O.M., 49-year-old male
  Right upper extremity
    Kinking of each prop. digit. a. and stenosis (<50%) of prop. digit. a. (II & III)
  Left upper extremity
    Kinking of each prop. digit. a, 50% stenosis and obst. of prop. digit. a.(II & V9)
  Lower extremities
    Tapering-off of rt. ant. tibial a.
Case 2. T.M., 55-year-old male
  Right upper extremity
    Tapering-off of prop. digit. aa. (II, III, IV, V)
  Left upper extremity
    Tapering-off and stenosis of prop. digit. aa. (II, III, IV, V)
  Lower extremities
    Moth-eaten configuration of lt. post. tibial a.
    Moth-eaten configuration and tapering-off of rt. ant. tibial a., and stenosis of lt. ant. tibial a.
Case 3. Y.T., 58-year-old male
  Right upper extremity
    Tapering-off of prop. digit. aa. (II, IV)
  Left upper extremity
    Tapering-off of prop. digit. aa. (II, IV, V)
  Lower extremities
    Obst. of bilat. superficial femoral arteries
Case 4. S.K., 61-year-old male
  Right upper extremity
    Kinking of each prop. digit. a., tapering-off or obst. of prop. digit. aa. (II, III)
  Left upper extremity
    Severe kinking of each prop. digit. a and stenosis (> 50%) of prop. digit. aa. (II,III,IV,V)
  Lower extremities
    75% stenosis of lt. ext. iliac a. and tapering-off of lt. ant. tibial a.

Case 5. H.H., 64-year-old male
Right upper extremity
Stenosis (less than 50%) of prop. digit. aa. (II,III,IV) and
obst. of prop. digit. a.(V)
Left upper extremity
Stenosis (< 50%) of prop. digit. aa. (II,III,IV,V)
Lower extremities
Stenosis of lt. superf. fem. a., lt. dorsalis pedis a. and rt. post. tibial a.

An arteriography of the upper extremities revealed kinking or coiling, stenosis and/or tapering-off of the proper digital arteries in all 5 cases. However, common digital arteries and both ulnar and radial arteries were without any findings arteriographically. An arteriography of the lower extremities revealed 75% stenosis of the external iliac artery in 1 case, obstruction and stenosis of the superficial femoral artery in 2 cases, and obstruction or stenosis of the anterior or posterior tibial arteries in 2 cases (Table 3). In case Y.T., complete obstruction of the bilateral superficial femoral arteries was observed. By means of a bypass, blood flowed normally through the popliteal arteries, but, pulsation was defective bilaterally.

Discussion

With the increase in aging workers, VD subjects frequently suffer also from hypertension, diabetes mellitus, hyperlipidemia, and so on. In such cases, some of the VD subjects are also seen to have obstructive changes in the arteries of the lower extremities. Typical cases of such abnormalities are TAO and ASO. Prior to the advent of arteriographic examinations, we had to select cases which we only had a suspicion of having arterial abnormalities. Hypothenar hammer syndrome (post-traumatic digital ischemia; occupational occlusive arterial disease; or ulnar artery thrombosis) is also one of the arterial abnormalities of the hand (palmar arches and ulnar artery) and it is diagnosed by an arteriography of the upper extremities (2, 3).

Our classification of arteriographic findings of the upper extremities is as follows:
Type-I: stenosis (< 50%) of each proper digital artery
Type-II: stenosis (>= 50%) of proper digital artery on more than one finger
Type-III: obstruction of proper digital artery on more than one finger
Type-IV: obstruction proximal to common digital artery.

Using this classification, the arteriographic findings of the upper and lower extremities in TAO and ASO were summarised as follows: in 3 TAO cases, the arteriographic finding of the upper extremities was Type-IV and the findings of the lower extremities were 3 below knee lesions with no high lesions; and in 5 ASO cases, the finding of the upper extremities was Type-III and the findings of the lower extremities were 2 below knee lesions and 3 high lesions (1 intra-pelvic and 2 above knee lesions)(Table 3).

Although the technique is quite simple and easy, palpation of superficial arteries of the lower extremities and upper extremities (Allen’s test) is always indispensable for the diagnosis and differential diagnoses of VD or HAV syndrome. In order to clarify the pathological status of the arteries of the upper and lower extremities, arteriographical examinations such as MR-AG should be actively performed.

Conclusion

Among 99 vibration-exposed male workers (56±9 years old) who had a detailed examination for VD, 19 cases (19%) showed a defect or weakness of pulsation in the dorsalis pedis artery and/or posterior tibial artery. Arteriographic findings of the upper extremities in 3 TAO cases were the obstructive changes at palm and forearm with 3 below knee lesions of the lower extremities. In 5 ASO cases, obstructions of proper digital arteries with 2 below knee lesions and 3 high lesions of the lower extremities were observed. Clinical importance of palpation of superficial arteries of the upper and lower extremities and the necessity of arteriography to determine the characteristics and localization of arterial lesions have been discussed based on our experiences in administrating the detailed examination to vibration-exposed workers.

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Response of neuroendocrine system in persons with different constitutional types to the experimental and occupational hand-arm vibration exposure

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Introduction

The effects of occupational hand-arm vibration exposure (VE) on the neuroendocrine system were investigated in many studies. Depression of functions of the hypothalamo-pituitary-adronocortical (HPA) and hypothalamo-pituitary-gonadal (HPG) systems, as well as lack of coordination in the regulation of hormonal secretion by the pituitary gland, were revealed among patients with vibration disease (VD) (1, 2.). Epidemiological, morphological and functional investigations carried out among riveters with long-term vibration exposure had shown that symptoms of the VD developed earlier and in a greater number of cases in persons of pectoral somatotype (PS) than in persons of abdominal somatotype (AS) (3,4.). The authors have earlier described different types of diurnal rhythms of Cortisol and Testosterone among workers of AS and PS under occupational VE (5). The aim of the present study is to compare the functional state of HPA and HPG systems in persons of AS and PS after experimental and occupational hand-arm VE.

Material and methods

The investigation was carried out on two groups of persons (see table 1). Group 1 consisted of 37 riveters in the ages of 23 to 45 years (mean 34.2 ±2,6; M±SD) with total time of VE 2.800 to 10.500 hours (6650 ±300, M±SD). The healthy subjects were selected after investigation of occupational histories and medical examination out of totally two hundred and fifty workers. The measurements of the vibration perception thresholds, finger temperature and cold test provocation did not reveal signs of vibration syndrome among the selected workers.

Group 2 consisted of 24 healthy persons in the ages of 20 to 30 years (25,8 ±1,4; M±SD) whose work was not connected with VE, physical strain or other harmful occupational factors.

The same medical examinations and physiological testing were performed and no one had any signs of vibration or Raynaud’s syndrome. These persons were exposed to 5 minute hand-arm vibration at 30 Hz with a vibration velocity of 121 dB (re. 5,6 x 10-2 m/s r.m.s.), repeated at the same time of the day for a total of 3 days. The grip force was 50 N and we classified this VE as medium stress factor.

For determination of the constitutional types more than 30 antropometric and morpho-functional dimensions were measured. Abdominal (AS) and Pectoral (PS) somatotypes were determined according to the classification of Bunak V. (6), which is based on the correlation of weight and height, horizontal and longitudinal sizes of the human body, the thickness of the skinfold etc.

The activity of HPA and HPG systems were estimated according to the concentrations of hormones Cortisol and Testosterone in saliva. It was shown in many studies that concentrations of steroids in saliva are highly correlated with the same concentrations in plasma and reflect the physiologically active serum unbound fractions of steroids (7,8).

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Table 1. Characteristics of groups of men under occupational (Group 1) and experimental (Group 2) vibration exposure (VE).

Group No.	**Somatotype** AS/PS	**Weight** Kg	**Height** m	**Bodymass index** Kg/m^2	**Age** Year
1 Total time of VE 6650 hours ± 300	Abdominal n=22	83.4±3.1	1.76±0.03	26.6±1.2	25.8±1.4
	Pectoral n=15	78.6±3.3	1.82±0.04	23.7***±0.9	
2 5 min hand-arm VE repeated for 3 days at 30 Hz and 121 dB (re 5.6x $10^{-2\ m/s}$)	Abdominal n=12	79.0*±2.0	1.77±0.01	24.8**±0.8	34.2±2.6
	Pectoral n=12	71.2±2.4	1.85 **±0.01	20.8±0.8	

Mean ± SD; * p< 0,01, ** p< 0,001, comparisons between A S and P S in group 2

*** p < 0,01 comparison between PS group 1 and group 2.

The procedure of collecting of the saliva samples is simple, stress-free non-invasive and allows investigation of the HPA and HPG system activity under different conditions. To investigate the activity and diurnal rhythm of Cortisol and Testosterone under occupational VE, samples of saliva were collected at 0700, 1100, 1500 1900 and 2300 hours from persons in group 1 during 3 ordinary working days.

For investigations of hormone activity under experimental VE in group 2 samples of saliva were collected during 3 days at 0700 and 0900 before, immediately and 30 minutes after VE, and at 1100.

The saliva samples were frozen for later determination of the hormone concentration by radioimmunoassay.

Results

Table 2 shows the response of HPA and HPG systems to 5 minute experimental VE of persons of A S and P S. Cortisol concentration was significantly higher (p < 0,01) at 0700 in persons A S than in persons of PS, but did not change significantly after VE. In persons of P S Cortisol concentration increased immediately after VE (p < 0,01) and preserved higher level during 30 min. after VE (p < 0,05) in comparison with persons of AS.

Testosterone concentration had increased 30 minutes after vibration exposure (p < 0,01) among persons of AS and remained significantly higher until 1100 (p < 0,01) in comparison with persons of PS, who did not show any changes to the experimental VE.

Table 2. Cortisol and Testosterone concentrations in saliva of men of Abdominal (AS) and Pectoral (PS) somatotypes under experimental vibration exposure (VE).

Concentration	**Somatotype**			**Time**		
		At 0700	Before VE	Immediately	30 min. after VE	At 1100 after VE
Cortisol (ng/ 100 ml)	Abdominal n=12	196**±10.2	75.4±6.1	46.5±5.6	52.4±5.2	44.2±5.0
	Pectoral n=12	148±14.0	60.4±7.0	78.6***$^{\Delta}$±3.6	67.0*±3.6	53.5±3.3
Testosterone (pg/ml)	Abdominal n=12	113±4.0	82± 4.8	91±4.6	101**$^{\Delta}$±5.3	95.5**±8.0
	Pectoral n=12	126±7.0	80.3±6.0	81.3±5.2	82±5.8	72.8±4.5

Mean ± SD; * p< 0,05, ** p< 0,01, *** p< 0,001

– comparisons between AS and PSD p < 0,01 comparison with the state before VE.

Table 3. Concentrations of cortisol (ng/ 100 ml) in saliva in men of Abdominal (AS) and Pectoral (PS) somatotypes under occupational (group 1) and experimental (group 2) vibration exposure (VE).

Group	**Somatotype**			**Time**		
		07.00	11.00	15.00	19.00	23.00
1	Abdominal n=22	335*$^{\Delta}$±26.1	158*±17.0	129±17.5	100±16.2	86$^{\Delta}$±16
	Pectoral n=15	262**±13.7	172 **±20.2	113±15.2	81±7.0	42±6.5
2	Abdominal, n=12	196$^{\Delta}$±10.2	44±5.0			
	Pectoral, n=12	148±14.0	53±3.3			

Mean ± SD * p< 0,01 comparison between AS of group 1 and group 2.

** p< 0,001 comparison between PS of group 1 and group 2.

Δ p< 0,05 comparison between AS and PS within each group.

Table 3 shows the changes of Cortisol concentration among persons of AS and PS during working days under occupational VE and under experimental VE at 0700 and 1100.

The diurnal rhythm of Cortisol concentration with the highest level in the early morning hours and then gradually decreasing until the night hours were well expressed among persons of both somatotypes in group 1.

The significantly highest level of Cortisol concentration was found at 0700 among persons of AS in group under occupational VE (p < 0,01, p < 0,05).

Persons of PS from the same group showed the significantly higher Cortisol concentration (p < 0,001) than persons of PS from group 2. The same tendency was noticed at 1100 (except for significant differences within each group). Persons of AS and PS from group 1 showed higher Cortisol concentration than in group 2 (p < 0,01, p < 0,001).

Table 4. Concentration of Testosterone (pg/ml) in saliva in men of Abdominal (AS) and Pectoral (PS) somatotypes under occupational (group 1) and experimental (group 2) vibration exposure (VE).

Group	**Somatotype**	**Time** 07.00	 11.00	 15.00	 19.00	 23.00
1	Abdominal n=22	112±8.8	77±5.6	82±5.0	77±8.4	70.3±5.0
	Pectoral n=15	125.2±14.7	97.3*$^{\Delta}$±7.5	86.3±7.7	70±7.3	68.6±8.2
2	Abdominal n=12	113±4.0	95,5**±8.0			
	Pectoral n=12	126±7.0	72,8±4.5			

Mean ± SD * p< 0,05 comparison between AS and PS in group 1.
p< 0,05 comparison between AS and PS in group 2.
Δ p< 0,05 comparison between PS of group 1 and group 2.

Table 4 shows the changes of T concentration among persons of AS and PS during a working day under occupational VE and under experimental VE at 0700 and at 1100. The diurnal rhythm of T concentration was manly preserved in persons of both somatotypes in group 1. The highest level of hormone was found at 0700 and was almost the same in both groups. At 1100 persons of PS had a higher concentration (p < 0,05) in group 1, but persons of AS had significantly higher levels of Testosterone (p < 0,05) in group 2.

Discussion and Conclusions

The results of this study showed that the diurnal rhythm of HPA system activity with the highest Cortisol concentration at 0700 was preserved among persons of both somatotypes in groups 1 and 2 under experimental and occupational VE. It was shown that under physiological conditions the early morning elevation of Cortisol concentration produces the full complex of metabolic effects including regulation of insulin secretion, carbohydrate, lipid and protein metabolism (9,10).

In our study we found significantly elevated levels of Cortisol in persons of AS and PS in the group under occupational VE. Persons from group under experimental vibration exposure (EVE) showed only 58.5% of Cortisol concentration in AS and 44.2% in PS at 0700; 27.9% in AS and 33,5% in PS at 1100 in comparison with persons of AS from group under occupational vibration exposure (OVE) (Figure 1).

It is a well known fact that Cortisol concentration rises during physical exercise, and along with other catabolic hormones, provides the metabolic response of the organism to stress factors (11, 12). Though the higher levels of Cortisol among the persons in group 1 did not exceed the physiological range, we notice a significantly elevated activity of the HPA system under occupational VE.

Group 1 consisted of healthy professional workers and we can suggest that higher levels of Cortisol concentration may constitiute one of the adaptive reactions to occupational VE.

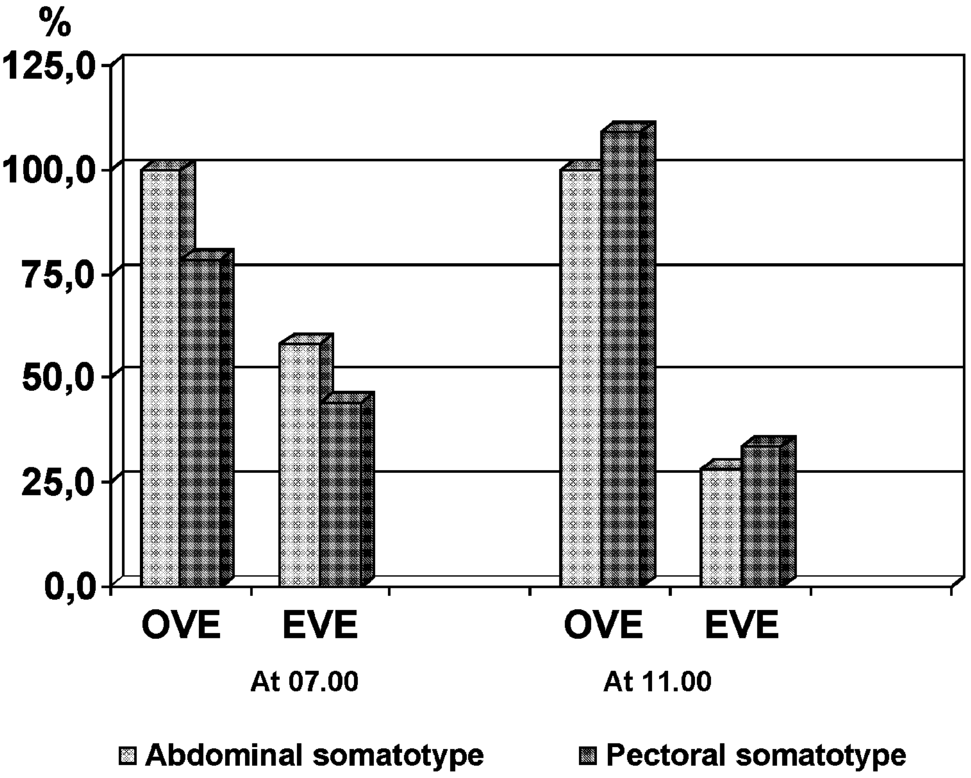

Figure 1. Comparison in percentage of Cortisol concentration in men of Abdominal (AS) and Pectoral (PS) somatotypes and for groups under occupational (OVE) and experimental (EVE) vibration exposure at 0700 and at 1100.

Persons of AS in both groups showed high levels of basal Cortisol concentration at 0700 and the absence of reaction to 5 minute experimental VE.

J. Petrides and colleagues have recently reported two different types of HPA system responses to physical exercise in groups of healthy moderately trained persons. The authors classified these types as ”high” and ”low” responders and proposed that different kinds of reactions to stress stimulation may underlie individual predisposition to the development of HPA dysfunction and disorders. (13).

It is not clear weather ”high” and ”low” responses depend on basal concentration of hormone or not. From our results we can suggest that absence of reaction to the medium stress factor (5 minutes VE) and the high level of basal Cortisol concentration are two probable endocrine characteristics of the abdominal somatotype.

In our study we did not notice any evident signs of activation or depression of the HPG system under occupational VE. However, we observed significantly higher concentrations of Testosterone among persons of PS at 1100 in group 1 and an increase of Testosterone concentrations 30 minutes after experimental VE among persons of AS. These two facts indicate the sensitivity of the HPG system to VE.

The postponed elevation of Testosterone that we observed in persons of AS is in accordance with literature. It was shown that in contrast to Cortisol, concentration of Testosterone did not rise rapidly after physical exercise, but increased significantly in the recovery period. (14). Another study revealed that the temporal relationship between changes in salivary Cortisol and Testosterone are consistent with direct inhibition of testicular secretion by high Cortisol concentrations (15). These facts may explain the absence of the HPG system reaction in persons of PS in group 2, which previously demonstrated increasing Cortisol concentration immediately after experimental VE.

Testosterone is a well known anabolic hormone and plays an important role in maintaining proteins in the muscle tissues (16). The absence of signs of depression of Testosterone concentration in Group 1 of our study is probably evidence of the adaptation of the HPG system in persons of both somatotypes due to occupational VE.

The results of the present study allow us to conclude:
Physiological response of HPA and HPG systems to hand-arm vibration exposure shows constitutional differences;
Activation of the HPA system within physiological ranges, in combination with preservation of functions of the HPG system in persons of both somatotypes, is one of the favourable adaptive variants of the neuroendocrine system to occupational vibration exposure.

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Cardiac autonomic nervous activity in response to cold in VWF patients

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Introduction

The pathophysiology of circulatory disturbances in patients with vibration-induced white finger (VWF) is characterised by an enhanced vasospastic response to cold, which can be due to an increased sympathetic nervous activity in response to cold in the patients (1). In recent years the power spectral analysis of heart rate variability has been developed to assess the sympathetic and parasympathetic nervous function separately, by dividing the power spectrum into high- and low-frequency components (2-4). The aim of the present study was to examine the cardiac autonomic nervous activity in response to cold in VWF patients, using the power spectrum analysis of R-R intervals.

Methods

The present subjects examined were 22 patients with VWF aged 59.3±3.6 years and 19 healthy controls aged 59.3±3.6 years. They all were selected from those without diabetes mellitus or heart diseases.

Subjects lay supine during the study. They rested quietly for about 30 min, then immersed the right hand into cold water at 10 °C for 10 min, and thereafter put the hand out of the water for 10 min. In the meantime, ECG and skin temperature of the index finger were automatically recorded with an ambulatory ECG recorder (Fukuda Denshi, SM-50) and an electrode thermometer (Takara Thermister, HR116). The room temperature was 27±1°C.

After the examinations, ECG signals were converted to R-R interval signals. The power spectrum was then calculated for 128 seconds with a software program using the algorithm of maximum entropy method (Fukuda Denshi), and was divided into the low-frequency component (0.02-0.15 Hz: LF) and the high-frequency component (0.15-0.40 Hz: HF). The LF/HF ratio is considered to show a measure of sympatho-vagal balance, an index of sympathetic nervous activity (2-4).

In the pre-cold exposure, ECG signals were analysed for 128 seconds which ended one minute before the beginning of the immersion. During the cold exposure, four consecutive series of 128 seconds were analysed with the first one that started 30 seconds after its commencement. In the post-exposure, four consecutive series were analysed, in which the first one began one minute after the end of the immersion.

Results

As shown in Figure 1, the LF/HF ratio in the VWF patients tended to be larger than that in the controls in the pre-exposure, though it did not differ significantly. During the cold exposure, the LF/HF ratio in the patients increased greatly in the first 1-2 minutes

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following the immersion, while the ratio in the controls increased little, so that the ratio in the VWF patients was significantly greater than that in the controls. In the post-exposure, it tended to be still greater in the VWF patients.

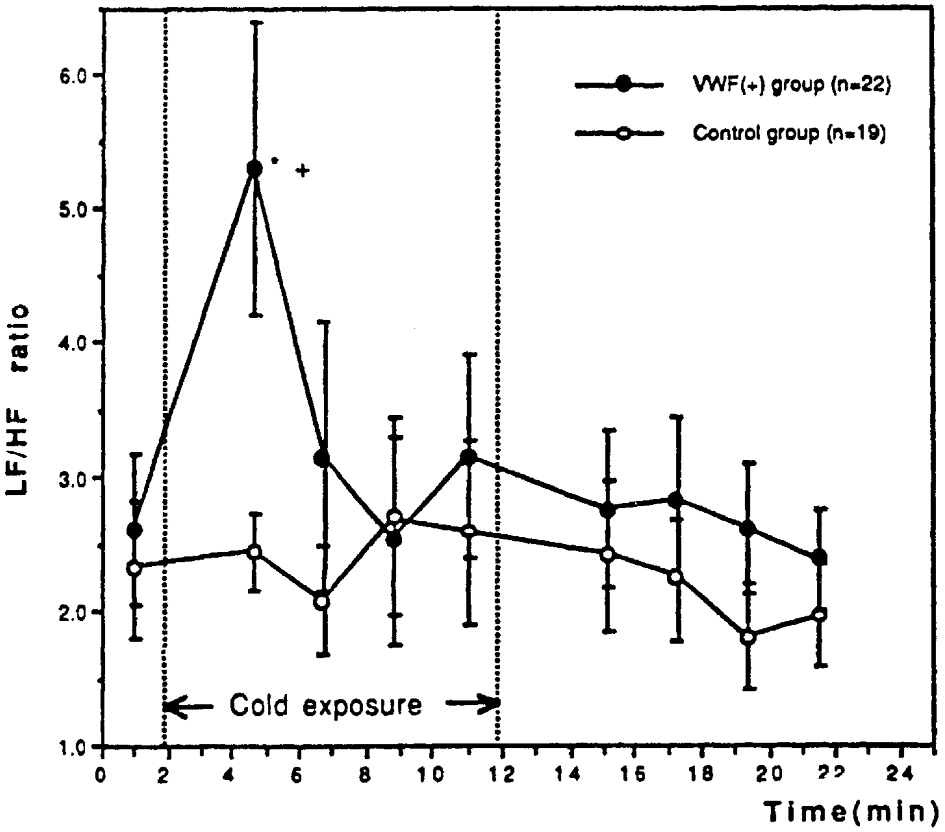

Figure 1. LF/HF ratio (mean ± SE) of VWF group and controls.
(* $p<0.05$ compared with controls; + $p<0.05$ compared with pre-exposure).

Figure 2 shows that finger skin temperature tended to be lower in the VWF patients in the pre-exposure period, though the difference was not significant. In the cold exposure, skin temperature dropped rapidly in the first three minutes of the exposure. Then it was significantly lower in the patients than in the controls at the 4th to 10th minutes of the cold exposure and also in the post-exposure period when its rewarming was delayed in the VWF patients.

Discussion

The present spectral analysis of R-R intervals showed that the cardiac autonomic nervous activity of VWF patients is more likely to shift to the sympathetic dominant in response to cold than that of healthy controls. As a result, VWF patients have an increased cardiac sympathetic activity in response to cold.

The sympathetic activity in VWF patients increased to its peak in the first 1-2 minutes of the cold exposure. Meanwhile, skin temperature dropped rapidly in the first 3 minutes and then became lower than that of the controls. These findings indicate that an increased sympathetic activity in response to cold contributes to an enhanced vasospastic response in VWF patients. It is considered that the increased sympathetic response to cold play a role in circulatory disturbances of the feet as well as the hands in VWF patients (5).

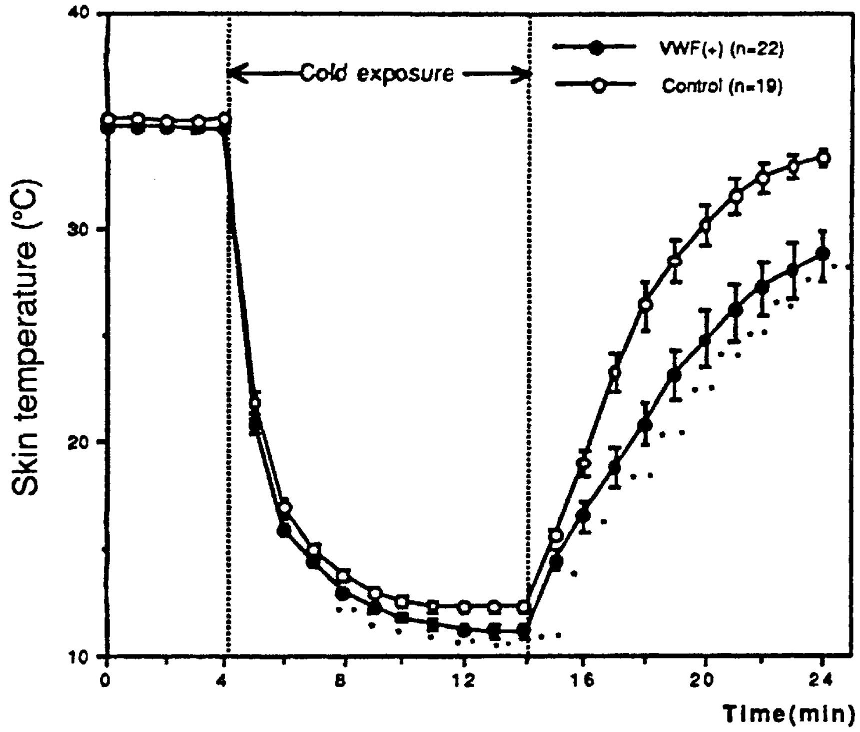

Figure 2. Skin temperature of right index finger (mean ± SE).
(* p<0.05 compared with controls).

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Effects of room temperature, seasonal condition and food intake on cold immersion test for diagnosing hand-arm vibration syndrome

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Introduction

For diagnosis of the hand-arm vibration syndrome, the cold immersion test using different water temperature and duration of immersion, such as water at 10°C for 3 minutes (1), at 10°C for 10 minutes (2), at 15°C for 1 minute (3), at 15°C for 3 minutes (4), has been reported in Europe and North America. The standardisation of the vascular assessment method, constituted by measurement of finger skin temperatures as well as finger systolic blood pressures, is under discussion in the International Organisation for Standardisation (5).

In Japan, peripheral circulation and sensory tests including finger skin temperature measurement immersing one hand in cold water at 10°C for 10 minutes are widely accepted (6, 7, 8). The test has a wide application in clinical diagnosis, health examination and epidemiological studies. The test results are thought to be influenced by the environmental factors shown in Table 1. We investigated the effects of room temperature, seasonal condition and food intake on the test results, especially finger skin temperature.

Table 1. Environmental factors influencing finger skin temperature during cold immersion test.

(1) room temperature
(2) season
(3) circadian rhythm
(4) food intake
(5) smoking
(6) alcohol
(7) clothing
(8) others

Subjects and method

Three experiments were performed.

In experiment 1, for the effect of room temperature, six healthy males aged 23 to 29 were examined repeatedly under six different room temperatures at 10°C, 15°C, 20°C, 22.5°C, 25°C and 30°C. The seasons were autumn (November) and winter (December). The average values of outdoor atmospheric temperatures at the periods were similar; 12.4°C and 9.0°C, respectively.

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In experiment 2, for the effect of seasonal condition, eight healthy males aged 28 to 39 were examined under room temperatures at 10°C, 20°C and 30°C, repeatedly in winter (February), spring (May), summer (August) and autumn (November). The average values of outdoor atmospheric temperatures were 4.5°C in winter, 12.4°C in autumn, 17.7°C in spring and 24.5°C and 27.3°C in summer.

In experiment 3, for the effect of food intake, six healthy males aged 21 to 27 were examined repeatedly 1 hour after, 3 hours after meal and after fasting for 13 hours. The room temperature was at 22.5°C and the season was summer (August) and winter (February), while average outdoor atmospheric temperatures were 26.6°C and 7.6°C, respectively. The energy content of the meal taken before the experiment was controlled as 754 kcal.

The left hand of each subject was immersed in stirred water at 10°C for 10 minutes, and the change of skin temperature of the left middle finger was measured. Every subject wore four items of clothing; an undershirt without sleeves, a shirt with sleeves, underpants and trousers. For room temperature at 10°C and 15°C, two and one white overalls were also worn, respectively.

For the statistical test, analysis of variance was used.

Results

Figures 1 and 2 show changes of finger skin temperature during the immersion test under different room temperatures. The finger skin temperature was strongly affected by the room temperature; those before immersion varied from 16°C to 34°C, at the 5 minute point after immersion they were from 12°C to 26°C. Between the room temperatures at 15°C and 25°C, the average values of finger skin temperatures before exposure and at the 10 minute point after immersion changed with a range of more than 10°C. The effect of room temperature in every measuring point was statistically significant (two-way analysis of variance, $p<0.05$, $p<0.01$).

Figures 3, 4 and 5 show the changes of finger skin temperature during immersion test under different seasonal conditions at the room temperatures of 10°C, 20°C and 30°C, respectively. The effect of seasonal conditions in every measuring point was statistically significant (three-way analysis of variance, $p<0.01$). In particular, the finger skin temperatures in summer were higher than those in other seasons. Those under the room temperature at 30°C in autumn were lower.

Figures 6 and 7 show the changes of finger skin temperature during the immersion test under different conditions of food intake in summer and winter, respectively. The room temperature was 22.5°C. The average values of the finger skin temperature in summer indicated no remarkable differences among the three conditions. Those in winter tended to be higher at 1 hour after a meal and lower after fasting for 13 hours (two-way analysis of variance, $p<0.1$).

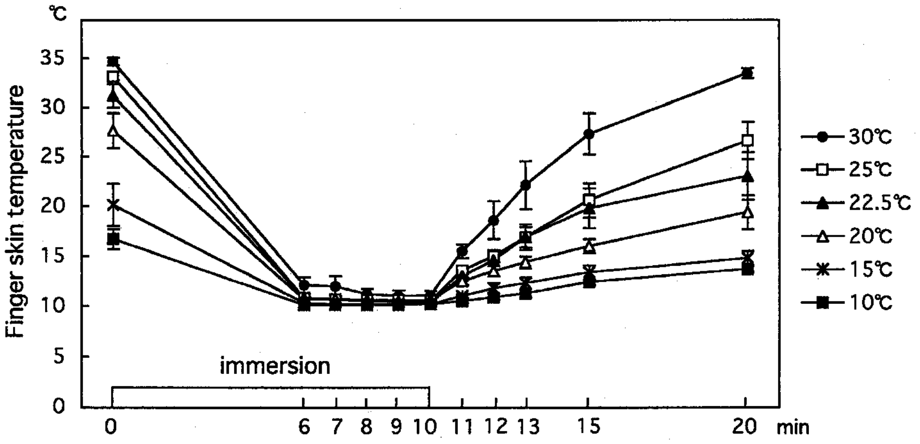

Figure 1. Changes in finger skin skin temperature during immersion test under different room temperatures (n=6, mean±SE).

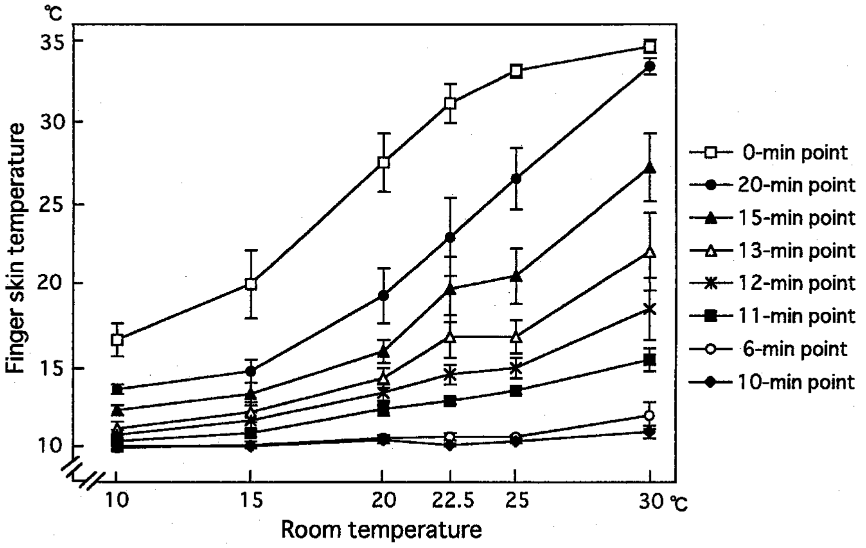

Figure 2. Effects of room temperature on finger skin temperature during immersion test (n=6, mean±SE).

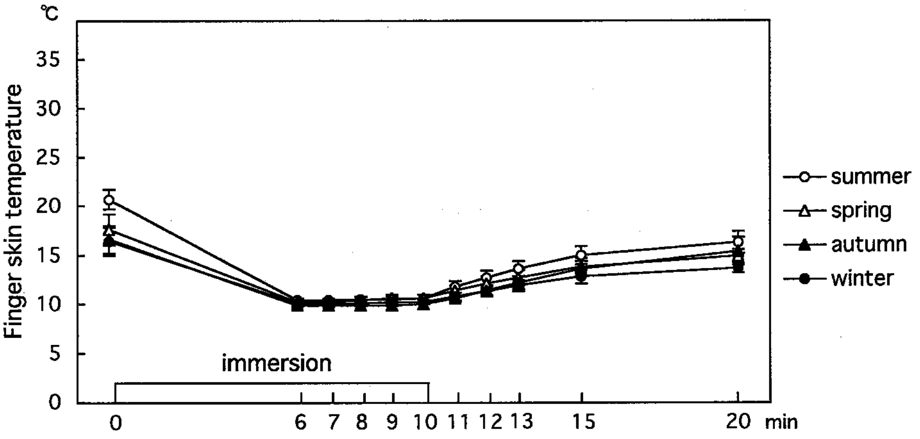

Figure 3. Changes in finger temperature during immersion test under room temperature at 10°C (n=8, mean±SE).

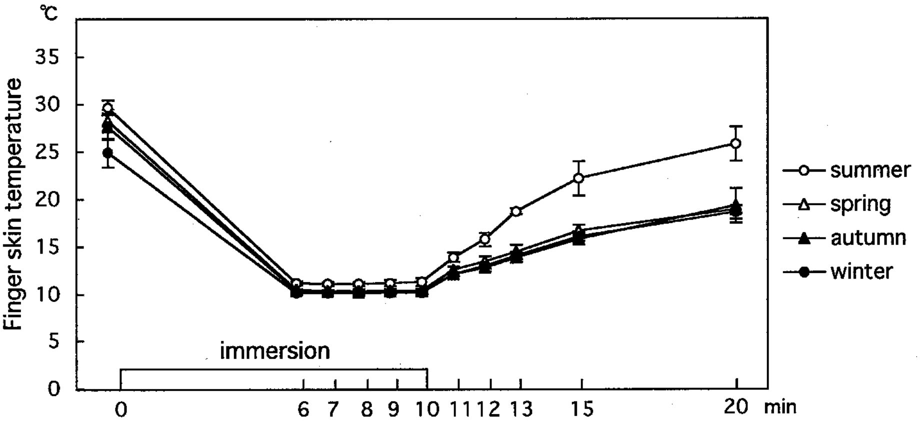

Figure 4. Changes in finger temperature during immersion test under room temperature at 20°C (n=8, mean±SE).

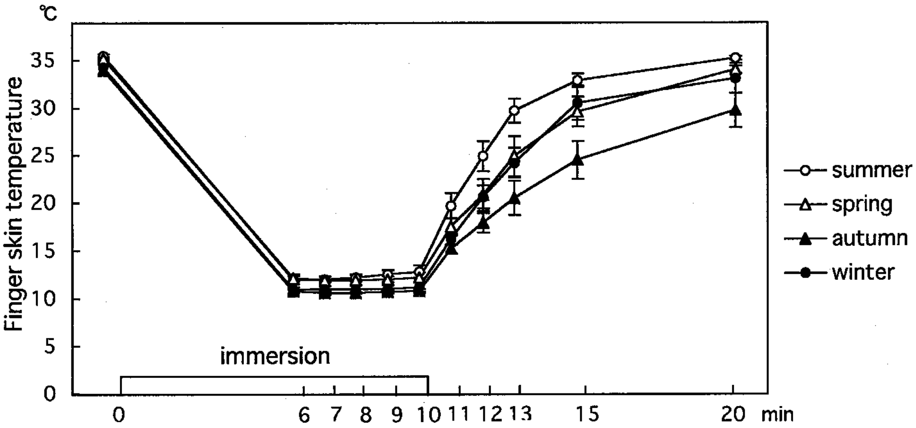

Figure 5. Changes in finger temperature during immersion test under room temperature at 30°C (n=8, mean±SE).

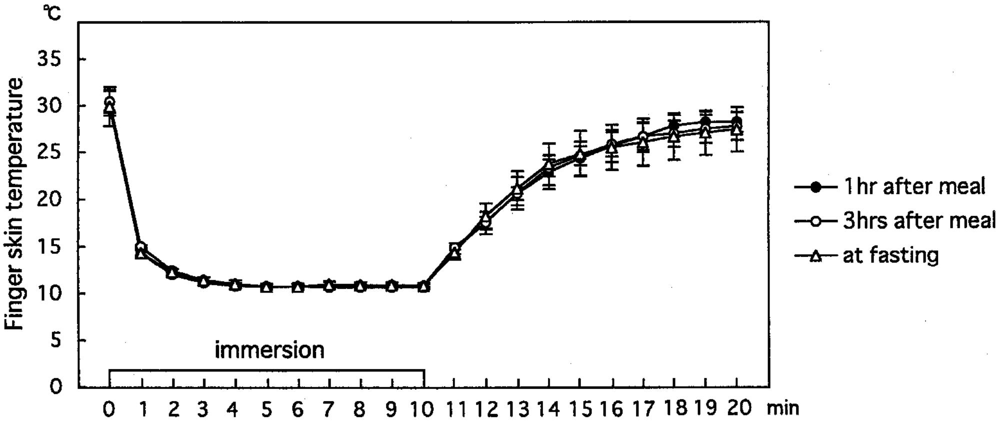

Figure 6. Changes in finger temperature during immersion test under different conditions of food intake. The room temperature was 22.5°C (summer, n=6, mean±SE).

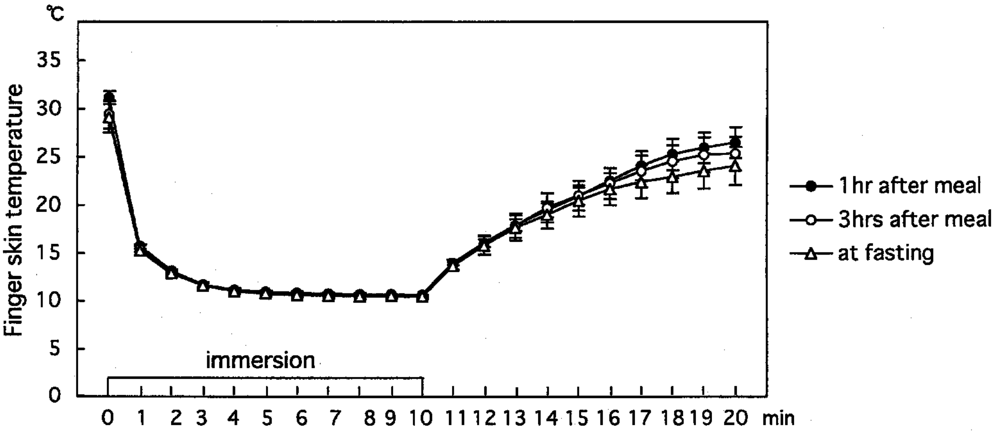

Figure 7. Changes in finger temperature during immersion test under different conditions of food intake. The room temperature was 22.5°C (winter, n=6, mean±SE).

Discussion

A change of 1°C of room temperature in the range between 15°C and 25°C induced a change of more than 1°C of finger skin temperature before and at the 10 minute point after cold immersion. The finger skin temperature during the cold immersion test in summer was especially higher than in other seasons. From comparison of the finger skin temperatures between workers with VWF and without VWF in field examinations, Kurumatani (9) reported that the effect of room temperature on the finger skin temperature was large, and room temperature from 20°C to 23°C has a relatively larger diagnostic significance of VWF when comparing with those under 20°C and over 23°C. The finger skin temperature was strongly affected by room temperature. The room temperature should be strictly controlled.

The finger skin temperatures in summer were higher than those in other seasons. Those under the room temperature at 30°C in autumn were lower. These effects of seasonal condition on the finger skin temperature were also reported by Azuma (10). Although the results differ from each other more or less, the following points are common to them. The finger skin temperatures during the cold immersion test are affected by seasonal factor and the values in the hot season are higher than those in the cold season.

The basal metabolic rate in Japanese general people is reported to be affected by seasonal condition. As shown in Figure 8, that in summer is lowest and in autumn tends to increase faster beyond the decrease of environmental temperature (11). The effects of seasonal condition on the finger skin temperature were seen to be the reverse of changes of the basal metabolic rate. However, cutaneous vasoconstriction is induced in a cold environment for maintaining the core temperature. Seasonal effects on the basal metabolic rate and finger skin temperature can be understood as coordinated mechanisms for the purpose. For estimating circulatory function using the finger skin temperature, the effect of the seasonal condition must be taken into consideration.

Although the finger skin temperature indicated no remarkable differences among three different conditions of food intake in summer, those in winter tended to be higher at 1 hour after a meal and lower after fasting for 13 hours. Takano et al (12) investigated the influence of food intake on cold-induced vasodilatation (CIVD) of finger. The CIVD responses after food intake significantly increased compared with those before food intake.

Food intake increases the metabolic rate because of its specific dynamic action (SDA). The SDA may last up to 6 hours after the food intake (13). It was reported that sympathetic discharge is increased after food intake (14). The reason for the difference of food intake effect between summer and winter is unclear. One possible explanation is that basal sympathetic tonus in winter is higher than that in summer. The effect of food intake was not so large; however, it may be better that the cold immersion test before 1 hour from meal and after fasting for more than 4 hours is avoided.

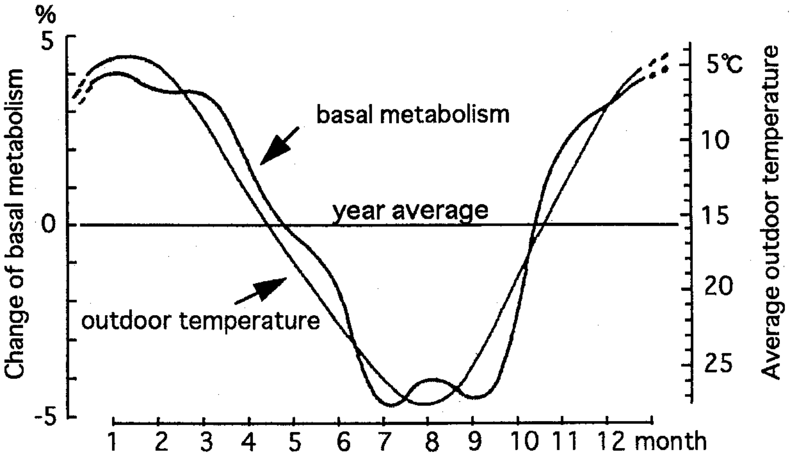

Figure 8. Effect of seasonal condition on the basal metabolic rate in Japanese general people (Sasaki, 1977).

Conclusion

For estimating circulatory function of the upper extremities using the finger skin temperature during the cold immersion test, the room temperature should be strictly controlled, and the effects of the seasonal condition and food intake must be taken into consideration.

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Palmar sweating reaction to vibration stress

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Introduction

The habitual use of vibrating tools such as chain saws and pneumatic hammers has results of injuries in the peripheral blood vessels and nerves, giving rise to Raynaud's phenomenon and numbness in the fingers. One of these signs and symptoms has palmar hyperhidrosis. In fact, according to Matoba et al. (1). about 70% of patients with hand-arm vibration syndrome (HAVS) have suffered from palmar hyperhidrosis, of which rate depends on the severity of the disease. For the mechanism of the occurrence, both of central and local theories, are proposed respectively by several investigators (2, 3). Although palmar sweating is actually controlled by cholinergic sympathetic fibers, the mechanism for the palmar hyperhidrosis in the patients with HAVS is still unclear. We examined healthy men to clarify the mechanism of palmar sweating induced by vibration stress in relation to the autonomic nerve tone.

Methods

The subjects were 20 healthy male volunteers aged 19 to 25 years (mean age 21.5). No one had a history of peripheral vascular disease or of injury to the neck, trunk, or upper limbs. None had previously experienced any significant exposure to hand transmitted vibration. All but three of them were non-smokers, and the three were prohibited to smoke for two hours before experiment. The subjects were not allowed to make conversation or to have sleep throughout the experiment. Informed consent was obtained from all of the subjects before experiment.

The activity level of the autonomic nerve tone at rest was examined by photoplethysmographic responses to auditory stimuli using the digital photoplethysmography (Hokanson EC-5R) (4). First, the subject was kept in a sound-proof room with his fingers situated at the level of his heart in a supine position. The probe was set on the tip of his right middle finger. After confirming that the amplitude of the digital plethysmogram had been stabilized, the noise of 90 dB in magnitude and 800 Hz in frequency was given to the subject through a headphone for 10 seconds. The recovery course of the amplitude of the plethysmogram once reduced by the auditory stimulation was observed. The patterns of the recovery were divided into four types according to the following criteria. Normal (N) type was that the amplitude reduced by the auditory stimulation recovered within 30 seconds after cessation of the stimulus. Intermediate (I) type was that recovery was more than 80% of the initial amplitude at 60 seconds. In delayed (D) type, the recovery was up to 80% or less of the initial amplitude at 60 seconds. I and D types showed hyperreactivity in the autonomic nerve tone. Poor response (P) type showed only minimum reduction (within 30%) in amplitude on the auditory stimulation. After resting in a relaxed state on a bed for 20 minutes, the activity level of autonomic nerve tone at rest was examined.

After examining the autonomic tones, palmar sweating volume was measured using the ventilated capsule method (HIDROGRAPH; AMU-100). The subject sat on a chair

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and a capsule was placed on the right palm (Figure 1). Twenty minutes after confirming that both of the sweating volume and the digital plethysmogram had been stabilised, the following experiments were made.

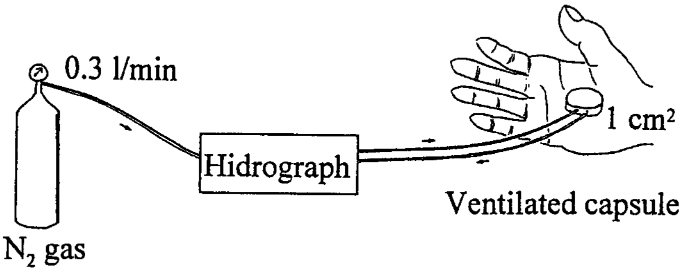

Figure.1 A scheme of the experimental apparatus.

First, the subject was asked to grasp the handle without vibration with his left hand for 3 minutes by the constant power of 5 kgW. When 20 minutes had passed after the experiment in control condition, the second experiment started. The subject took a grasp of the handle of a vibrator generating the sinusoidal vibration of 30 m/s^2 at 125 Hz for 3 minutes. Then the subject took rest for 20 minutes getting ready for the next experiment. Confirming that the subject had no tingling in his fingers, the third experiment started.

The procedure was the same in the second experiment except the magnitude of 50 m/s^2 in vibration acceleration level. Palmar sweating and digital plethysmogram were continuously recorded on the palm and the tip of the middle finger, respectively, in the right hand, non-exposed side.

The increased amount of palmar sweating and the plethysmographic amplitudes were analysed between before and during each stimulus, and before and after treatment with some drugs, 100mg of sulpiride, 1mg of prazosin hydrochloride, and 10mg of scopolamine butylbromide. All the experiments were conducted in a sound-proof room at an ambient temperature at 24°C and relative humidity of 60%.

Results

With regard to the activity level of autonomic nerve tone, 17 subjects out of 20 showed N type and 3 I type. No one showed D or P type.

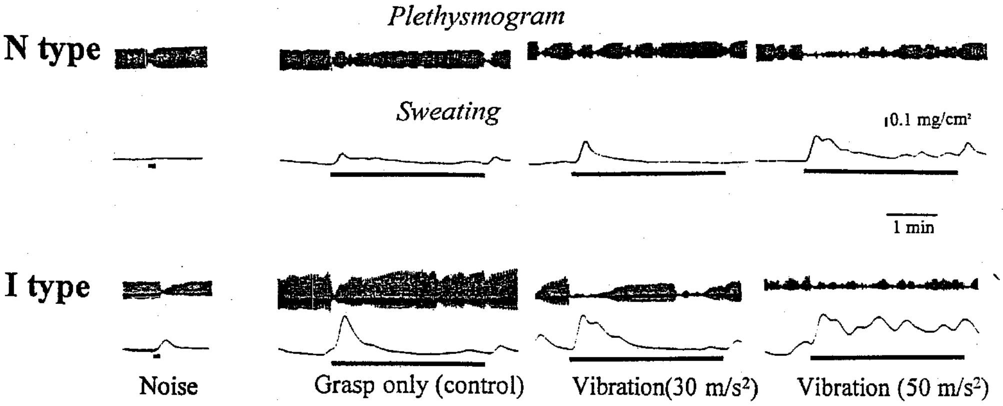

Figure 2. Changes of digital plethysmogram and palmar sweating to each stimulus in N type and I type.

In N type, grasp produced a rapid decrease in the plethysmographic amplitude and a marked increase in palmar sweating. But both responses had been recovered to the pre-experimental level during the grasp. It had the same tendency under the vibration stress of 30 m/s^2. However, responses to 50 m/s^2 were much more than those to 30 m/s^2. The sweating reaction was shown to be like a wave. In I type, the sweating response was much greater than that in N type (Figure 2).

During grasp only, the palmar sweating increased +98.8% on average as compared to the controls. Vibration stress led to a marked increase in sweating: an increased rate of +243.0% in 30 m/s^2 and +900.0% in 50 m/s^2. The sweating response to the vibration of 50 m/s^2 was 9 times greater than that for the grasp only.

Figure 3 indicates the effect of three kinds of drugs orally administered on the digital plethysmogram and palmar sweating in the vibration level of 50 m/s^2. The administration of sulpiride, (an inhibitor of the hypothalamus), increased partially the amplitudes of the plethysmogram and decreased partly the palmar sweating during vibration stress. Prazosin dilated the finger blood vessels almost completely, showing the maximal amplitude of the plethysmogram. Sweating was inhibited by the administration of prazosin. No changes in the amplitude of the plethysmogram were observed by scopolamine butylbromide, anticholinergic drug. However, palmar sweating was completely inhibited during vibration exposure.

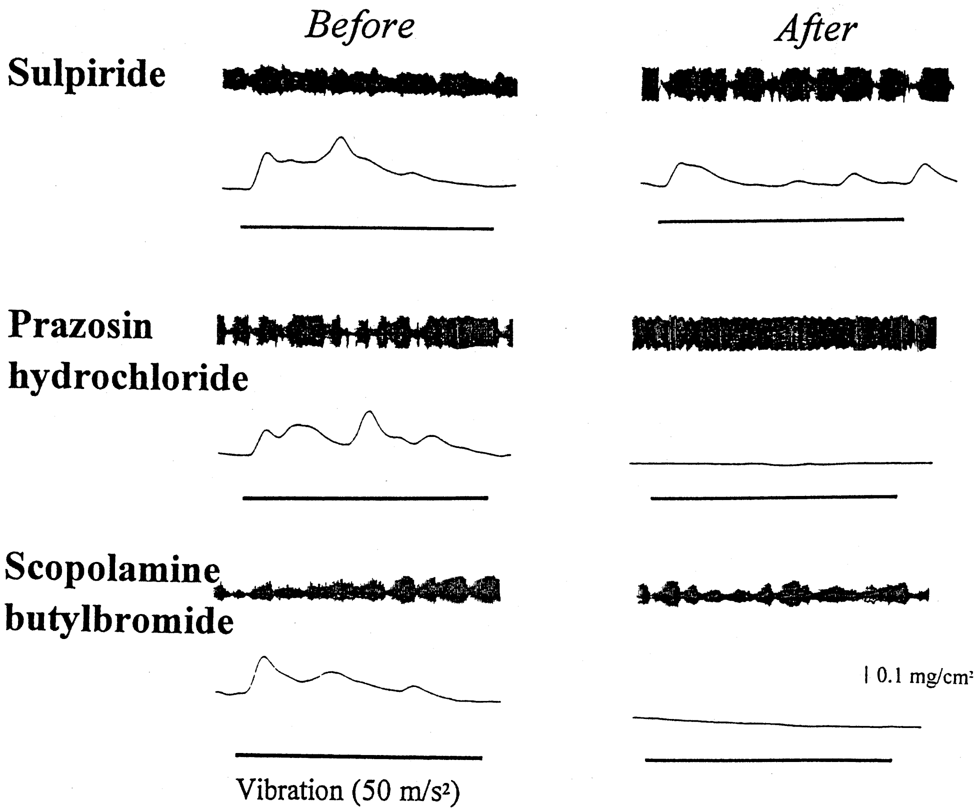

Figure 3. Changes of digital plethysmogram and palmar sweating by vibration in drug intervention.

Discussion

In general, the magnitude and the noise level of vibrating tools in the occupational field range from 0.316 to 100 m/s^2 and 80 to 120 dB (A), respectively. These intensities of vibration and noise levels can possibly stress the human body, leading not only to injury of the peripheral blood vessels and nerves but also to disorders of the autonomic nervous system, mainly sympathetic nervous system. In fact, according to the review of 300 cases by Matoba et al. (1), the patients with HAVS showed exceeding excitation of the sympathetic nervous system and 70% of all the patients have suffered from palmar hyperhidrosis. These signs and symptoms depend on the severity of the disease. In this study, we experimented on 20 healthy subjects in order to find the difference of the sweating response in relation to the activity level of the sympathetic nervous system at rest.

At first, we examined the activity level of the autonomic nerve tone at rest. The digital plethysmography combined with auditory stimuli could express the activity level of the autonomic nervous system (5). It is based on the physiological reaction to the higher center of the autonomic nervous system. Noise as a stressor stimulates the hypothalamus and the limbic lobe of the cerebral cortex, in which the higher center of the autonomic nervous system exists. Arterioles in the fingers are innervated by the sympathetic vasoconstrictor, of which excitation causes vasoconstriction in the arterioles. Accordingly, the excitation of the sympathetic nervous system can be revealed as a decrease in the amplitude of the digital plethysmogram. When white noise of 90 dB is applied to the human body, the plethysmographic response occurs within 10 seconds. The responses are divided into 4 types, ie N, I, D, and P type. I and D types are definitely hyperreactive, and P type is hyporeactive. In this study, all of the 20 healthy subjects showed N or I type, which indicates that they have intact sympathetic responses. We must pay attention to the grade of severity when we consider the palmar hyperhidrosis in the patients of HAVS. According to Matoba et al. (6), the patients with grade IV severity are in the hyporeactive autonomic nerve tone and show no palmar hyperhidrosis. Their sympathetic nervous system would be too exhausted to cause much sweating.

Sakakibara et al. (6) have reported on the combined effects of vibration and noise on palmar sweating in healthy subjects. They referred to a marked, but a transient increase in palmar sweating of a non-exposed hand under the condition of vibration of 100 m/s^2 in magnitude. In our investigation, weaker vibration stress was applied. We have partly obtained the same results, but partly different ones. In our study, increased sweating remained throughout the vibration of 50 m/s^2 in magnitude, a phenomenon which was not observed in the study of Sakakibara et al. (7).

Comparing the sweating responses in the two kinds of vibration magnitude, sweating in 50 m/s^2 was larger than that in 30 m/s^2. We were able to indicate the dose-response relationship between palmar sweating and the magnitude of vibration in the acute and short exposure. The bigger the vibration became, the more clearly the sweating tended to show a wave-like form.

To elucidate the relationship between palmar sweating and the autonomic nerve activity, we used three kinds of drugs, sulpiride (inhibitor of the hypothalamus), prazosin hydrochloride (α-adrenergic blocker) and scopolamine butylbromide (anticholinergics). The changes of palmar sweating and digital plethysmogram were observed both before and 80 minutes after taking these drugs. The decrease of palmar sweating during vibration after taking sulpiride suggests that the palmar sweating responds to vibration through the higher center of the autonomic nervous system. Scopolamine butylbromide inhibited the palmar sweating during vibration. Pharmacologically, an anticholinergic drug can be considered to block the muscarinic receptor of the sweat gland, which leads to the inhibition of palmar sweating. Although the palmar sweating occurred physiologically through cholinergic nerve activation, even prazosin hydrochloride inhibited palmar sweating during vibration exposure. These findings suggest that the palmar sweating during vibration stress is due to the adrenergic sympathetic fibers as well as cholinergic fibers physiologically.

Conclusion

The palmar sweating responses to the vibration exposure in the non-exposed hand increased in parallel to the acceleration level. The increase in palmar sweating by vibration stress may relate to the higher center of the autonomic nervous system. Such responses would be physiologically caused by the adrenergic sympathetic fibers as well as cholinergic nerve fibers.

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Transient vibration from impact wrenches: Vibration negative effect on blood cells and standards for measurement

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Introduction

This paper shows how the cell membrane of red blood cells is destroyed by transient vibration from impact wrenches. It also describes how ISO 5349 (1) filters away these transients without taking their negative effect into account. It is also shown that these transients can be dampened substantially. Moreover, because blood cells are destroyed, it is likely that transient vibrations will have a harmful effect on other biological tissues of the hand including nerve cells. The reason for using blood cells as an indicator of biological damage from transient vibration is that the impact is easy to detect and measure.

Vibration from hand held tools that produce transient vibration, such as impact wrenches in car repair work shops, are a common cause of vibration-related injuries (2). Such injuries occur even though these tools have a typical vibration level of about 3 m/s^2 (as measured in accordance with ISO 5349) and are used only for 10 minutes per day. This may be compared with a grinder whose vibration level is often 6 m/s^2 and is typically used for several hours per day. The transmitted vibration dose is several times higher from the grinder in comparison to the wrench. Thus, one would suspect that vibration-related injuries would be greater among people working with grinders than they would among people working with impact wrenches; however, evidence suggests this is not the case. The vibration dose is calculated by multiplying exposure time by acceleration squared.

It is our belief that the transient vibration peaks from the impact wrenches cause these injuries in the human hand. This effect, however, is not covered by ISO 5349.

Methods

To investigate whether transient vibration has an impact on biological tissue, an experimental procedure was designed that allowed cow blood to be filled into soft polyurethane rubber containers mounted on the following parts of an impact wrench and a grinding machine.

1. The handle of a half inch pneumatic impact wrench with aluminium housing
2. The handle of a half inch pneumatic impact wrench with aluminium housing and an internal vibration dampening mechanism
3. The socket of the impact wrench
4. The handle of a 180 mm pneumatic vertical grinding machine with a standardised unbalanced wheel
5. The handle of an 180 mm pneumatic vertical grinding machine with grinding wheel.

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The test time was 15 minutes for all measurements. The impact wrenches were run on a fixed nut (case 1, 2 and 3), the grinders were run unloaded in the air (case 4) and during grinding under normal working conditions (case 5).

The vibration was measured close to the container to allow comparisons with these measurements and the results from the blood tests. Both the hand-arm-weighted acceleration according to ISO 5349 and the unfiltered acceleration were measured.

The hand-arm-weighted acceleration was measured with a mechanical filter and a B&K 4384 accelerometer using a B&K 2635 charge amplifier. The signal was analysed in a Norsonic 830.

The unfiltered acceleration was measured with a B&K 4374 accelerometer with a weight of 0.7 gram and mounted to the surface with X-60, a stiff gap-filling glue often used in strain gage measurements. The mounted resonance frequency was calculated to be well above the measuring range. To restrict analysis to accelerations that were within the specifications of the accelerometer, we used a B&K 2635 charge amplifier and the signal low pass filtered at 30 kHz.

The peak acceleration amplitude is largely dependent on how high up in frequency the acceleration is measured. To compare measurements care must be taken that they are carried out in the same way with the same frequency limit. The vibration from an impact wrench probably has a frequency content well above 30 kHz.

DC shift is often a problem when measuring transient vibration using piezoelectric accelerometers without a mechanical filter for hand-arm-weighted measurements. The DC shift mainly generates a low frequency noise that will seriously disturb the hand-arm weighted measurements measuring up to only 1250 Hz. In addition, there is the effect of the integration of the signal, which will further suppress the high frequency content. However, when the peak amplitude is of interest and measurements are taken up to 30 kHz, the amplitude of the DC shift is negligible compared with the measured signal. Because of this, there are no problems using piezoelectric accelerometers without a mechanical filter for peak amplitude measurements of high frequencies.

Spectrographic method for the determination of lysis of red blood cells

If the membrane of a red blood cell is disrupted, the red-coloured substance (haemoglobin) is released to the blood plasma. In biological terms, the process is called lysis. The extent of lysis of a blood sample can be quantified spectrographically through the measurement of light absorbance of the released haemoglobin.

Special care should be taken not to contaminate the blood sample with any water of ordinary quality. This may disrupt the blood cells through osmotic effects, causing erroneous analytical results. The blood sample ought to be fresh and the analysis carried out promptly after the experiment to avoid natural degrading effects.

The blood samples (5 to 10 ml) to be analysed are first treated to separate the blood plasma from the blood cells. This is accomplished by centrifugation at 2800 rpm for 5 minutes at a radius of 10 cm. These conditions will provide a clear plasma fluid without jeopardising the analyses through damage of the blood cells.

The plasma samples may have to be diluted so as not to obtain excessive readings of absorbance with loss of accuracy. Dilution is performed with a physiological sodium chloride solution of 0.9% concentration. For reference purposes, non-exposed blood is treated likewise to provide a sample for use as a “blank” in the spectrographic analyses. Diluted samples are measured against references diluted identically with the given salt solution. By preference a double beam spectrometer is used. Before taking sample graphs, the cuvettes are filled with identical reference solutions to set the absorbance reading at a zero level.

A diagram covering the visible wavelength region of interest is shown in Figure 1. Absorbance peak values at 540 nm have been used for the calculations. To obtain an instrument reading corresponding to 100% lysis of blood cells, a blood sample was first frozen to -70¡C, thawed, and then treated with ultrasound. This procedure is known to completely destroy the blood cells. The corresponding absorbance value represents 100% lysis; other sample readings can then be related to that absorbance value.

Figure 1 illustrates a spectrogram of lysed red blood cells. The two curves were obtained for a non-loaded and a loaded operation of a grinding machine during a 15 minute interval. Apparently, the load does not influence the degree of hazardous effect.

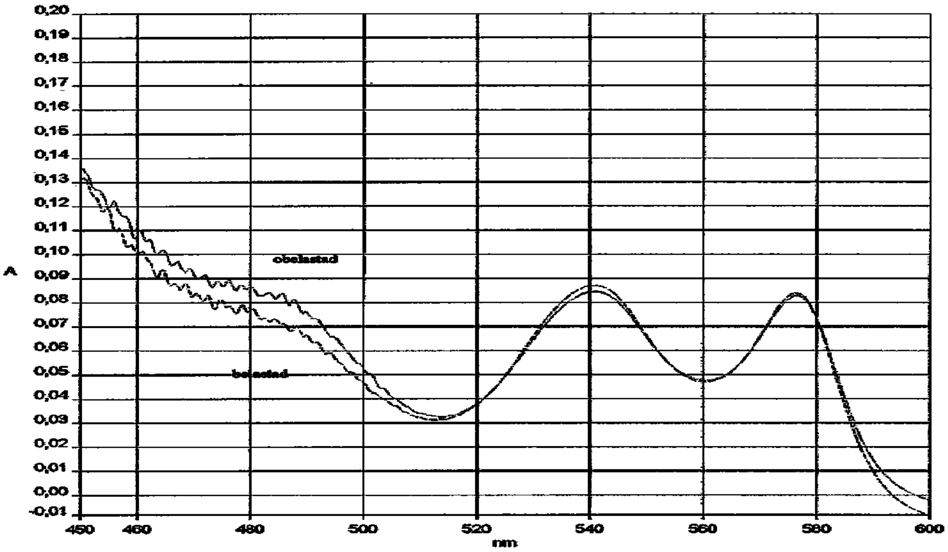

Figure 1. Absorbeny against wavelength.

Results

The results from the blood cell experiment show that the rate of destruction is closely correlated to the peak vibration amplitude and that there is no correlation to the ISO 5349 vibrations.

Table 1.

Test case	Percentage of destroyed blood cells	Peak vibration amplitude, (m/s^2)	Measured ISO5349 vibration, (m/s^2)
1. Handle of impact wrench	0.4 %	15 000	2.2
2. Handle of impact wrench with a dampening mechanism	0.07 %	2 000	2.4
3. Impact wrench socket	100 %	> 30 000	10
4. Vertical grinder with unbalanced wheel	0.1 %	500	6.5
5. Vertical grinder with grinding wheel and grinding	0.1 %	1 000	7.1

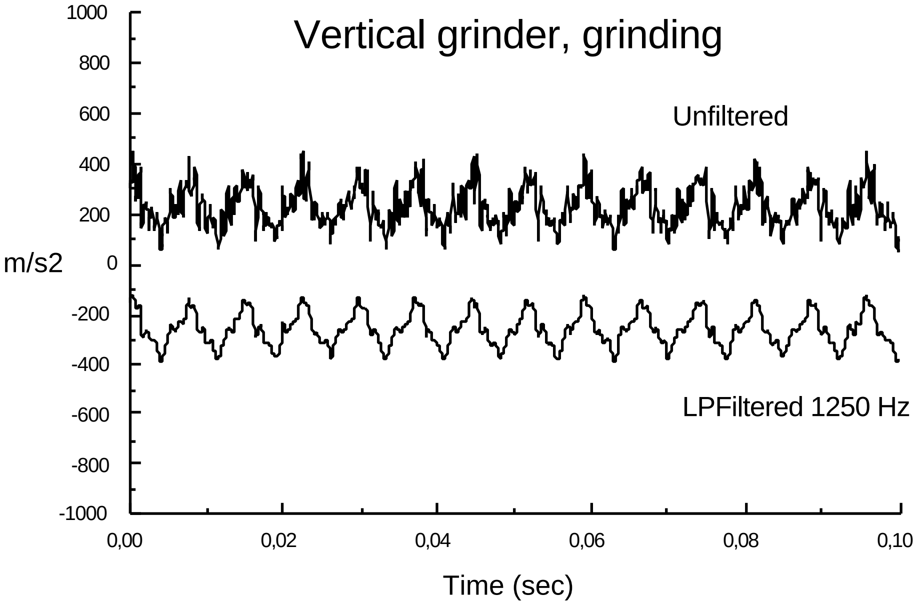

Figure 2. Grinder.

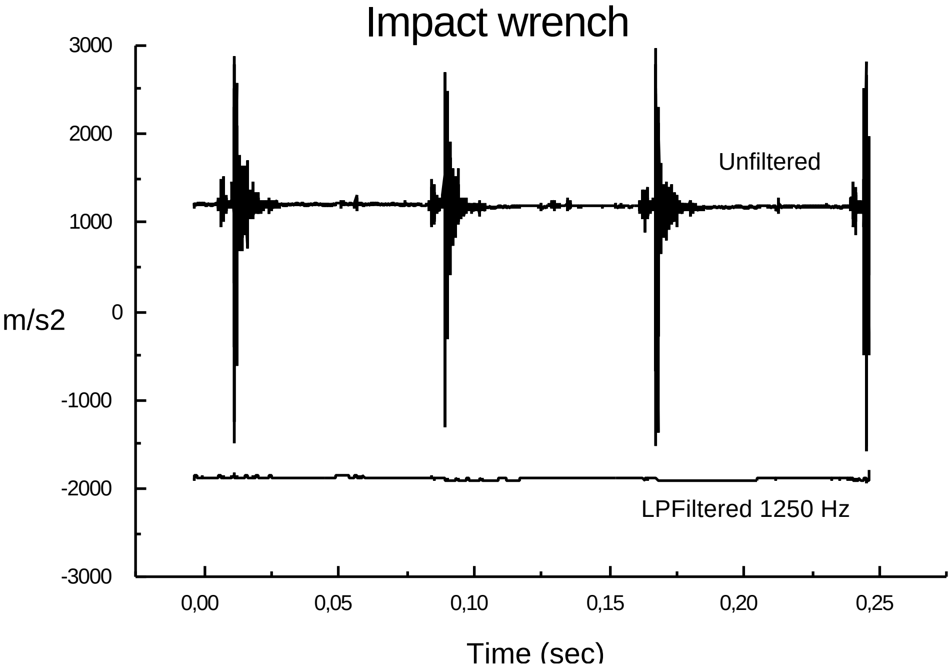

Figure 3. Impact wrench.

Figures 2 and 3 display the influence of filtering the acceleration at 1250 Hz from a grinder and from an impact wrench, respectively, as prescribed in ISO 5349. As can be seen, the very high transients from the impact wrench are almost totally eliminated by the filter, whereas the acceleration from the grinder is much less affected. The vibrations in Figures 2 and 3 were measured up to 10 kHz, which accounts for why the amplitudes do not correspond to those given in Table 1.

Discussion

The results clearly demonstrate a relationship between damages to the cell membranes of blood cells and the exposed transient vibration. The results further show that the values, according to ISO 5349, do not reflect this relationship since the high transient peaks are almost completely eliminated by the filter. Even further suppression of the transient signal is accomplished in ISO 5349 when the acceleration signal is integrated to velocity and the rms value is calculated over several seconds during the measurement interval.

ISO 5349 specifies how much vibration energy is transmitted to the hand. The question is whether this is a relevant approach for transient vibrations. It may be more relevant to consider which forces the hand is subjected to. The peak acceleration informs us of how big the forces are, as described by the equation F=ma. As a comparison, one may consider the adage that driving on a bumpy, gravelled road for one minute is as harmful as driving on a highway for one minute and then hitting a brick wall. In other words, the amount of transmitted vibration energy is the same but the forces are certainly not.

The issue then is to develop a measurement standard that better reflects the problems with transient vibrations. What must be done is to evolve a method that takes into account both the peak amplitude and the frequency of occurrence. Concerning the measurement of peak amplitude, a method such as that used for the measurement of impulsive noise could be useful. In such a case, a filter with a well-defined rise time measures the peak amplitude. Nevertheless, the problem with taking into account the effect of how often the peaks occur remains unsolved.

Conclusions

- Impact wrenches generate very high transient acceleration peaks, causing high stresses in the tissue when transferred to the hand.
- The transients cause destruction of the cell membrane of blood cells subjected to these peaks, and it is likely that other biological tissues in the hand are affected as well.
- The filtering in ISO 5349 functions to almost completely eliminate these peaks and thus fails to take into account the associated risks.
- Transient peaks can be significantly reduced to a low cost by redesigning the tool.

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Vascular and neurological impairment in forest workers of Sardinia

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Introduction

Vibration pathology due to the use of chain saws has been investigated in several studies.

Similar to what has been observed in angioneurosis from vibrating tools typical of the mining and mechanical industries, the physical characteristics of vibrations and vascular and osteoarticular pathology have been investigated with special interest.

All studies in the literature stress the high incidence of vascular, osteoarticular and neurological alterations in forest workers using chain saws and this explains the great attention paid to this kind of pathology in all countries.

Materials and methods

Our study includes 25 subjects who work or worked as woodcutters. Their occupational activities were in all cases performed in the woods of Sardinia and consisted of cutting down trees and lopping off branches with chain saws. They worked an eight-hour day for five days a week in all seasons of the year. We excluded from our study all subjects with a previous vibration risk of different origin (jobs in quarries or mines, machine shops, etc.). We considered only subjects who had a job seniority of at least three years. The longest exposure to risk was found in a woodcutter with 29 years of working activity; mean exposure of all subjects was 14.5 years.

The age of subjects examined varied from 26 to 73 years (mean age 51.6); 18 of these were still working, while eight subjects had left the risky activity, for periods varying from one to seven years.

As concerns the type of the chain saws used, they were the most widely diffused brands on the market and had similar technical characteristics. All chain saws were powered by internal combustion, two-stroke, single-cylinder engines; fuel was a mixture of regular fuel and mineral oil at a ratio of 25 (sometimes as much as 40) to 1, and were air-cooled. Volume varied from 50 to 120 cc., with a speed from 7000 to 8500 rpm and a weight ranging from 5 to 14 kg. (subjects examined normally used chain saws of middle to heavy weight) and an overall length, including blade, between 30 and 150 cm. Many of these chain saws are equipped with silencers, anti-vibration handles (with rubber bonded metal shock absorbers) and safety systems (chain brake systems, shields, oil sumps, etc.). Our cases include 12 smokers, 8 former smokers and 5 who have never smoked.

As concerns referred symptoms: all subjects reported symptoms clearly similar to Raynaud's symptomatology, with the appearance of a pale crisis in one or more fingers, followed by the cyanosed phase, five woodcutters complained of one of the two phases of Raynaud's phenomenon and only three subjects had no clear vascular involvement, their symptomatology being entirely neurological and represented by prickles and paresthesia.

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In all cases we examined vascular functionality by Doppler C.W., photoplethysmography Laser Doppler flowmetry, in basal conditions and after a “cold-test”, venivasomotor reflex, capillaroscopy and cutaneous thermometry. X-rays of the osteo-articular districts most exposed to vibration trauma were performed on all subjects.

We conducted a study on neurological abnormalities in 19 subjects (age 38-64 years, Mean 53.2 years) by performing an electromyography with a coaxial electrode needle on the adductor muscle of the thumb, thus determining the speed of motor neurone conduction of the ulnar nerve; in eight cases we also performed the test for ischemia under electromyographic control for 10 minutes.

Results

In all cases routine examinations did not reveal pathological elements worthy of note, nor were alterations of the great vessels, as documented by the Doppler C.W., observed; in one case, photoplethysmography, showed an abolition of the pulsatory waves in some fingers in basal conditions.

Finally, in 20 subjects, still in basal conditions, it was possible to highlight alterations due to peripheral vascular hypertonia. Laser Doppler flowmetry performed on ten subjects showed rest values below our normal laboratory reference values and the venivasomotor reflex was clearly altered; likewise, perfusion units during cold testing in eight cases were quite close to biological zero.

Through photoplethysmography after “cold testing” we were able to diagnose our cases as hand-arm vibration syndrome in 16 subjects (52.38%), vascular hypertonia in 7 subjects (26.20%) and 2 functionally normal subjects (21.42%). Video-capillaroscopy showed a reduced number of capillaries with avascular areas, giant capillaries, interstitial oedema and reduced flow in most of the subjects.

Electromyographic examination revealed normal voluntary activity and nerve conduction. Neuromuscular hyperexcitability with the typical picture of tetanic spasm was noted in two out of eight subjects tested with provoked ischemia of the forearm for 10 minutes.

Conclusions

We underline the high incidence of vascular functional alterations documented by photoplethysmography, Laser Doppler flowmetry and capillaroscopy, despite nearly normal electromyography and other neuromuscular tests. Moreover, we can assume that a relatively new test like Laser Doppler flowmetry can be considered quite useful in determining the vascular functional balance of workers exposed to hand-arm vibration syndrome risk.

Table. Mean values and standard deviation of Laser Doppler flowmetry in ten cases.

AGE	JOB SENIORITY	Rest Flow 3rd finger	S. F. 3rd finger	VAR%	Cold Test 3rd finger
Yrs	Yrs	P.U.	P.U.	%	P.U.
44.7 6.2	14.9 6.3	60.3 16.2	31.1 18.3	48.1 19.7	10.8 8.5

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Possibilities and potential pitfalls of combined bedside and quantitative analysis of somatosensory functions with emphasis on examination of neurogenic pain patients.

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Neurogenic pain is part of the neurological disease spectrum and may be an expression of severe medical pathology. Apart from traumatic nerve damage a number of diseases may be accompanied by neurogenic pain, e.g., stroke, multiple sclerosis, syringomyelia/bulbia, herpes zoster, etc. Neurogenic pain has multiple disguises and may in addition be mimicked by non-neurological pain conditions.

Pain due to neuropathy is projected and, with few exceptions, confined to the innervation territory of the damaged peripheral nerve, root or central pathway (6, 7). Therefore, it is mandatory to meticulously survey the distribution of pain, preferably by including a pain drawing made by the patient. A thorough history regarding, e.g., start of pain, the temporal pattern of pain, aggravating factors, and earlier treatment outcomes is important. Pain descriptors are generally of low diagnostic value since there is considerable overlap between descriptors used in neurogenic and nociceptive pain states.

Since pain in neuropathy is due to lesion or dysfunction of the somatosensory system it is reasonable to look for signs of altered sensibility (6, 7). A careful bedside examination of somatosensory functions, using an array of instruments (e.g., a camel hair brush or cotton for the sensation of touch, a cold and warm metallic roller for temperature sensations, a pin for the sensation of pain) to explore the entire spectrum range of fibres/pathways is crucial (5) since sensory aberrations may be confined to single modalities. To avoid a chaotic exploration of somatosensory functions, a tentative diagnosis should guide the sensibility examination. Therefore, this procedure should optimally be performed as the final part of the diagnostic work up when collected information up to this point has been evaluated. The result of such a bedside examination is often valid for adequate diagnosis and clinical management. If necessary, quantitative sensory testing techniques may also be added to further characterise the somatosensory status (1, 2, 6, 9, 10). The use of detailed techniques for somatosensory examination, especially those monitoring the small fibre channels (10), is mandatory to complement the use of standard clinical neurophysiological methods which fall short in demonstrating small fibre system pathology as well as positive phenomena such as dynamic mechanical allodynia.

In patients with nerve damage, with or without spontaneous pain, typical findings include hypoesthesia/hypoalgesia in various combinations with uni- or polymodal hyperesthesia as well as hyperalgesia and allodynia (6, 9, 10). Temporal (e.g., aftersensation, abnormal latency) and spatial (e.g., faulty localization, extraterritorial spread) sensory aberrations are also frequently found. Hypoesthesia is most frequently characterised by an increased perception threshold and a rightward shift of the stimulus-response function. In a fraction of patients the perception threshold is unaltered and the

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hypoesthesia can be detected during bedside examination procedures only (6). Occasionally the reverse may occur with sensory alterations confined to the perception threshold. In such cases sensory quantification with threshold tracking techniques will be mandatory to detect nerve damage (6).

A source of potential pitfalls when interpreting signs of altered sensation in different painful conditions is the observations of sensory dysfunctions in experimental pain (e.g. 3, 8) and in subgroups of patients with nociceptive pain states (4). It is widely appreciated among clinicians that patients with clear cut nociceptive pain, especially musculoskeletal pain, not infrequently report focal and/or referred symptoms such as numbness and paresthesia, reminiscent of neurological involvement. It has previously not been systematically studied whether these patients, or even patients with nociceptive pain without such symptoms, have sensory alterations in the focal pain area or in the region of referred symptoms. The presence of such phenomena points to intermodality interaction in the central nervous system set up by activity in the nociceptive system, and may be a source of confusion. The diagnostic work up must be evaluated with this alternative in mind.

Sensory examination is a crucial part of the diagnostic work up in patients with chronic pain. The outcome of the diagnostic work up must be critically evaluated and a reasonable history as well as findings compatible with neuropathy should underlay the diagnosis of neurogenic pain. Further characterisation of sensibility in patients with pain of different pathophysiologies is warranted to improve diagnostic accuracy.

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Rationale for measuring vibrotactile perception at the fingertips as proposed for standardisation in ISO 13091-1

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Introduction

The draft of ISO 13091-1 defines two broadly equivalent, psychophysical methods for determining vibrotactile perception thresholds at the fingertip: *method A*, in which the stimulating probe is simply a flat-ended cylinder; and *method B*, in which the probe has a "surround", or rigid, planer annulus on which a fingertip rests and through which the probe contacts the skin surface (1). To this end the draft specifies acceptable environments for performing vibrotactile threshold measurements; the provision of support for the subject's arm and upper body; the stimulating probe geometry; the skin-stimulator contact conditions, in particular, the skin indentation or contact force and, for method B, the probe-surround gap and surround contact force; the waveform and frequency of the stimulus; the psychophysical algorithm; the preparation and instruction of subjects; and the conduct of the vibrotactile test. The requirements are driven by inter-related physiological and psychophysical mechanisms.

The purpose of this paper is to summarize the rationale for the measurement methods proposed, recognising that the future standard is required to yield reproducible and comparable results; provide thresholds mediated by a single mechanoreceptor population to facilitate interpretation, and; enable thresholds from different receptor populations to be obtained from one apparatus by changing the stimulation frequency.

I. Mechanoreceptor properties and vibrotactile thresholds

The tactile performance of the hand is well known to depend on neural activity in four populations of specialised nerve endings, which are commonly described by their response to mechanical indentation of the skin surface, namely: SAI - slowly adapting, type 1; SAII - slowly adapting, type 2; FAI - fast adapting, type 1, and; FAII - fast adapting, type 2 (2). In glabrous skin, the acuity of SAI receptors primarily determines the resolution of the spatial features of a surface, such as ridges or edges, while the acuity of FAI and FAII receptors is primarily responsible for distinguishing surface texture such as silk from sandpaper, and skin movement (3, 4). The SAII receptors primarily signal skin stretch.

This information has been established from neural action potentials recorded from single tactile units in response to externally applied skin displacements. When sinusoidal displacements of different magnitudes and frequencies are applied to single units of the four mechanoreceptor populations in the fingertips, the frequency ranges of maximum neural activity may be established (5). The measurements require precise control of the stimulus, the positioning of the subject, and skin-stimulator contact. Most importantly, a reliable method for the percutaneous recording of action potentials from *individual* human nerve fibres within the arm in response to the tactile stimulus at a fingertip is required.

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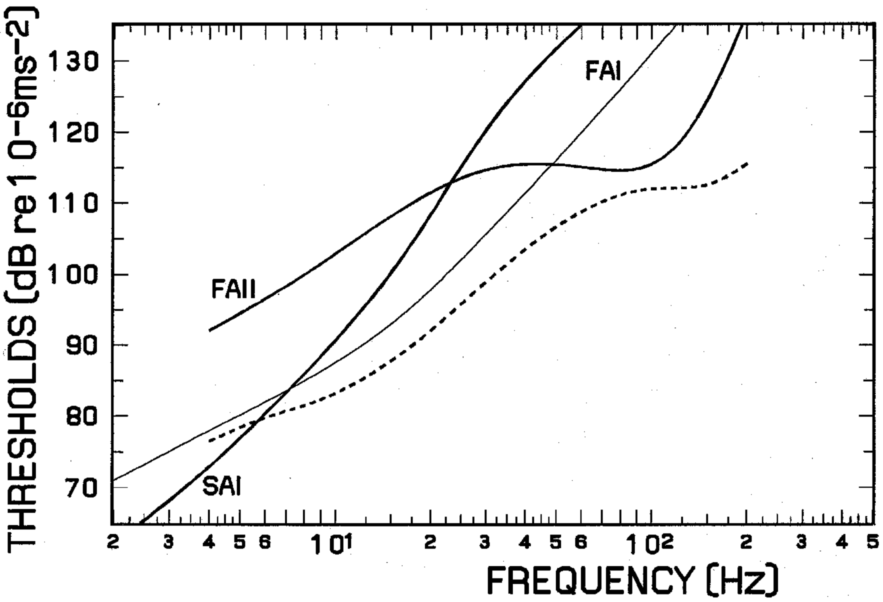

Figure 1. Frequency contours estimating the onset of sensation at the fingertip derived from neural action potentials of single SAI-, FAI-, or FAII-type mechanoreceptive units in response to sinusoidal skin indentation (solid curves). The contours have been adjusted for the change in density of receptive fields at the fingertip relative to the lowest value recorded in the hand. Psychophysical thresholds obtained with the same skin-stimulator contact conditions are shown by dashed line. For further explanation see text. Data from (2, 5, and 7).

It is possible from such detailed information to define contours expressing the same rate of neuronal discharges per stimulus cycle, which have been shown in animal studies to characterise the physiological response (6). If the information corresponding to the onset of neuronal activity is combined with knowledge of the innervation density of different mechanoreceptor populations, it is possible to estimate a value for the threshold of the perceived response to the stimulus at the fingertip. The results for one such estimate are shown by the solid lines in Figure 1. The neuronal thresholds are derived from contours of one action potential per two stimulus cycles constructed from the data of (5). The physiologically-based ”perception” thresholds have been adjusted for the numbers of receptive units per unit skin area at the fingertip relative to the lowest observed values in the hand for each mechanoreceptor population, using the innervation densities reported by Johansson and Vallbo (2). Contours of physiologically-based ”perception” thresholds are shown in Figure 1 as a function of frequency for the SAI, FAI, and FAII receptors by solid lines of different width. Note that each population appears to respond at lower stimulation than the others in different frequency ranges.

In a related study, psychophysical measurements of human vibrotactile perception were conducted on the hand using essentially the same skin-stimulator contact as the neuro-physiological studies, namely a 6.0 mm diameter probe with no surround, and a static skin indentation of 1.0 mm (7). The psychophysical vibrotactile perception thresholds obtained under these conditions at the fingertip with sinusoidal skin stimulation are shown by the dashed line in Figure 1, and can be seen to resemble the contours derived from the physiological data. Moreover, distinct, and different, sensations were reported by the subjects in response to stimulation at different frequencies. At frequencies below 4-8 Hz, the sensation was of the skin being ”pushed” up and down; at frequencies above this range but below 40-60 Hz, the sensation was of skin flutter or ”tingling”; and at higher frequencies the sensation was described as a diffuse ”buzzing”. Inspection of Figure 1, and other evidence, (2-6) suggests that the distinct sensations and pyschophysically-determined thresholds may be linked to activity in specific mechanoreceptor populations in well- defined frequency ranges: SAI, at about 6 Hz and below; FAI at between about 10 and 40 Hz; and FAII at frequencies above about 70 Hz. These observations lead to the association of psychophysically determined, vibrotactile perception thresholds with responses from *individual* mechanoreceptor populations *under suitably defined conditions of stimulation*, and forms the scientific basis for ISO 13091-1.

II. Skin stimulation

Skin-stimulator contact

Probe and surround. All direct evidence of mechanoreceptor responses to vibrotactile stimuli have been obtained without a surround. When the tip of a flat-ended, cylindrical, stimulating probe is intentionally positioned so that its edges intersect the boundary of the receptive field of a single tactile unit, the neuronal activity of FAI, and to some extent SAI, receptors is increased (8). This observation suggests that psychophysically determined, vibrotactile perception thresholds may be more sensitive when the edges introduced by a probe, or surround, are present. If, however, the diameter of the stimulating probe is chosen so that its edges have a high probability of intersecting the boundary of the receptive fields of individual tactile units, it may be argued that edge-driven activity will always be present in the responses of SAI and FAI units. In view of the finding that the receptive fields of individual units tend to be approximately circular and overlap extensively at the fingertips (2), this condition will be assured if the probe diameter is comparable to that of the receptive fields of the SAI and FAI units. From the reported areas of these receptive fields (9), the mean receptive field diameter is 3.6 mm. These considerations lead to the recommended probe diameter of 4.0 mm.

Skin indentation. In the absence of other controlling factors, the introduction of a surround may thus be expected to produce only small changes in SAI- and FAI-mediated vibrotactile perception thresholds with appropriate selection of probe diameter. A critical consideration, however, is the static skin indentation, which is known to influence psychophysical perception thresholds slightly at frequencies mediated by the SAI and FAI receptors, and significantly at frequencies mediated by the FAII receptors (10, 11). In consequence, it appears that the static skin indentation or, equivalently, contact force must be carefully controlled in order to yield reproducible and comparable psychophysically- determined, vibrotactile perception thresholds.

The selection of appropriate skin indentation is influenced by several considerations. Firstly, the neurophysiological and psychophysical data on which our understanding of the roles of the various mechanoreceptors in vibrotactile perception, and consequently our interpretation of thresholds, is based, was obtained for dynamic skin indentations of between 0.7 and 1.3 mm (7, 5). The corresponding *static* skin indentation, on which sinusoidal stimulation is to be superimposed in ISO 13091-1, was 1.0 mm (7). Secondly, the thickness of the flesh at the fingertip above the underlying bone is, typically, 5.0 mm in adult males (12), and can be expected to be no more than 3.0 mm in the smaller fingers of females. Thirdly, for skin indentations in excess of 1.5 mm, a substantial reduction in vibrotactile threshold (i.e., increase in acuity) is observed with increased skin indentation for thresholds mediated by FAII receptors in the absence of a surround, as is evident from Figure 2. A similar change in gradient of the function shown in Figure 2 is observed in comparable measurements conducted with a surround at a skin indentation of 2.5 mm (11). These considerations, together with the need to maintain contact with the skin, suggest that thresholds obtained by methods A and B will deviate less for smaller rather than larger skin indentations, with an optimum static skin indentation being no less than 1.0 mm, and no greater than 1.5 mm.

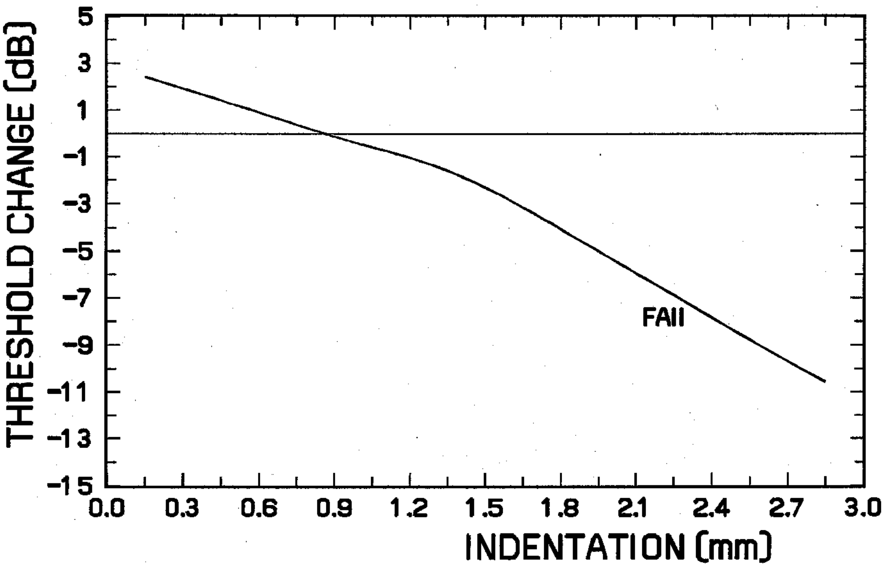

Figure 2. Influence of static skin indentation on vibrotactile threshold mediated by FAII receptor for 3.0 mm diameter stimulating probe and no surround. Data are for 100 Hz.

Psychophysically-determined, vibrotactile perception thresholds at the fingertips of healthy persons in which skin indentation has been carefully controlled are shown in Figure 3. The results are for subjects with mean ages: A_1 - unspecified (ages ranged from 17 to 36 years) (7); A_2 - 39.9 ± 5.0 years (13), and; B - 28.8 ± 6.8 years (14). In view of the large discrepancy at some frequencies between thresholds obtained with, and without, a surround when skin indentation is not controlled (14), the overall agreement between the results in Figure 3 is encouraging. The extent to which controlling skin indentation unifies thresholds obtained using method A or B in ISO 13091-1 can be seen from Figure 3 at frequencies from 20 and 40 Hz. At these frequencies, the close agreement between mean thresholds obtained with, and without, a surround, the close agreement between mean thresholds obtained with, and without, a surround, and with different probe diameters implies there is little effect of surround, or probe diameter (from 3.0 to 6.0 mm), on thresholds that are mediated by the FAI receptors. Thresholds at these frequencies are known to be little affected by the subject's age (15). The deviation between thresholds obtained by methods A and B at frequencies above 100 Hz, which are mediated by the FAII receptors, would appear to be primarily due to the different static skin indentations employed, as the two results obtained without a surround but with different probe diameters, methods A_1 and A_2, are in close agreement. Adjusting the results obtained by method A_2 to a mean age comparable to those of the other data would reduce the mean thresholds by about 3.0 dB at frequencies between 100 and 200 Hz (15). This adjustment is insufficient to eliminate the difference in thresholds obtained by methods A_2 and B, and introduces a difference of this magnitude between thresholds obtained by methods A_1 and A_2.

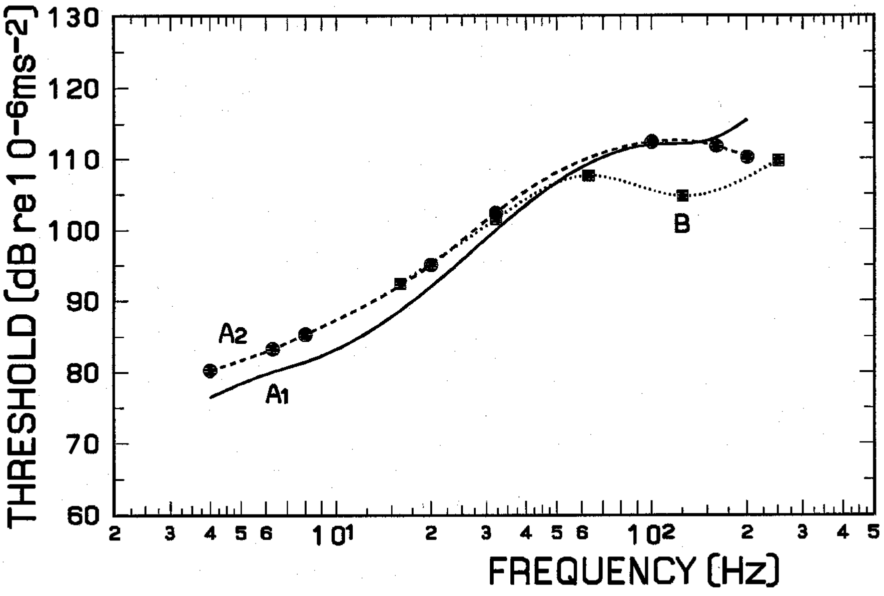

Figure 3. Comparison between mean thresholds obtained using: A_1 - 6.0 mm diameter probe, 1.0 mm static skin indentation, no surround, and continuous stimulation;(7) A_2 - 3.0 mm diameter probe, 0.7 mm static indentation, no surround, and intermittent stimulation (13), and; B - 6.0 mm diameter probe, 10.0 mm surround, and 2.8 mm static skin indentation (14).

Stimulus waveform

Intermittent stimuli. Psychophysical experiments are usually performed with intermittent stimuli, commonly in the form of tone bursts, to permit the use of two (or more) interval, forced-choice measurement strategies, in which the subject’s detection task is aided by the contrast between the feelings experienced with, and without, the stimulus. The duration of each stimulus and the quiescent interval between stimuli must be controlled to reduce errors in threshold determinations introduced by forward masking, or adaptation (i.e., temporary threshold shift). The former results in elevated (i.e., masked) thresholds if the quiescent period between stimuli is too short, or if the previous stimulus is too intense, that is, is substantially above threshold (16). Inspection of (16) reveals that vibrotactile thresholds are elevated if stimuli of the same frequency and duration are repeated within 400 ms. The threshold error is greater the more the first (masking) stimulus is above the true (i.e., unmasked) threshold. These considerations are the basis for the minimum quiescent interval (0.6 s) and the maximum rate of change of stimulus amplitude specified for intermittent stimuli in ISO 13091-1.

A maximum stimulus duration must be specified to avoid temporary threshold shifts during the measurements (17). In addition, a minimum stimulus duration must also be specified for the measurement of thresholds mediated by the FAII receptors (0.6 s), to avoid thresholds elevated by a lack of temporal summation (18).

Reference to Figure 3 reveals that the mean thresholds recorded by method A_2, which employed intermittent stimuli with single-cycle rise and fall times, are identical to those recorded using method A_1, which employed continuous stimuli. Thus, switching transients associated with the commencement and termination of the stimulus do not appear to dominate vibrotactile threshold determinations, presumably because the (acceleration) threshold acuity at high frequencies is less than that at lower frequencies (see Figure 3).

Continuous stimuli. Threshold determinations using continuous stimuli are equally susceptible to errors introduced by forward masking, or adaptation. For these reasons, the total time required for a threshold determination is restricted to avoid errors caused by temporary threshold shift (16), while the maximum rate of change of stimulus amplitude is set by forward masking, to 3 dB/s.

It should be noted that method A_1 in Figure 3 employed a rate of change of stimulus amplitude of 7.5 dB/s for determining the threshold of FAII receptors, which is expected to result in masked (i.e., elevated) thresholds being obtained. This inference could account for much of the difference in thresholds between methods A_1 and A_2 when the latter are adjusted for the age difference between subjects, and part of the difference in thresholds between methods A_1 and B.

Test frequencies. The test frequencies are chosen from within the ranges at which thresholds are mediated by single mechanoreceptor populations, to optimize the responses from three different populations, SAI, FAI, and FAII (e.g., see Figure 1). The frequencies for obtaining mechanoreceptor-specific vibrotactile perception thresholds are specified with a margin to allow for detailed variation in measurement methods to for: SAI - less than 6.3 Hz; FAI - in the range from 16 to 32 Hz, and; FAII - greater than 100 Hz.

III. Threshold Estimation

Test environment

Motion between the subject’s finger and the probe unrelated to the stimulus can mask the stimulus and so introduce errors in threshold determinations.

Background vibration. Building vibration is a common source of extraneous motion, as are the instrumentation and furniture used for threshold determinations (e.g., cooling fans, chair rocking). The potential for introducing errors in vibrotactile thresholds from these sources may be eliminated by specifying the allowable site vibration measured with the stimulating probe in contact with the fingertip. The background vibration is specified in terms of masking the minimum descending threshold of a healthy subject at the stimulation frequency.

Physiological ”noise”. Breathing, the pumping action of the heart, and normal (involuntary) muscle tremor all introduce motion between the fingertip and stimulating probe. These physiological sources of ”noise” can result in erroneous, that is, masked vibrotactile thresholds if not minimised by the provision of appropriate support for the forearm, hand and arm (19).

Other factors. Room temperature, the posture adopted by the subject, the background noise, and extraneous visual or audible stimuli, can influence the determination of vibrotactile thresholds if they introduce discomfort or otherwise distract the subject from the threshold detection task.

Subject preparation and performance

Prior activities. It is evident subjects should not engage in activities that may influence a subsequent threshold determination (e.g., exposure to hand-arm vibration or repetitive hand motion, consume stimulants, vigorous activity), and should rest seated (e.g., for at least five minutes) before commencing the test.

Preparation. Appropriate test sites need to be selected for stimulation, by inspecting the fingertips for callosities and other skin defects that could influence the results.

Instruction. The same description of the test procedure should be provided to each subject. The information needs to include: an overall explanation of the test; a description of the sensations likely to be felt, and; an explanation of the response task to be performed. The subject should be familiarised with the sensations and response task before commencing threshold determinations.

Skin temperature. Vibrotactile perception thresholds are influenced by skin temperature. A convenient way of eliminating the need to record this variable, which may change during a test, is to restrict the range of allowable skin temperatures to that in which the temperature-induced threshold variation is within the measurement error (e.g., 27 to 36°C).

Performance. It is important to recognise that the co-operation of the subject is required to obtain meaningful thresholds. Monitoring the inconsistency of a subject’s response to the stimulus provides a means for controlling errors introduced by the psychophysical algorithm, and provides an immediate test of the reliability of the results.

Threshold Calculation.

The vibrotactile threshold is calculated for a 50% probability of stimulus perception. As the sensation magnitude is related to the physical magnitude of the stimulus by a power law (20), the threshold is calculated from the arithmetic mean of ascending and descending threshold values when both are expressed in units of dB re 10^{-6} ms^{-2}. The initial ascending and descending thresholds are omitted from the calculation to permit larger amplitude changes to be initially employed, in order to establish more rapidly upper and lower bounds for the threshold.

Conclusions

The draft of ISO 13091-1 provides a consistent set of requirements based on the physiological and psychological mechanisms currently known to influence the determination of vibrotactile perception thresholds, and may be expected to yield reproducible and comparable results both when method A, and B, are used.

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A standardised test battery for assessing vascular and neurological components of the hand-arm vibration syndrome

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Introduction

Hand-transmitted vibration causes various vascular and neurological disorders. Vibration-induced white finger (VWF) is the most common vascular disorder and is a compensated industrial disease in the United Kingdom and some other countries. The condition is observed as episodic blanching of the fingers in response to cold. Neurological symptoms reported by workers exposed to hand-transmitted vibration include numbness and tingling.

Four of the tests currently recommended to assess vascular and neurological disorders amongst vibration-exposed workers are the measurement of finger systolic blood pressures following cold provocation and the measurement of finger skin temperatures following cold provocation (for detecting VWF), and the measurement of vibrotactile thresholds and the measurement of thermal thresholds (for detecting neurological disorders). Low finger systolic blood pressures following cooling compared to those measured at warmer temperatures, and lengthy rewarming times following cooling, are considered to be indicative of exaggerated vasoconstriction in response to cold, a sign of VWF (e.g. 2, 9). Decreased sensitivity to thermal and vibratory stimuli are considered to be consistent with vibration-induced neuropathies (e.g. 4).

The tests are currently performed using a variety of different methods. Results obtained using different methods may not be comparable and so the necessity for standardising test methods has been recognised. This study outlines four measurement methods proposed for standardisation.

Method

From a review of the literature, possible test methods were identified. The methods were selected so that they could be conducted during pre-employment screening or the routine examination of workers exposed to hand-transmitted vibration. They could also provide evidence of disorders in workers pursuing claims for compensation. Consideration was given to factors influencing intra-subject variability and inter-subject variability, and to the sensitivity and specificity of the methods to vascular or neurological disorders.

Results

General test conditions

The environment in which tests are conducted is known to influence the results. Too warm or to cool an environment results in increased false negative or false positive diagnosis of VWF, respectively (24). Factors influencing evaporation from the skin

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surface, such as clothing, air flow and humidity, are hypothesised as influencing peripheral blood flow. Finger skin temperature is known to influence vibrotactile thresholds, especially below about 22°C (10). Acoustic noise, including the occurrence of sudden noises, can influence vascular measurements (1) and might influence neurological thresholds through masking, fatigue or distraction. Vaso-active and neuro-active physical and chemical agents (e.g. vibration exposure, cold exposure, medication, and alcohol) can also influence the results.

It has been concluded that the four tests should be performed in a room at a mean temperature of 22°C (± 2°C) with air flow not noticeable and an ambient noise level of about 50 dB(A). Control over neuro-active and vaso-active physical and chemical agents prior to the measurements is recommended. Subjects should wear light indoor clothing; they should be habituated to the test environment for 15 minutes before measurements begin, or until finger skin temperature is stabilised at a temperature above 22°C, which ever is greater. It is recommended that neurological tests are performed before vascular tests.

Subjects should be seated or supine during the tests, with the wrist held straight. Neurological tests should be performed on one finger innervated with the median nerve and on one finger innervated with the ulnar nerve and on both hands. For vascular tests, the hands should be supported at about heart height, the subject should not be permitted excessive movement in order to ensure blood flow is maintained in the resting state.

When determining psychophysical thresholds, the use of written instructions and the presentation of a practice trial are recommended as they reduce inter-subject variability. These are not necessary for vascular tests, but adequate information should be given to avoid changes in central nervous system activity due to anticipation.

Thermal thresholds

A low cold threshold, high hot threshold or wide neutral zone can be considered indicative of dysfunctions to the thermal sensory system. Often, only the neutral zone is reported, although abnormality may be characterised by either hot or cold thresholds and not as well characterised by changes in the neutral zone. Changes in hot thresholds may occur before changes in the cold threshold (14). The method of limits is recommended as it allows determination of the hot and cold thresholds independently.

An applicator is set to a reference temperature and placed in contact with the finger. The temperature of the applicator is then increased or decreased until a heating or cooling sensation is felt by the subject, who then responds (a judgement), resulting in the return of the applicator to its reference temperature. This procedure is repeated a number of times to give a mean hot and a mean cold threshold. The neutral zone is calculated from the difference between the mean hot threshold and the mean cold threshold.

The number of judgements during a threshold test must be sufficient to converge on the true threshold. Between five and ten judgements have been found sufficient for good estimates of the threshold value (26, 28). It is recommended six judgements be made with the mean of the last four being used to calculate the threshold value.

The rate at which temperature is incremented and decremented during a threshold test has a significant effect on thermal thresholds. Rates of change of temperature between 0.1°C/s and 2.0°C/s have been shown to give consistent and repeatable thresholds (26). An incremental rate of 1°C/s is suggested.

The duration at the reference temperature judgements might affect thermal thresholds. A minimum duration of 3 seconds at the reference temperature between judgements is recommended. A reference temperature between 30°C and 34°C has been shown to result in the most repeatable threshold determinations (27). It is recommended that 32°C be used.

The contact force between skin and applicator must not be excessive so as to avoid masking and fatigue. Different forces result in different contact areas between an applicator and the skin. Contact forces of about 2 N have generally been used (e.g. 27, 28). A contact force of 2 N is suggested.

Vibrotactile thresholds

Vibrotactile thresholds reflect the function of the mechanoreceptors and the large myelinated fibres associated with these nerve endings. High vibrotactile thresholds are assumed to be indicative of damage to the peripheral nervous system (e.g. 4). Several different psychophysical algorithms have been implemented to determine vibrotactile thresholds (21). The up-and-down method of limits (the von Békésy tracking method) is recommended. The method requires less time for threshold determination than forced-choice algorithms and thresholds measured in this way can be sufficiently repeatable (20).

Using this method, the magnitude of vibration is incremented at a constant rate and when subjects judge that they perceive the vibration they respond. The stimulus magnitude is then decremented at a constant rate until the subjects judge they no longer perceive the vibration and remove their response. The direction of change of stimulus magnitude is again reversed. Several such reversals are recorded and the threshold is calculated from the mean of the mean peak (ascending judgements) and the mean trough (descending judgements). The first peak and first trough should be ignored when calculating the mean threshold.

An intermittent pure tone stimulus has sometimes been used to provide a quiescent interval (4). Such an interval serves to contrast physiological noise with the applied stimulus. However, the difficulty in specifying, producing and controlling a clean signal with pulsed stimuli leads to the recommendation that a continuous, pure tone stimulus should be used to determine vibrotactile thresholds. Waveform distortion must be minimised.

The duration of application of a vibratory stimulus can influence vibrotactile thresholds. Exposure to suprathreshold stimuli during a measurement may result in a temporary threshold shift, TTS (4). The measurement duration must be sufficient to allow the threshold to converge on its true value without causing fatigue or a TTS. Between 30 and 45 seconds is considered suitable.

The difference between ascending and descending judgements when using the up-and-down method of limits increases with increased rate of change of vibration magnitude. Thresholds obtained with step changes in stimulus intensity might be affected by the dynamic response to the change and are limited to the size of the step. A continuous rate of change of 3 dB/s is recommended.

There are assumed to be at least four main types of mechanoreceptor in the glabrous skin, two quickly adapting receptors (FAI and FAII) and two slowly adapting receptors (SAI and SAII). The quickly adapting receptors are sensitive to vibration: lower frequencies (e.g. 10 Hz - 65 Hz) are detected by the FAI receptors (Meissner’s corpuscles); higher frequencies (e.g. 45 Hz - 400 Hz) are detected by FAII receptors (Pacinian corpuscles) (e.g. 11). Some studies suggest that among persons exposed to hand-transmitted vibration, thresholds mediated by Pacinian corpuscles may be affected before thresholds mediated by Meissner’s corpuscles (4). For diagnosing vibration-induced neuropathies, therefore, mechanoreceptor specific thresholds should be obtained. There is overlap between the frequency ranges to which mechanoreceptor populations are sensitive. The overlap is influenced by contact conditions and subject conditions. Frequencies of 31.5 Hz and 125 Hz are the centre frequencies of octave bands in the frequency ranges for which mechanoreceptor specific thresholds for FAI and FAII can be obtained and are therefore recommended.

The conditions of contact between a vibratory stimulus and the skin surface has a significant effect on the perception of a vibration stimulus. Increasing the contactor size reduces vibrotactile thresholds mediated by Pacinian corpuscles. This reduction is further influenced by the presence of a surround, and the gap between the surround and the contactor (11). The presence of a static surround around a contactor increases the spatial gradient produced by the excitation and reduces FAI thresholds. The use of a surround is recommended so as to localise the threshold to a defined area on the skin and to aid the determination of Meissner’s corpuscle specific thresholds. The gap between a contactor and a surround affects thresholds: for low frequencies, thresholds increase with an increasing gap; for high frequencies, the thresholds decrease with increasing gap (11). A planar, circular contactor 6 mm in diameter, with a gap between contactor and surround of 2 mm, is considered suitable for measurements.

Finger push force on a surround, contactor push force on the skin and skin indentation have all been shown to alter vibrotactile thresholds (18). To minimise variability caused by these parameters, they should be controlled at the minimum pressure on the finger needed to maintain contact between skin and contactor during measurements. Contact conditions may be controlled by using a defined contactor force or by controlling skin indentation. Individual variations in the mechanical properties of the skin make it impossible to control both. A static contactor push force of 1 N, or a static skin indentation of 2 mm, with a finger push force on the surround of 2 N are recommended (18).

Rewarming times

Many different combinations of duration, temperature and hand conditions have been used for measuring the response of finger skin temperatures (FSTs) to cold provocation. It has been recommended that the temperature, duration and conditions of cold provocation should be chosen so as to achieve maximal vasoconstriction in subjects with VWF with minimal discomfort (5, 25).

Thermal imaging devices and point transducers (e.g. thermocouples) are both considered useful transducers for measuring FSTs (6). The relative expense and difficulty in calibrating thermal imaging devices, as well as the impracticality of using such devices during immersion of a hand in water, suggest point transducers are preferable for measurements, provided several precautions are taken: transducers should have a low heat capacity and be of small contact area to avoid influencing temperature changes at the measurement location; transducers should be placed so as to maintain good contact with the skin; transducers should not be in contact with surfaces other than the skin at the measurement location; transducers should be allowed to settle until the recorded temperature stabilises (25).

Cold provocation has been applied to different areas of the hand and arm. Most authors have cooled one hand with immersion up to the wrist, this can be sufficient to induce vasoconstriction in fingers affected with VWF. Both hands can be immersed if required. A hand is usually immersed in a temperature-regulated water bath;

environmental chambers and cold air have been suggested but are considered impractical.

Too cold a temperature during immersion can cause a cold-induced vasodilation (25) and pain (5). Too high a temperature will not be sufficient to cause vasoconstriction in those with VWF. A temperature between 10°C and 18°C has been observed to elicit minimum blood flow (8). Comparisons between different water temperatures have shown no significant advantage of using water temperatures below 10°C whilst these low temperatures can cause pain (5). Although a water temperature of 10°C appears to have the highest frequency of use, 15°C has been shown to be sensitive to VWF (9), this temperature also causes less pain and discomfort and is easier to achieve than 10°C. A water temperature of 15°C is recommended.

In general, rewarming curves show that FSTs tend to approach their minimum value after about 5 minutes of cooling. Applying ischaemia to the immersed hand(s) aides in the decrease of FSTs (25). However, this has not been shown to be beneficial in the diagnosis of VWF. Durations of cold provocation greater than 5 minutes do not appear to improve the diagnostic sensitivity or specificity of this test compared to longer durations. It is suggested that 5 minutes immersion, without ischaemia, is used to provoke cold-induced vasoconstriction while maintaining a reasonably short testing time and minimising subject discomfort.

Removal of the hand(s) from water allows cooling of the skin by evaporation if they are wet. The use of a covering during immersion, which is removed during recovery, prevents effects of evaporation, or of drying the hand, on FSTs. The covering should be thin-walled and/or of high thermal conductivity to minimise any insulation effects. The covering should be loose enough not to restrict skin blood flow. The covering should be removed immediately on removal of the hand from cold provocation.

Following cooling, the hand should be rested in a comfortable position at the level of the heart, any support for the arm or hand should be small and of low thermal conductivity (e.g. wood). The hand should be dry and compression of blood vessels should be avoided. The FSTs should be monitored until they have recovered to their starting temperature, or for 10 minutes, whichever is shorter: low FSTs 10 minutes after cold provocation may be considered indicative of exaggerated vascular response to cold.

The measurement location depends on the transducers being used. The site of interest might also depend on the reported symptoms. It is desirable to obtain measurements at as many sites on the hands as possible: the measurements may be finger specific (9). It is not necessary to measure both the dorsal and volar surfaces of the fingers since they tend to exhibit similar rewarming characteristics (6).

Finger systolic blood pressures

A technique for the measurement of systolic blood pressure in the fingers using a strain gauge, a pressure cuff and a cooling cuff has been proposed (22). A pressure cuff is used to hold the finger in an ischaemic state while water, controlled at specified temperatures, perfuses a cooling cuff placed distal to the pressure cuff. Following a period of cold provocation, pressure in the pressure cuff is slowly reduced until blood re-enters the finger. This return of blood flow is detected by a transducer placed distal to both cuffs, and the corresponding cuff pressure is defined as the systolic blood pressure. The pressure in a reference finger is obtained simultaneously without the application of cooling. Vasomotor tone is assessed by comparing the response of the digital arteries to a temperature causing vasoconstriction with the response at a temperature causing vasodilation, correcting for whole-body effects using the measurement made on the reference finger. The procedure has been adapted to incorporate local cooling of the digit into the pressure cuff itself, simplifying the measurement procedure (23). These methods have been widely adopted for the measurement of finger systolic blood pressure.

When measuring blood pressures, the return of blood flow to the distal phalanges of the test and reference fingers can be monitored using mercury-in-elastic strain gauges. Several other types of transducer have also been used for the detection of blood flow in the distal phalanges: photoelectric cells have been used to note changes in skin colour and Doppler methods have also been used to detect blood flow in the fingers. Experience suggests that Doppler methods appear more variable than the strain-gauge and photocell techniques. Some photocell techniques may detect blood flow in the skin but not in the digital arteries. The strain-gauge technique is recommended. When using a strain-gauge technique, prior to the application of pressure, the finger should be emptied of venous blood by light external compression so that a reasonable volume change occurs on return of blood flow.

The effect of cuff size on finger systolic blood pressure measurements has been investigated (13). Cuff widths of 24 mm placed on the medial phalanges of the index, middle and ring fingers give systolic blood pressures similar to those on the arms. On the little finger, a 24 mm cuff placed on the proximal phalanx, or a 20 mm cuff placed on the medial phalanx, gives finger systolic blood pressures similar to arm systolic blood pressures. These cuff dimensions are recommended. Cuffs should be thin-walled and/or of high thermal conductivity and should be soft enough so as to maintain contiguity with the finger surface during measurement.

Two or three temperatures of cold provocation are generally used, 30°C to induce vasodilation and 15°C and/or 10°C to induce vasoconstriction (2, 7). A procedure for the measurement of FSBPs at more than two or three temperatures is prohibitively lengthy for use in routine diagnosis and screening programs. The use of cold provocation at 15°C is recommended for eliciting vasoconstriction in most subjects. If no exaggerated vasoconstriction is observed at 15°C amongst subjects reporting VWF, further cooling to 10°C is required. The increased stimulus intensity and additive effects between provocations increase the vasoconstrictive response at 10°C (19). No recovery is required after cold provocation before a repeated measurement is made at the same temperature, or a measurement is made at a different temperature (19).

The internal temperature of the finger during cooling, measured by means of thermocouples inserted in the subcutaneous tissue, is within 1°C of the cuff temperature after 5 minutes of thermal provocation with ischaemia (22). Five minutes is recommended as a suitable duration for cold provocation.

The measurements of finger systolic blood pressure may be finger specific (i.e. sensitive to vascular dysfunction in the test digit) (16). It is desirable to assess the FSBPs in as many fingers as possible. The number of fingers undergoing cold provocation might increase sympathetic nervous system activity and hence vasomotor tone, this effect being exaggerated amongst subjects with VWF (17).

A vasoconstrictive response of a reference finger to cold provocation of an adjacent finger might be detrimental to the sensitivity of the method to the detection of VWF (17). Various locations for reference measurements are reported in the literature Since the thumb is least commonly affected by VWF, it is recommended for the reference measurements.

Conclusions

A test battery (thermal thresholds, vibrotactile thresholds, rewarming times and finger systolic blood pressures following cold provocation) is defined for detecting components of the hand-arm vibration syndrome (HAVS).

The tests are performed in a room at 22°C with subjects habituated for 15 minutes, or until finger skin temperature is above 22°C. Subjects are seated or supine for tests. Neurological tests are performed on both hands using the index or middle finger and the little finger. Neurological tests are performed before vascular tests.

Thermal thresholds are measured by applying a stimulus to the distal phalanx with a force of 2 N, a reference temperature of 32°C and a rate of change of temperature of 1°C/s. The stimulus is held at the reference temperature for 3 seconds between each of 6 judgements. The first two hot and cold judgements are ignored. The hot threshold, cold threshold and neutral zone are reported in degrees Celsius (°C).

Vibrotactile thresholds are obtained by applying sinusoidal vibration at 31.5 Hz and 125 Hz to the distal phalanx using a circular contactor, 2 to 6 mm diameter, concentric to an annular surround, allowing a gap of 2 mm between contactor and surround. A force of 2 N is applied to the surround while the contactor applies a force of 1 N (or indents the skin by 2 mm). The rate of change of vibration magnitude is 3 dB/s and measurement duration 30 to 45 seconds. Vibrotactile thresholds are reported in ms^{-2} r.m.s.

Rewarming times are measured on the hand most affected by blanching (or on both hands simultaneously). Skin temperature should stabilise for 2 minutes, before immersion to the wrists in water at 15 °C for 5 minutes with the hands inside a thin waterproof covering. On removal from the water, the covering is removed and the hand supported at heart level for 10 minutes of recovery. Skin temperatures are reported in degrees Celsius (°C), from the beginning of stabilisation to the end of recovery.

Finger systolic blood pressures are measured on all fingers (or on fingers most affected by blanching) with a simultaneous reference measurement. Pressure cuffs (24 mm wide) are placed around the index, middle, ring and little fingers (test fingers) and around the thumb (reference finger). Supra-systolic pressure is applied to all cuffs and water (at 30°C, 15°C, or 10°C) perfuses test finger cuffs for 5 minutes before all cuffs are deflated at 3 mmHg/s. Transducers placed distal to the cuffs detect the return of blood flow. Finger systolic blood pressures are reported in millimetres of mercury (mmHg), percentage finger systolic blood pressures at low temperatures relative to those at 30°C, corrected for changes in the thumb, are calculated.

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Effects of push forces on vibrotactile thresholds measurement

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Introduction

Peripheral neuropathies in the upper extremities may occur by occupational exposure to hand-transmitted vibration. These occupational diseases cause a variety of disorders of the fingers, hands and arms.

Neurological disturbances and vascular disorders (called Raynaud’s phenomenon or vibration-induced white finger) are important symptoms of the vibration syndrome(1). Fingertip vibrotactile thresholds have been used to quantify the neuropathy produced by hand-transmitted vibration (2)-(6). Vibrotactile thresholds have also been used to estimate the acute physiological effects of hand-transmitted vibration exposure on the sensory system, and to investigate a permissible limit for occupational exposure to vibration. Many studies have related the temporary threshold shifts (TTS) in vibratory sensation to the severity of vibration exposure (7)-(18). Vibration sense thresholds at the fingertip are sometimes used to evaluate the neuropathy. The vibrotactile thresholds on the finger are known to be dependent on the measuring equipment, the procedure and the method or algorithm. Researchers have used many different types of vibrotactile measurement equipment all around the world(19).

The Working Group 8 (Vibrotactile Perception) of ISO/TC108/SC4 has worked to optimize testing procedures and interpretation of vibrotactile perception thresholds since 1991. Although the Committee Draft International Standard ISO/CD 13091-1(20) has been proposed by ISO/TC108/SC4/WG8 for measuring equipment, measuring algorithms, and conditions. International agreement has not yet been achieved when considering the measuring conditions of contact for vibrotactile thresholds, unlike audiometers standards. Therefore, a few researchers have considered the measuring equipment and measuring algorithm by using the commercially available vibrometers (19), (21)-(24). From these results, they found that all vibrotactile threshold determinations should take into account the frequency of vibration, the area of contact with vibration, the conditions surrounding the contact area, the contact force, the push force, the finger temperature. Also, they found that the method of determining vibrotactile thresholds which controlled push force, contact force, and surround gave the greater repeatability. One researcher has onsidered the relationship between contact conditions at the stimulus interface, the effects on relationship between contact conditions at the stimulus interface and the effects on vibrotactile thresholds for the Meissner’s and Pacinian corpuscles (25). He found that a surround force between 2 N and 3N is suitable for the detection of neuropathies using vibrotactile thresholds. Also, a probe contact force of 0.5 N to 1 N, or a skin indentation relative to the point of contact of the probe and the skin of 1.5 mm to 3 mm, gives suitable contact conditions for obtaining mechanoreceptor thresholds which are independent of small change in contact conditions. But, it is not clear whether the results of the contact conditions can be applied to the Japanese people.

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The purpose of this study was to investigate the effects on vibrotactile thresholds for Pacinian corpuscles under different contact conditions using Japanese subjects.

Methods

Equipment

The equipment conditions of the ISO/CD 13091-1 are shown in Table 1. As shown in Table 1, the ISO/CD 13091-1 equipment is used for measuring vibrotactile thresholds at three kinds of mechanoreceptor, SA I, FA I, and FAII. These frequencies are 4, 25, and 125 Hz. Also, the following conditions are defined by the ISO/CD 13091-1; contact area is 4.0±2.0 mm diameter, contact force is 0.1±0.05 N, surround of type A is probe-skin contact force controlled directly, surround of type B is 1.5±0.5 mm probe-surround gap, surround-fingertip force of type B is 0.5 - 1 N, the contact force of type B is 0.35±0.18 N, and the measuring algorithm is the up-down method. The ISO/CD 13091-1 equipment can measure the acceleration of the thresholds. There is no commercially available vibrometer according to the standard of ISO/CD 13091-1 around the world. Also, the conditions of the skin-stimulator contact are not clearly established, whether the results of the contact conditions can be applied to the Japanese people. In this study, the tactile thresholds were measured by the equipment as shown in Figure 1.

Table 1. Summary of requirements for measurement method.

Contents	ISO/CD 13091-1	
Mechanoreceptor	SAI, FAI, FAII	
Frequency (Hz)	4.0, 25, 125 Hz	
Subject support	full length of forearm, hand and finger; seat with back rest	
Skin temperature	27 - 36 °C	
Test room temperature	20 - 30 °C	
Probe tip geometry	flat ended cylinder	
Probe tip diameter	4.0 ± 2.0 mm	
Skin-stimulator contact	No Surround - type A	Surround - type B
skin indentation	1.0 ± 0.5 mm	1.0 ± 0.5 mm
contact force	0.1 ± 0.05 N	0.35 ± 0.18 N
probe-surround gap	-	1.5 ± 0.5 mm
surround force	-	0.5 - 1.0 N
Measurement algorithm	up-down/von Bekesy	
Vibration measurement	r.m.s.magnitude and frequency of stimuli	

The system provides computer controlled measurement of tactile thresholds for vibration stimuli. It consists of a vibrometer unit force meter as shown in Figure 1. The vibrometer unit housed a vibrator, which is mounted on a counter-balance providing a constant upward contact force between the probe and the subject’s finger. A sliding counter-weight allows this force to be adjusted, if required. An accelerometer was mounted on the vibrator, with the contact probe attached to its upper surface. The probe, which had a flat circular end of 6 mm diameter, protruded through a circular hole of 10 mm diameter in a plastic plate. This plate was fitted with strain gauges to monitor and control the push force from the finger. The vibrometer unit also houses the electronics for conditioning the accelerometer and strain gauge output signals and the power amplifier for driving the vibrator. A pre-determined set of selected vibration frequencies (in the range 16 to 500Hz) is automatically presented. The acceleration magnitude corresponding to the vibrotactile threshold at each frequency is computed at the end of each test using procedures defined in BS 6655(26) and ISO 6189(27). The vibrotactile threshold is then taken as the mean of the averages separately. The vibrotactile threshold is then taken as the mean of the average peak and the average trough. Standard deviations are also computed, from the square root of the mean variance of the peaks and troughs. In this experiment, the vibration magnitude is controlled by a computer (HP85F) which generates the vibration signals to the Function Synthesizer (NF 1915). The synthesizer sends the signals from a computer to the vibrator and to the Oscillo scope. This system used the unit of ms^{-2} rms. These acceleration signals were pre-determined set as 2.5dB level rate.

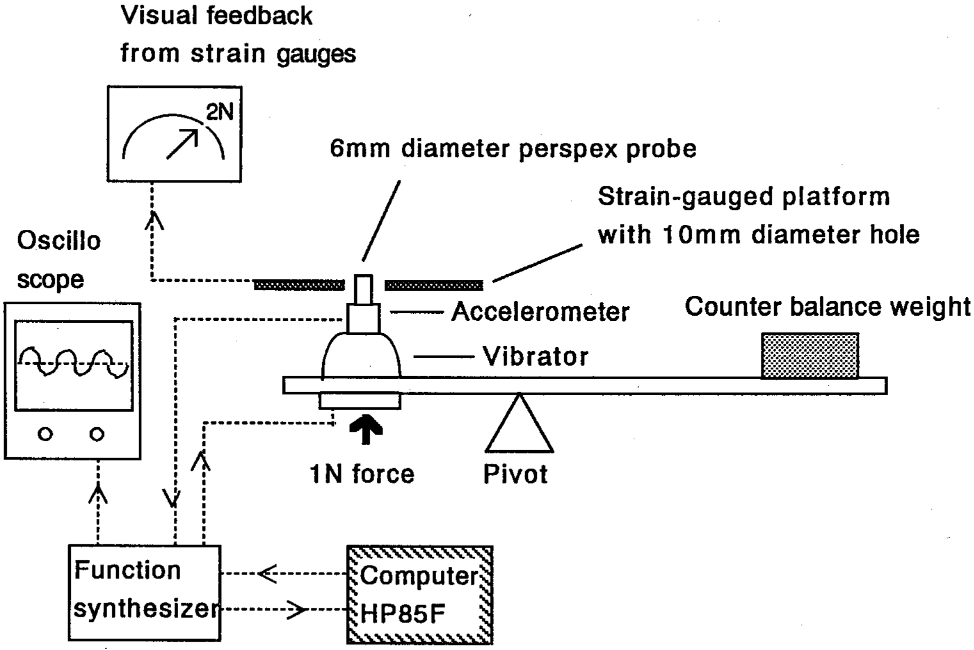

Figure 1. Vibrotactile measurement equipment of type B.

Subjects

Eight male subjects participated in the study. They were healthy, 22 year old students of the Kinki University, having no history of neuromuscular or vascular disorders. No subjects had occupational experience operating hand tools, nor had they suffered any serious injuries of the upper extremities before.

Procedure

The experiment was performed on three different days and measured once a day on each subject. Before the experiment all subjects read each instruction sheet provided in the Appendix. The conditions of the surround type B adopted in this experiment are almost the same as Table 1 except the contact force and surround force. The probe contact force of the contact conditions was 1N. Seven different surround forces on a stationary surround to the vibrating probe (0.25N, 0.5N, 1N, 1.5N, 2N, 2.5N, and 3N) were used in the experiment.

First, the right-hand finger temperature was measured, because the skin temperature is known to affect thresholds. This experiment was performed only when the finger temperature was above 23°C. If the finger temperature was below 23°C, the subject had to rest in a room until the finger temperature was at or above 23°C. Each subject was seated with their right forearm laid on an armrest and put the middle finger of the right hand on the vibration tip. The mean and standard deviation (SD) of the finger skin temperature was 30.4°C (SD 0.6°C). Vibrotactile thresholds were measured for each push force at 125 Hz. The subject watched a meter carefully to maintain his push force to the appointed level.

The UD method(28) were used in the experiment. The up-down method called the UD method, is one of the psychophysical algorithms which are used for threshold determinations. The UD method is a simple generalisation of the most orthodox algorithm for estimating the 50 percent threshold. The level of the test stimulus is varied in steps of a constant size, 2.5dB was adopted in this experiment. When a "feel" response is obtained, the following stimulus is presented at the next lower level, and when a "not feel" response is obtained, the following stimulus is presented at the next higher level. The experiment continued through 6 turn arounds. The threshold value is determined by the mean value from the peaks and the troughs (R1 to R6) in the following Equation (1). The step size, stimulus starting point, and turn around numbers have not been standardised for vibrotactile thresholds.

$$\text{Thresholds} = (R1 + R2 + R3 + R4 + R5 + R6) / 6 \qquad (1)$$

After all measurements of the vibrotactile thresholds under different surround forces, the subject had to answer a questionnaire for which surround push force was comfortable to measure the vibrotactile thresholds during the measurement.

Results and discussion

Figure 2 shows the mean vibrotactile threshold results and the standard deviations obtained from eight subjects as a function of surround force. The results of 2N of the surround force corresponded with the results of Maeda’s results (23). Table 2 shows the summarised analysis of variance. The analysis of variance was adopted to examine the influence of the surround forces, the subjects and the measurement days on vibrotactile thresholds.

It seems that increasing the surround force on a surround had the effect of decreasing the sensitivity of the Pacinian corpuscles from Figure 2. There was no significant difference between results obtained on different surround forces and different days. The main effect of subjects was statistically significant ($p < 0.01$). From the questionnaire to subjects, the most comfortable surround force during the experiment was 1N.

Lindsell concluded that a probe contact force between 0.5N and 1N, or a skin indentation relative to the point of contact of the probe and the skin between 1.5mm and 3mm, with a surround force between 2N and 3N, resulted in mechanoreceptor specific thresholds, independently of small changes in contact conditions. He also recommended that these parameters would be suitable for standardisation (25).

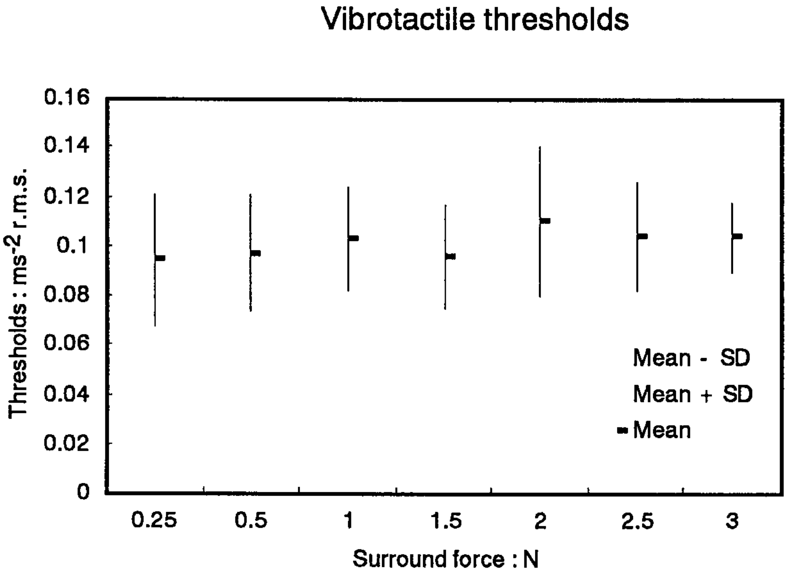

Figure 2. Relation between surround forces and vibrotactile thresholds.

Table 2. Analysis of variance summary table of the measured vibrotactile thresholds with different surround forces and different days and subjects.

Factors	Sum squares	Deg. of freedom	Mean square	F.ratio
A (subjects)	0.0414	7	0.00591	13.21**
B (surround forces)	0.00453	6	0.000755	1.69
C (days)	0.00195	2	0.000975	2.18
A*B	0.0280	42	0.000667	1.49
A*C	0.00811	14	0.000579	1.29
B*C	0.00685	12	0.000571	1.27
Errors	0.0376	84	0.000448	
Total	0.12844	167		

** $p < 0.01$

On the other hand, considering the results of the current experiment, it was clear that the vibrating probe force 1N and the surround force on a stationary surround to the vibrating probe 1N were good conditions to measure the vibrotactile thresholds for the Japanese people test and for standardisation.

Conclusion

From the measurement of the vibrotactile thresholds for Pacinian corpuscles under different contact conditions using Japanese subjects, the following things are concluded:

1. There was no significant difference between results obtained on different surround forces and different days. The main effect of the subject was statistically significant ($p < 0.01$). From the subject questionnaire, the most comfortable surround force during the experiment was 1N.

2. It was clear that the vibrating probe contact force 1N and the surround force on a stationary surround to the vibrating probe 1N were good conditions to measure the vibrotactile thresholds for the Japanese people test and for standardisation.

Appendix -Instructions for subjects

The aim of this experiment is to measure the vibrotactile thresholds using different surround forces. Please take part in the measuring vibrotactile thresholds using the following procedure.

<Vibrotactile Perception Test>

This is the equipment for the measurement of your vibration sensitivity. Before the measurement the finger temperature of your right hand will be measured. If your finger temperature is higher than 23°C the experiment will start. If not, you have to rest to warm up your hand in a room.

Measuring procedure

1. Please sit down in your most comfortable pose, and put your right arm on the arm-rest.
2. Support your middle finger to contact on the small plastic tip.
3. You must touch carefully looking at the feedback meter for the different specified surround force, because the contact force between finger and probe must be fixed.
4. When the meter becomes stable the measurement will start. At the beginning the vibration is a very small amplitude, gradually it gets higher. You can confirm the vibration by looking at the oscilloscope.
5. With each vibration, we will ask you whether you can feel it or not. You have to answer clearly "feel" or "not feel".
6. We will change the vibration amplitude according to your response.

Please maintain the push force during the measuring period.

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Equivalent skin-stimulator contact forces for vibrotactile measurements with, and without, a surround

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Introduction

An international standard currently under development in ISO/TC108/SC4 specifies two basic methods for measuring vibrotactile perception thresholds at the fingertip: *method A*, in which the stimulating probe is simply a flat-ended cylinder, and; *method B*, in which the probe has a "surround", or rigid, planer surface on which a fingertip rests, containing a hole through which the probe contacts the skin surface (1).

The purpose of this study was to measure the dependence of skin indentation on the static force applied by a stimulating probe both with, and without, a surround for the preferred measurement parameters specified in reference 1: namely, a 4 mm diameter stimulating probe with, if present, a 7 mm diameter surround.

A complete description of this study will be published elsewhere.

Apparatus and procedure

Method A. A version of the apparatus described in references 2 and 3 was used. The subject was seated comfortably with a back rest. The chair supported the subject without rocking or twisting. Support was provided by an armrest for the full length of the forearm, hand, and the finger to be tested. The forearm was horizontal, the palm upwards, and the fingers were in relaxed, natural positions curving upwards (close to the neutral position), as can be seen from Figure 1. A 4 mm diameter cylindrical probe, suspended from one arm of a beam balance, the fulcrum of which was mounted on a vertical track, was then lowered onto a fingertip. The position of the fulcrum was adjusted by means of a vernier screw. The plastic probe tip was positioned approximately midway between the centre of the whorl and the fingernail, with its axis of symmetry perpendicular to the plane which is tangential to the skin surface at the point of contact. The static force exerted by the probe on the flesh of the fingertip was increased gradually in a sequence of steps, and the skin indentation required to re-establish balance of the beam was determined for each step by measuring the lowering of the fulcrum. Contact between the skin surface and the probe tip was first established by a static force of 0.005 N, which was the initial force for all measurements.

Throughout a sequence of measurements, taking about 15 minutes, the subject was required not to move. For the probe diameter and range of forces used (0.005 - 0.06 N) there was little change in indentation after each step increase in contact force had stabilized (typically less than 0.06 mm). The contact force was measured with an accuracy of ±0.001 N, and skin indentation with an accuracy of ±0.02 mm. The skin temperature at the fingertip and the precise stimulation site marked for future reference.

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Figure 1. Experimental arrangement for method A.

The subjects were healthy male laboratory workers with no visible skin defects at the sites chosen for measurements, nor history of collagen disease. Measurements were repeated on each subject over a period of several days to establish the repeatability of the procedure.

For skin indentations in excess of 2 mm, the test-retest repeatability of the indentation resulting from application of a given contact force was typically within ±10%. For skin indentations of less than 1 mm, the test-retest repeatability decreased, and reached ±50% for a contact force of 0.025 N.

Method B. An annular disk, with an outer diameter of approximately 58 mm and a hole 7 mm in diameter centred on its axis of symmetry, was first machined to weigh 100 g. The procedure described above for the method A measurement (without surround) was repeated with one additional step: immediately before the probe was lowered onto the skin of the subject, the 100 g disk was balanced on the fingertip. The disk was positioned by eye so that it rested horizontally with the 7 mm diameter hole centred on the desired measurement site. The probe was then lowered onto the fingertip through the centre of the 7 mm hole in the disk (see Figure 2). In this way skin indentation could be measured for the probe diameter (4.0 mm), gap between the probe and surround (1.5 ± 0.5 mm), and surround-fingertip contact force (1 N) specified as preferred skin-stimulator contact values in reference 1.

The measurement was intrinsically more difficult to perform than that without the surround. Although at first sight balancing the disk on the fingertip would appear difficult, the task was readily mastered by all experimenters. Positioning the probe centrally within the hole in the surround was done by eye, and required precise positioning of the stimulator. For this reason the stimulator base was machined flat, and slid easily on the smooth, horizontal surface of the supporting table. The test-retest repeatability of the skin indentation resulting from application of a given contact force was similar to that obtained without a surround.

Figure 2. Experimental arrangement for method B showing details of the surround and probe.

Results

The static indentation of the skin at the fingertip is shown in Figure 3 for three male subjects (aged from 43 to 72 years), for values of static force ranging from 0.025 to 0.6 N, together with a curve showing the mean indentation for these subjects. The results with, and without, a surround were obtained from the same subjects and fingertips (digit 3). Each symbol represents the mean value of repeated measurements conducted on a subject for a given contact force. The curves are smoothed, locally-weighted least squares fits to the mean values obtained from each subject.

The results were obtained at a room temperature of 22 ±1°C, and for skin temperatures from 30 to 34°C.

Discussion

The results of this study indicate that the presence of a surround effectively stiffens the flesh at the fingertip, thereby resisting static indentation by the stimulating probe for all values of the applied force. For the specific case of a 4 mm diameter probe applied to produce a skin indentation of 1 mm, as proposed in reference 1, an applied force of 0.10 N is required for method A (without surround), whereas a force of 0.35 N is required for method B (with surround) when the surround-fingertip contact force is 1 N.

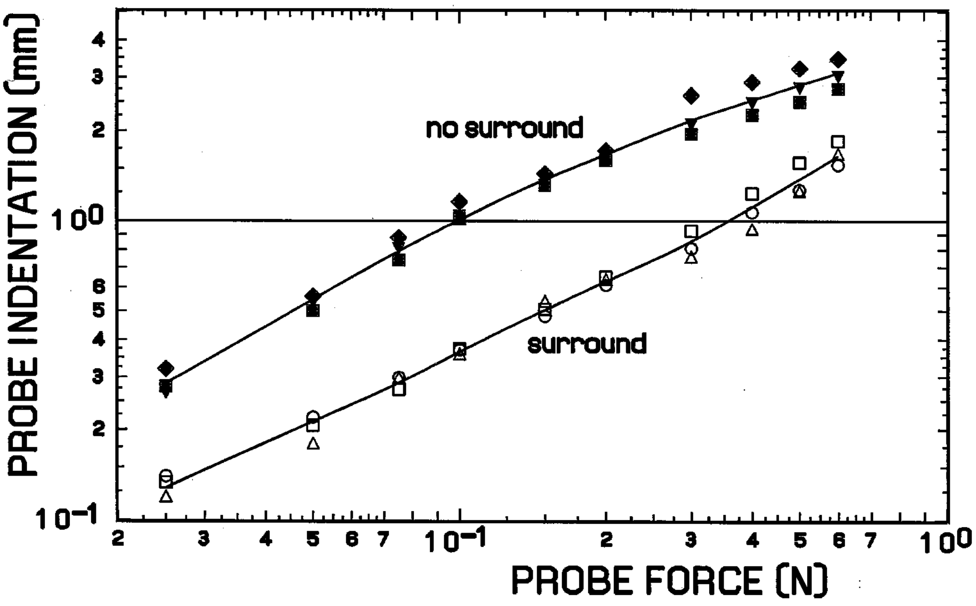

Figure 3. Indentation of the skin at the fingertip for values of the static force with which a 4 mm diameter stimulating probe is applied to the skin. When a surround is present, the gap between the probe and surround is 1.5 mm, and the surround-fingertip contact force is 1 N.

A skin indentation significantly less than 1 mm would restrict the performance of an instrument for measuring the vibrotactile thresholds of subjects with reduced sensitivity such as occurs in some peripheral neuropathies. A skin indentation substantially greater than 1 mm would lead to vibrotactile stimulation conditions for which there is no supporting neurophysiological evidence to establish the types of nerve endings that mediate the vibrotactile thresholds (4). Also, the tissue thickness above the bone at the fingertip is typically only from 4 to 6 mm in adult males (5), and will be less in females.

Conclusions

The measurements shown in Figure 3 provide an empirical basis for specifying skin-stimulator contact forces for measuring vibrotactile perception thresholds at the fingertips with, and without, a surround.

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Vibration-induced neuropathy of the hand

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Introduction

The hand-arm vibration syndrome includes several symptoms, the most significant being white fingers, neuropathy, and muscle weakness. Although the white finger disease has been a well known symptom for a very long time, neuropathy of the hand has gained increasing interest over the recent years (20, 21, 22, 29). One expression for this is the new classification system suggested in Stockholm 1987, with separate scales for vasospastic and sensory problems of the hand (3, 11). In this review vibration-induced neuropathy of the hand is addressed with respect to occurrence, importance, pathophysiology, diagnosis, and treatment.

The problem

Neuropathy of the hand is a very common problem among workers using hand-held vibrating tools. In a recent analysis of one hundred vibration-exposed workers (29), about 80% were found to suffer from such neuropathy, either as an isolated syndrome (48%) or together with vasospastic problems (32%). Neuropathy of the hand often occurs at an early stage - before white fingers - and may sometimes appear with cold intolerance, i.e. discomfort at exposure to a cold environment, without true blanching of the fingers. Of the one hundred vibration exposed workers, 27% had abnormal cold intolerance (29). Numbness and impaired sensibility of the hand result in clumsiness as well as impaired dexterity and coordination, and these patients often have increasingly severe problems carrying out work with high demands on hand function. In our experience, neuropathy of the hand is therefore often the true reason for vibration-exposed patients to change or quit their work. The wellknown decreased grip strength of the hand (9, 10, 25), in our material occurring in about 20%, may be, at least in part, based on an impaired sensory feedback: an abnormal sensory feedback leads to difficulties in initiating and regulating grip strength in the hand.

The human hand is a sense organ and can be regarded as an extension of the brain to the environment (19). Hand sensibility is crucial for the capacity to perform fine manipulative tasks and fine precision movements, since such grip functions are the result of integrated sensory and motor functions. Hand sensibility has one protective component and one *descriptive, stereognostic* function. Protective sensibility involves thin fibres responding to temperature and pain stimuli, for example, and thin fibre dysfunction may therefore compromise normal protective mechanisms of the hand. It has been demonstrated in experimental studies that thin fibres are damaged early in vibration-induced neuropathy (21). In vibration-exposed patients this is often expressed in difficulty differentiating between hot and cold, for instance, when taking a shower. Thin autonomic nerve fibres in the sympathetic nervous system are of importance for the regulation of vascular tonus, and abnormal vasoconstriction may therefore be linked hypothetically to such thin fibre pathology.

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Vibration may, however, also interfere with receptor function and conduction in large myelinated fibres and may thus interfere with stereognostic functions of the hand (detection and recognition of shapes and textures) as well proprioception (ability to feel e.g. finger joint positions). Stereognostic as well as proprioceptive functions are extremely important for hand function in numerous everyday activities like gripping and lifting items and tools without the use of eye sight (19). For instance, lifting a milk package without the aid of vision requires a hand grip around the package of exactly the right force, strong enough to lift the package but without crushing it. As soon as the package tends to slip out of the grip the modified sensory input automatically increases the grip strength to exactly the right level. Along with “motoric programs”, based on memory and experience, the grip around the package is set to the correct level from the beginning, but if the package is heavier or lighter than was expected, hand sensibility immediately modifies the grip strength and sets it at the correct level. It is obvious that any interference with these fine sensory functions is immediately reflected in considerable impairment of hand function at work, at leisure and at home.

Pathophysiology and levels for injury

Sensory perception is based on cellular structures within the nervous system at several peripheral levels, from the skin receptors to the dorsal root ganglia, as well as pathways and centres in the spinal cord and brain. Theoretically, sensory disturbances may be based on dysfunction at any one of these levels. Since high frequency vibration is not distributed over long lengths in extremities, there are reasons to belive that nerve dysfunction, associated with use of hand-held high frequency tools, is primarily based on injury to very distal structures. On the other hand, low frequency vibration may well be transferred to more proximal structures in the nervous system.

Mechanoreceptors and terminal nerve fibres

The sensibility in the glabrous skin of the human hand is based on free nerve endings for detection of temperature and nociceptive stimuli, as well as on several types of mechanoreceptors responding to skin deformation (33). Fast adapting mechanoreceptors, including Meissner’s end organs (localised in association with epidermial papillae) and Pacini’s end organs (situated in deep layers of the dermis) respond to rapid intermittent deformation and vibrotactile stimuli. Slowly adapting mechanoreceptors, including Merkel’s end organs (in association with epidermal papillae) and Ruffini’s end organs (situated in the dermis) respond to constant touch. In addition, Ruffini’s end organs respond to stretching of the skin and are therefore of major importance to proprioception (8). All these mechanoreceptors are crucial to hand function. Being situated close to the vibration source, mechanoreceptors may easily be damaged by vibration trauma. Also, free nerve endings, detecting pain and differences in temperature levels, may easily be damaged which may perhaps contribute to explaining the very frequently occurring cold intolerance in vibration-exposed patients.

It has been demonstrated that dental technicians, working with high frequency vibrating tools, show a high incidence of sensory disturbances resulting in impaired dexterity and hand precision, and specific neurophysiological techniques have made it possible to localise the nerve injury to terminal nerve fibres and mechanoreceptors in these patients (14). At clinical investigations these patients generally show increased vibration thresholds, indicating injury to fast adapting mechanoreceptors and/or terminal nerve fibres in the fingers.

Nerve trunks in hands and arms

In experimental animal systems the effect of vibration on nerve fibres has been extensively studied. Intraneural changes, occurring as a result of vibration, include microvascular oedema (20), deterioration of neurofilaments, primarily in thin nerve fibres (21), subcellular changes in Schwann cells and myelin (15), and increased synthesis of growth factors such as IGF-1 in the vibrated nerve trunk (13). Thus, vibration induces a “conditioning lesion effect” - expressed in a temporarily improved regeneration potential (7), which is probably based on effects both on the non-neuronal cells (Schwann cells) and on the neuron itself (1). An early cellular response, such as proliferation of the non-neuronal cells, which is most pronounced close to the vibrating source, has been detected using immunocytochemistry (or incorporation of 5bromooxyuridine into mitotic cells) on vibration-exposed rats (Dahlin personal observations). This may be preceded by an increased expression of the immediate early gene, *c jun*, indicating an early injury. Signs of axonal injury have also been observed both by electronmicroscopy (20) and by immunocytochemistry (upregulation of NGF-receptor; Dahlin personal observations).

Observations in experimental animals correlate well with recent findings in human biopsy material from the dorsal interosseus nerve just proximal to the wrist level in vibration exposed workers (28). The characteristic findings were a breakdown of myelin in various stages of development, axonal degeneration and interstitial and perineurial fibrosis. Furthermore, the demyelination process seemed to cover an extended period of time. The findings suggested that demyelination may be the primary lesion in vibration-induced neuropathy, followed by loss of axons due to impaired regeneration. Fibrosis may be a reaction to an incomplete regeneration and oedema. Neurophysiologically, demyelination and loss of axons appear as reduction of conduction velocity and nerve response amplitudes respectively (16). Such changes are seen in carpal tunnel syndrome. It is theoretically possible that a vibration-induced nerve injury to the median nerve in the carpal tunnel and a carpal tunnel syndrome may produce similar neurophysiological findings.

Clinically, the digital nerves are heavily exposed to vibration when the hand grips around a vibrating tool, and vibration-induced neuropathy of the hand may often be due to structural and functional alterations in these nerves. The result is constant numbness and impaired sensibility of the digits with unfavourable consequences to dexterity and hand function. It is a common misunderstanding that vibration-induced neuropathy is always based on carpal tunnel syndrome. However, in our material (31) only 22 out of 80 vibration-exposed patients had clinical carpal tunnel syndrome expressed as nocturnal paraesthesiae of the hand and either a positive Tinel sign or Phalen’s test,.

The carpal tunnel

Work with vibrating hand-held tools as well as hard manual work represent an increased risk for aquiring carpal tunnel syndrome (17, 35) and if carpal tunnel syndrome occurs in a male, the patient very often has a history of vibration exposure. The tight carpal tunnel compartment may add a compression insult to nerve fibres already damaged by vibration, so that compression and vibration together may contribute to numbness and sensory disturbances within the median nerve innervated territories of the hand. The compression component may be based upon a flexor tenosynovitis resulting from repetitive wrist movements during hard manual work, and it may not be easy to specifically isolate the vibration factor from the compressive factor in these cases. Decompression of the median nerve in these patients usually results in some improvement (2, 12), but some degree of neurological problems may sometimes remain on the basis of established vibration-induced nerve fibre changes at the level of the carpal tunnel (28). It is also important to remember that symptoms mimicking carpal tunnel syndrome, i.e. nocturnal paraesthesiae in the hand, may sometimes be based on nocturnal swelling of fingers. Increased tissue pressure in the small compartments between the fibrous septa of the finger pulps may interfere with the function of mechanoreceptors as well as terminal median nerve fibres, the result being nocturnal numbness and paraesthesiae which may mimic a true carpal tunnel syndrome. In such cases, of course, nerve decompression at the level of the carpal tunnel would have no beneficial effect at all.

The role of vasa nervorum

Nerve trunks have a well developed microvascular system comprising vascular plexa in all layers (18). Impulse conduction and axonal transport are dependent on the energy supply provided by these vessels and any interference with intraneural microcirculation may also lead to nerve dysfunction. However, the tonus of these *vasa nervorum* is regulated by tiny sympathetic nerve fibres in their vascular walls (18) and it is known that a high sympathetic drive will induce constriction of these vessels (27). Thus, there is a complicated interaction between nervous and vascular systems in the hand. Nerves are dependent on the blood flow in their intraneural microvessels, which in turn are dependent on tiny nerve plexa in the walls. Constriction of intraneural microvessels might perhaps result in “white nerves” which, in turn, may affect the blood flow in the digital arteries since their tonus is regulated by fibres in the digital nerves. Nerve function and vascular function are therefore intimately connected, and the true pathophysiology of vibration-induced neuropathy and white fingers respectively, may therefore be difficult to sort out. We may deal with one disease with a complex pathophysiology, or with two separate problems.

Dorsal root ganglia and the spinal cord

In experimental animal studies proximal sciatic nerve segments of the left sciatic nerve have been sutured to distal segments of right sciatic nerve (29). In one series of experiments the left limb was vibrated before the surgical procedure. In such cases there was a temporary negative shift in regeneration potential of the system, indicating that the proximal nerve segment and its sensory nerve cell bodies in dorsal root ganglia had been influenced by the vibration, and that changes in cellular metabolism in the nerve cells had occurred. Similar findings have been observed in other models following vibration exposure (1). These findings indicate that vibration of a limb in an experimental animal may influence the metabolic turnover at a level close to the spinal cord, e.g. in the dorsal root ganglia. There is also a theoretical reason to believe that the cells in the spinal cord can be affected by the vibration exposure.

The brain

It is well known that changes in sensory input from the hand in primates may induce pronounced functional reorganisation in the sensory cerebral cortex. Normally the fingers are projected as bands in the somatotopic center of the brain, the borderlines between these bands being very sharp and well defined. However, when the functional demands of one finger are increased (i.e. when a patient learns to read in Braille with the index finger) (24) this finger expands its territory at the expense of other projectional areas. It has recently been demonstrated in monkeys that intermittent, rapid motions, such as repetitive opening and closing of the hand, can lead to measurable somatosensory changes with degradation of the sensory representation of the hand and digits as well as motor control problems (4, 5). The corresponding areas in the motor cortex, regulating motor activities of the hand, are to a great extent dependent on the modulating and regulatory input provided by the sensory cortex, and it has been proposed that the functional somatosensory changes may contribute to explaining the dystonia, cramps, and motor dysfunctions sometimes seen in patients using their hands in monotonous, iterated activities. Whether also *vibration*, representing an ultimate form of rapid, iterated, and monotonous tissue displacement, may have effects on somatosensory functional organisation, with secondary influence on sensory perception as well as precision motor performance of the hand, is not known but remains an attractive hypothesis.

Diagnosis/classification

Diagnosis of vibration-induced hand problems is to a large extent based on subjective symptoms, although results from neurophysiological assessment, tactilometry, and physiological investigation of vascular functions in the hand can sometimes contribute to the diagnosis. Besides, the classification of vibration-induced neuropathy, according to the Stockholm Workshop Scale (3) is based primarily on subjective symptoms. There is a need for refined methods offering objective numerical data for early diagnosis of vibration-induced neuropathy as well as for development of improved classification systems. A scoring system for the extent of impairment of *handfunction* would be an important contribution in this context.

Tactilometry

It is well known that perception thresholds for vibration are increased even at an early stage of vibration-induced neuropathy (20, 22), especially of higher frequencies. Tactilometry has proved a useful diagnostic tool for early detection of vibration-induced neuropathy - not alone, but together with a relevant history and physical findings in addition to clinical tests (22). Increased perception thresholds to vibration are seen at a much earlier stage than are pathological findings in the two-point discrimination test (30). Using Sensibility Index as a measure (22) (the ratio between the integrated surfaces under the test curve and the age-matched reference curve in the tactilogram) pathological values were seen in at least one finger in 73% of symptomatic patients in Strömberg's material (30). Characteristic of vibration-induced neuropathy are increased vibration perception thresholds in the index and little fingers of both the right and left hand as opposed to idiopathic carpal tunnel syndrome or ulnar nerve neuropathy which usually show pathology only in the index and little fingers respectively (22). Regardless of symptoms - sensorineural, vascular or both - the patients have impaired vibrotactile sense as a common denominator (30). The vibrotactile perception thresholds increase as the sensorineural symptoms become worse. No such relation is seen between vibrotactile sense and the severity of the vascular symptoms (30). Tactilometry can therefore be used to monitor the progression of sensorineural symptoms but not of vascular ones which appear to persue a different line of development. The presence of cold intolerance is an indication of neural injury as evidenced by severe impairment of the vibrotactile sense (30). We have found tactilometry very useful for scanning large vibration-exposed patient materials on a group basis, and also in longitudinal follow-ups of individuals in risk occupations.

Neurophysiology

Results from nerve conduction studies across the carpal tunnel in vibration-exposed patients suffering from carpal tunnel syndrome usually show a tendency toward less pathological values than in patients suffering from idiopathic carpal tunnel syndrome (26). Studying 73 patients, Strömberg found impaired median nerve conduction in the palm and across the wrist, but not in the forearm (31). The ulnar nerve was not affected. Patients with sensorineural symptoms have neurographic changes indicating median nerve involvement in the carpal tunnel to an extent not seen in patients with vascular or combined symptoms (31). There is no relation between neurographic findings and the severity of sensorineural symptoms which may be due to a more severe distal injury (31). Results from fractionated neurography show the importance of very careful neurophysiological assessment in vibration-exposed patients since there are two injuries which in their early stages can be confused: one at receptor level in the fingertip and one at the level of the carpal tunnel. Among patients with sensorineural symptoms, the presence or absence of clinical carpal tunnel syndrome is not reflected in the neurographic findings, indicating the degreee of diagnostic complexity (31). Therefore, in vibration-exposed patients suffering from carpal tunnel syndrome, it is especially important to perform a careful neurophysiological investigation before a carpal tunnel release is carried out: if the lesion is localised distal to the carpal tunnel, a median nerve decompression at the level of the carpal tunnel will not be effective.

Clinical tests

In clinical routine the most widely used test for sensibility is the “static” two-point discrimination (2PD) test (23). This is a test for stereognosis, requiring not only functioning mechanoreceptors of sufficient density, but also that the brain has the capacity to interprete the “spatial” message from the hand. As long as nerve fibres are correctly oriented this test usually remains normal (e.g. vibration-induced neuropathy, carpal tunnel syndrome). On the contrary, regenerated, mis-directed axons (e.g. following nerve transection and repair) usually produce a permanently impaired two-point discrimination capacity. In vibration-induced neuropathy this test remains normal unless the nerve injury is very severe. The Semmes-Weinstein monofilament test, measuring perception of constant touch, is a much more reliable clinical test which shows pathology even at an early stage in vibration-induced neuropathy.

In a hand therapist’s normal arsenal there is a large number of tests for hand dexterity and precision, some of them showing pathology very early in the vibration-induced neuropathy. In a recent study by Cederlund (6) the Semmes-Weinstein monofilament test for perception of touch/pressure, a shape identification test using small objects (2-5 mm), and the “moving” 2PD test for tactile gnosis showed the highest number of pathological outcome followed by Purdue pegboard test for dexterity and Moberg’s pickup test for functional sensibility. Studies are in progress to define a battery of sensitive clinical tests which could be useful for early diagnosis as well as for development of a classification system in vibration-induced neuropathy of the hand.

Treatment

Vibration-induced neuropathy is a progressive disorder which increases in severity with continuous, ongoing vibration exposure. In early stages, when there is oedema and slight myelin changes in the nerve, the symptoms may probably be reversible if vibration exposure is modified or interrupted. At later stages however, permanent changes in terms of axonal degeneration and fibrosis may occur in the nerve (28). In such cases the symptoms are probably irreversible with no possibilites to treat the sensory disturbances.

In experimental animal studies vibration exposure may induce an “alarm reaction” in the peripheral nerves of the vibrated extremity, resulting in a temporary shift in the regenerative potential. However, this effect may be blocked or minimised by local application of Ca^{2+} blockers (34). These observations indicate that early functional changes induced in vibration-exposed nerve trunks may be reduced or reversed by Ca^{2+} blockers, an observation which may have future clinical potential.

Clinically documented useful principles for treatment of vibration-induced neuropathy are so far missing. Since the nerve lesion is progressive with continuous exposure, only prophylactic measures can help to reduce the occurence of vibration-induced neuropathy. Such measures include the use of adequate working tools, reduction of time periods of vibration exposure, and development of techniques for detection and diagnosis of vibrationinduced neuropathy even at a very early stage.

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Comparison of absolute thresholds for vibration at the fingertip and on the hand in two different postures

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Introduction

Vibration sensation in the glabrous skin of the hand has been investigated for different purposes: to identify mechanisms responsible for the perception of vibration, or for the detection of disorders caused by hand-transmitted vibration. Neurophysiological studies indicate that tactile stimuli may be detected by four types of mechanoreceptors identified as FA I (Meissner corpuscles), FA II (Pacinian corpuscles), SA I (Merkel discs), and SA II (Ruffini endings) (1). Psychophysical studies have determined vibrotactile perception thresholds at the fingertips and at the thenar eminence, and found that various factors affect perception. Verrillo and co-workers (e.g., (2-4)) demonstrated that vibrotactile perception depends on vibration frequency, duration, contact area, contact pressure, surround to the contact area, prior vibratory stimulation, skin temperature and age.

Vibration perception may be produced in various glabrous areas, including the fingers and the palm of the hand. There are many practical situations where vibration enters the hand through contact with the surfaces of vibrating power tools, possibly causing injury, or other objects held in the hand (e.g., car steering-wheels, electric-razors), causing discomfort or providing feedback on the environment.

A few studies have investigated the perception of vibration in glabrous skin using vibration transmitted to the whole hand, but no studies have been found comparing thresholds at the fingertip with those of the whole-hand. Vibrotactile perception thresholds were determined at 15 different points on the glabrous part of the human hand within the frequency range 25 to 1000 Hz, and compared the differences in perception thresholds between regions of the glabrous skin of the human hand (5). For vibration at both the fingertip and the whole hand, the available studies have been shown a range of threshold curves as a function of frequency, partly because different experimental conditions and different experimental methods have been used. The differences in published thresholds may also be due to different sensory mechanisms being involved as a result of the particular variables chosen for the whole-hand, such as the contact regions, postures, and force of the hand.

The purpose of this study was to compare absolute vibration perception thresholds (VPT) for hand-transmitted vibration in two different hand postures (grasping a handle, and with the palm pressing on a flat plate) with absolute thresholds for the perception of vibration at the fingertip. Vibration perception threshold contours were determined within the frequency range 8 to 500 Hz and were compared with results obtained in some previous studies.

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Methods

Subjects

Twelve healthy male volunteers, aged 22-33 years (mean 24.6 years), participated in the study. All subjects were non-smokers, right handed and not occupationally exposed to hand-transmitted vibration. Subjects were asked not to consume coffee, tea or alcohol for at least two hours prior to the tests. The hand and finger volumes were calculated by measuring dimensions of the right hand and the middle finger using a pair of vernier callipers. Finger skin temperature was measured before and after the threshold measurements; tests proceeded if the skin temperature was higher than 29° Celsius.

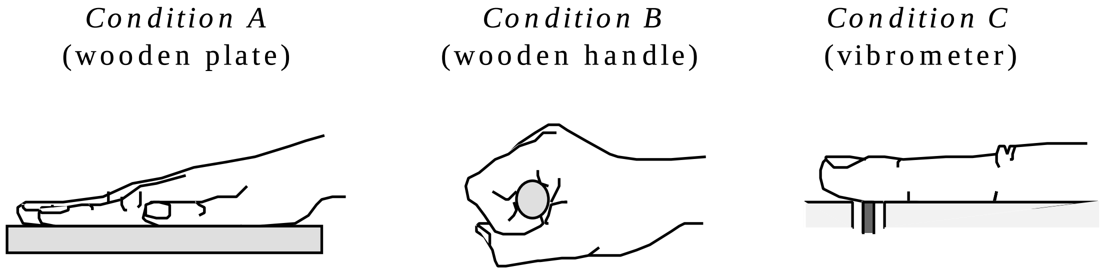
Experimental conditions

Three sessions were conducted using three devices to present the vibrotactile stimuli:

Condition A - a flat horizontal wooden plate (200 mm by 150 mm);
Condition B - a cylindrical wooden handle (30 mm diameter);
Condition C - *HVLab* tactile vibrometer (6 mm diameter contact area, 2 mm gap between contactor and fixed surround)

The hand posture was controlled in each condition as shown in Figure 1. In *Conditions A and B*, subjects used the whole of the right hand to contact the wooden surface (plate or handle) and maintain a push force of 10 N (no grip force); visual feedback of the force was shown on an analogue meter. The arm was supported by an armrest so as to be at the same height as the hand. For *Condition C*, the distal phalanx of the middle finger was placed over the vibrometer probe with a 2 N push force on the surround and an upward force of 1 N applied by the probe. The arm was supported by the vibrometer unit.

Each condition involved tests with seven frequencies of vertical sinusoidal vibration at the preferred octave centre frequencies from 8 Hz to 500 Hz. The order of presentation of the three sessions and the seven frequencies was randomised.



Condition A (wooden plate)

Condition B (wooden handle)

Condition C (vibrometer)

Figure 1. Hand and finger positions for the three conditions.

Procedure

Vibrotactile perception thresholds were determined with the up-and-down transformed response method (UDTR method) (6). Using a two-interval two alternative forced-choice (2IFC) tracking procedure, subjects were exposed to a series of trials. A trial consists of a 3 second period of the 'test' stimulus (at one of the seven frequencies) and a 3 second period of 'null' stimulus, separated by a 1 second "pause"; the order of the 'test' and 'null' stimuli was randomised. A light indicated when either stimulus was being generated. The task of a subject was to judge whether the first or the second stimulus was perceptible. The intensity of a 'test' motion commenced from a level the subject could not feel; a 'test' motion was increased by 2 dB following one incorrect response and decreased by 2 dB following three consecutive correct responses. A run was terminated after six reversals, giving 20 to 40 trials at each frequency, lasting approximately 4 to 7 minutes. An absolute threshold was calculated from the average of three peaks and three troughs, given by:

$$\text{Absolute threshold} = \frac{\left(\sum_{i=1}^{i=3} p_i + \sum_{j=1}^{j=3} t_j\right)}{n}$$

where p_i is the vibration magnitude of peak i, and t_j is the vibration magnitude of trough j, n is the number of reversal (= 6).

Subjects practised before each test, so that they were familiar with the test stimuli. This also provided an estimate of the subject's individual threshold prior to measuring the vibrotactile perception threshold.

Results

Figure 2 shows the median absolute threshold contours for three conditions, both as measured in root-mean-square acceleration and then as converted to peak displacement. It can be seen that the vibration perception thresholds varied with frequency in each condition.

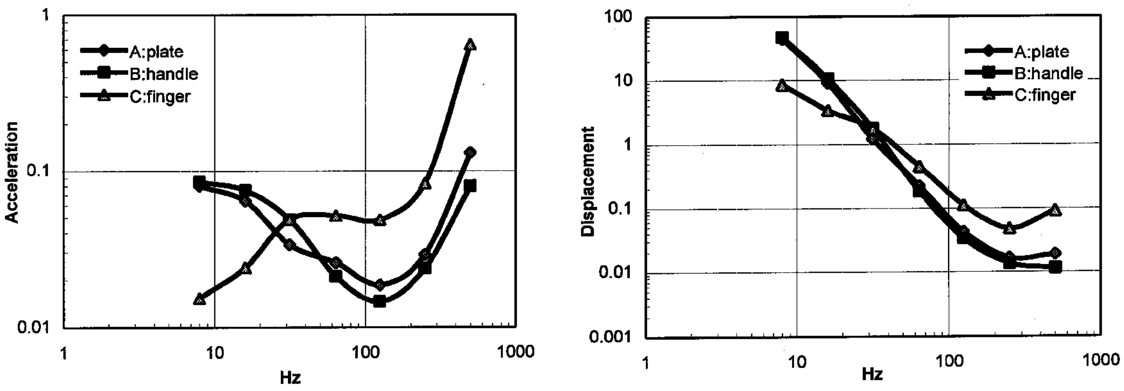


Figure 2. Median absolute vibration perception thresholds expressed in acceleration and displacement for 12 subjects in 3 conditions.

When using the handle and the wooden plate (*Conditions A and B*), a similar U-shaped threshold curve was obtained with greatest sensitivity (lowest acceleration) in the range 100 to 150 Hz. In these two hand postures, there were no significant differences between the thresholds at any frequency (Wilcoxon matched-pairs signed ranks test, $p>0.05$). Comparing the absolute thresholds for the hand (*Conditions A and B*) and the finger (*Condition C*), the absolute thresholds were significantly different (Friedman, $p<0.005$), except at 31.5 and 63 Hz (Friedman, $p>0.05$). At frequencies greater than 63 Hz, the threshold for the fingertip was consistently lower than that of the hands by approximately 10 dB (i.e. a ratio of about 3).

The vibration perception thresholds expressed in displacement show a steep decrease with increasing frequency. The most sensitive frequency in terms of displacement occurred in the range 125 to 500 Hz, although even lower thresholds are likely above 500 Hz.

As expected, there were some inverse correlation between vibration perception thresholds and finger skin temperatures measured before and after testing (Spearman, $p<0.05$). No significant association was found between vibration perception thresholds and the age, body size, or the finger and hand volumes of the subjects.

Discussion

The results indicate large differences in vibration perception thresholds between the hand (*Conditions A and B*) and the fingertip (*Condition C*). Similar threshold curves were obtained with the two different hand postures (*Conditions A and B: the wooden plate and the wooden handle*).

Some of the reasons for the sensory difference in vibration perception between the hand and the finger can be explained from evidence describing the psychophysical mechanisms of tactile sensation. There were probably two mechanoreceptor systems involved in the detection of the vibrotactile stimuli in the experiment. The ‘Pacinian system (FA II)’ was probably mainly responsible for the detection of stimuli at 63 Hz and higher frequencies, while a ‘non-Pacinian system (mainly the FA I)’ was mainly responsible for detection at frequencies of 31.5 Hz and lower frequencies. (7,8).

At frequencies above 31.5 Hz, lower thresholds were obtained with the hand in contact with the wooden handle and the wooden plate than with the fingertip in contact with the probe. This is possibly a result of spatial summation among FA II units, as proposed by Verrillo (7), adding to perception with the larger contact area of the hand. The contact areas were similar for the plate and for the handle, and the thresholds were similar. The probe was much smaller than these two surfaces and so the reduction in size may have been responsible for the 10 dB increase in the thresholds at frequencies above 63 Hz.

At low frequencies, lower thresholds were obtained with the fingertip on the probe than with the wooden plate and the wooden handle. This may have been caused by the surround around the probe increasing the sensitivity of the FA I units. Threshold sensitivity is increased by stimulus gradients when detection occurs via the non-Pacinian system (9-10).

The vibration perception thresholds were also compared with the results reported in other studies where similar contact sources had been used: a table, a handle, and a vibrometer, respectively. The comparisons are shown individually in Figure 3.

Table

Miwa (11) determined vibration perception thresholds and equal sensation contours over the range 3 to 300 Hz for hands pressing on a large flat plate; these data influenced the development of the frequency weighting now used to evaluate the hazards of hand-transmitted vibration. As shown in Figure 3 fairly similar vibration perception thresholds were obtained to the results of *Condition A,* with the lowest acceleration thresholds in the range 100 to 150 Hz. The U-shaped curve was more sharp than that for *Condition A,* possibly due to differences in the experimental conditions with a higher pushing force (50 N).

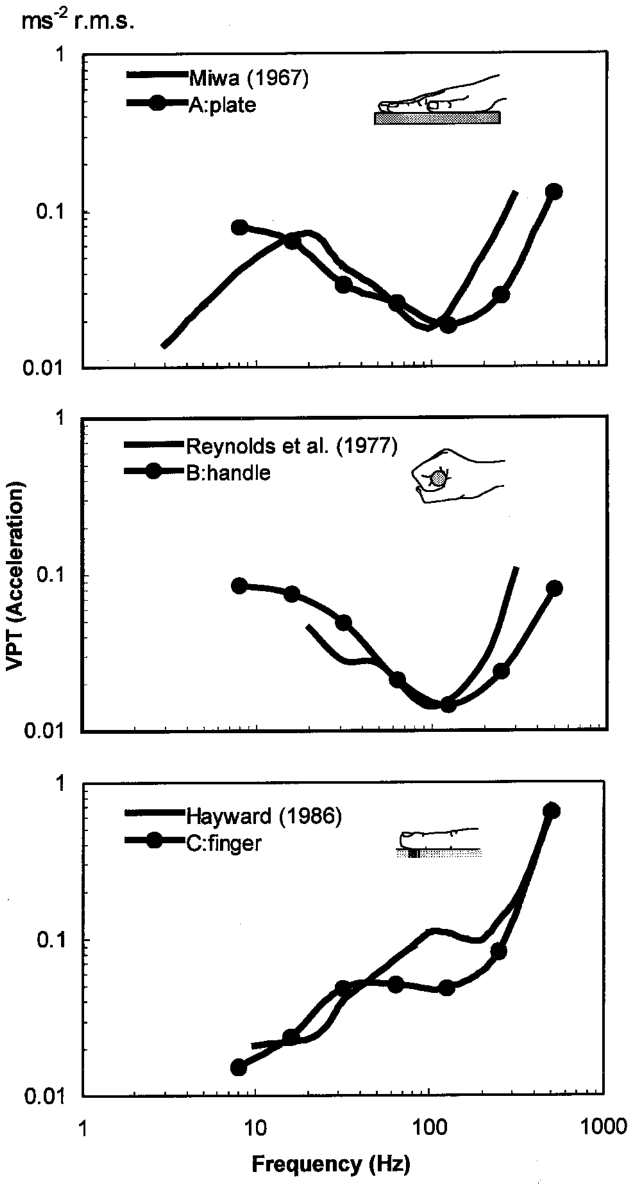


Figure 3. Comparisons of absolute perception thresholds obtained from other studies and in the experiment.

Handle

Reynolds *et al.* (12) determined absolute thresholds and equal sensation contours for different grip forces (8.9 N and 35.6 N) and three axes of vibration for both a palm grip and a finger grip. The results of absolute thresholds shown in Figure 3 are for conditions with a palm grip force of 8.9 N, using a handle 1.9 cm diameter. Similar vibration perception thresholds contours are observed when compared with the gripping posture in the present experiment.

Finger

Hayward (13) determined vibration perception thresholds on the index finger of the dominant hand over the frequency range from 16 to 500 Hz. The equipment geometry was very similar to that employed in *Condition C* of the present experiment, but the method utilised the ‘up-and-down method of limits’. The vibration perception thresholds from the two experiments are broadly similar in shape and similar in magnitude at low and high frequencies. The greatest difference in sensitivity is observed between about 60 and 300 Hz.

Conclusions

Vibration perception thresholds with different hand postures and different contact areas of the glabrous hand have been compared. As expected, the frequency dependence of the thresholds were consistent with mediation by both Pacinian and non-Pacinian mechanoreceptors. The vibration perception thresholds curves obtained with a flat wooden plate, a wooden handle, and a vibrometer had individual shapes similar to those found in other studies.

There were no significant differences in vibration perception thresholds with two hand postures (flat wooden plate and wooden handle), whereas there were appreciable differences in thresholds between these conditions and the vibration of the fingertip. The existence of the sensory difference has not been previously illustrated due to the absence of comparative studies for the different conditions. Thresholds for the perception of hand-transmitted vibration should not be assumed to be the same as thresholds for the perception of finger vibration.

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Quantitative thermal perception thresholds in relation to vibration exposure

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Introduction

Work in occupations which entail awkward postures, repetitive tasks, high musculoskeletal load and physical factors such as cold, vibration and mechanical stress, have been associated with disorders exhibiting neuropathic symptoms. The symptoms may reflect both negative (loss of sensation) and positive (e.g. paraesthesia) manifestations of nerve fibre dysfunction. The present study focuses on the effect of vibration on the function of the small calibre nerve fibres transmitting the sensory correlate of cold and warmth. The study aims were: to assess the risk of disturbed thermal perception in relation to vibration exposure, to investigate a possible exposure-response relationship and to analyse the possible relationship between thermal perception and sensory symptoms.

Methods

The investigation was a cross-section of 128 vibration-exposed and 62 non-vibration-exposed male workers. Thermal perception was determined by a Somedic modification of the "Marstock” method (1) with computer assisted automatic exposure and response recording (Thermotest; Somedic, Sales AB, Sweden). Thermal perception of cold and warmth was determined from the thenar eminences and the distal phalanges of the second digits of both hands.

Quantified personal energy-equivalent vibration exposure was assessed for all subjects. The vibration was measured in accordance with ISO 5349. Based on the results, a separate quantified estimate according to job title of the vibration exposure for the left and the right hand could be arrived at. Combining exposure times and intensities gave the left hand a 0.80 exposure to vibration compared to the dominant right hand.

Results

The mean perception threshold at the thenar region for the sensation of cold was 27.2°C, and 31.0°C for warmth. The corresponding values for the second digit were 25.1°C for cold and 34.2°C for warmth. The sensibility on the right hand side was impaired compared to the left. The mean neutral zone at the thenar test site was increased 0.64°C (95% CI 0.37°C - 0.90°C) for the right hand compared to the left hand. Measurements from the distal phalanges of the second digit revealed less perceptual sensibility for both cold and warmth, (Figure 1). The trend between the vibration exposure categories was significant for the neutral zone at the thenar test site both for left (0.01) and right (0.00) hand side. The risk of contracting reduced thermal sensibility was increased for all test sites. Subjects with symptoms of nocturnal

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numbness have an increased risk of having wider neutral zones. The rate ratio for an increased neutral zone at the thenar eminence was 2.80 (95% CI 1.17 - 6.67) for the right hand and 2.72 (95% CI 1.12 - 6.63) for the left hand.

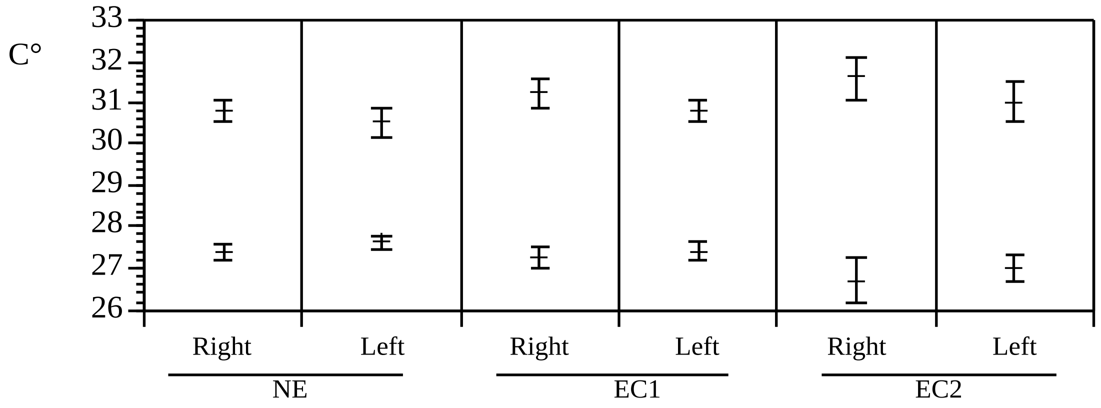

Figure 1. Thenar warm and cold perception thresholds (mean, 95 % CI) for the right and left hand in relation to cumulative vibration exposure (CVE) categories.
NE; 0 mh/s^2, EC1; 0 < CVE ≤ 24000 mh/s^2), EC2; CVE >24 000 mh/s^2.

Discussion

In this cross-sectional study hand intensive work including vibration exposure was associated with an increased risk of impaired thermal perception. This outcome is consistent with the results from clinical experience, threshold shift measurements (2), clinical case series (3,4) and case-control studies (5). Virokannas et al (5) found reduced cold perception thresholds and wider neutral zones for lumberjacks than for matched controls. This neutral zone pattern was similar to that observed for the crude values by Bovenzi et al (6) but which disappeared when they adjusted for age and drinking habits.

Conclusion

The results of this study indicate sensory impairment, as assessed by increased perception thresholds for warmth and a lowered threshold for cold, associated with cumulated vibration exposure. The effect appeared at vibration levels below the currently suggested standards. Quantitative sensory testing of thermal perception offers the only possibility of assessing this specific hazard to the peripheral neurosensory system.

Acknowledgement

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Comparison of thermal perception thresholds on the fingertip for vibration exposed and controls

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Introduction

Work with vibrating power tools may cause symptoms of sensorineural disturbances in the hand, such as impaired tactile and thermal sense, numbness and paræsthesia (for an overview, see (2)). In hand-arm vibration associated neuropathy, conceivable target structures are mechano- and thermo-receptive afferents supplied by myelinated and non-myelinated nerve fibers, respectively. The present study focuses on the effect of vibration on thermal afferents in the glabrous skin of the hand, i.e. naked nerve endings with thin non-myelinated nerve fibers mediating perception of cold and warmth. Measurements of thermal perception thresholds (TPTs) for cold and warmth have therefore be carried out on two groups of young males one of which consisted of professional users of vibrating hand-held power tools.

Methods

The investigation was a cross-section of 246 vibration-exposed workers and 88 non-vibration-exposed controls, respectively. All subjects were males aged between 18 and 32 years. None had symptoms of diseases known to cause sensory neuropathies, such as diabetes, metabolic disturbances, etc. TPTs for cold and warmth were determined by a modified version of the "Marstock" (1) method (Apparatus: Thermotest®, Somedic Sales AB, Sweden). Measurements were bilaterally taken on the index finger (distal and middle phalangs), index plus middle finger tips together and on the arch of the foot.Quantified personal energy-equivalent vibration exposure was assessed in accordance with ISO 5349 (3) for subjects in the exposed group.

Results

The results from the assessment of vibration exposure showed that 151, 69 and 26 people fell into the categories: Exp1<1.5 m/s^2, Exp2=1.5-3.0 m/s^2 and Exp3>3.0 m/s^2, respectively. The exposed group had used vibratory hand-held power tools for an average of 4.5 years. The highest exposure levels were found among welders.

Mean (±Sd) absolute TPTs for cold (TPT_C), warmth (TPT_W) and neutral zone (TPT_{NZ}), split by groups, are shown in Table 1. The neutral zone is defined as the arithmetic difference between TPT_W and TPT_C. As can be seen, the exposed category had on average, a somewhat lower TPT_C and higher TPT_W and a wider neutral zone as measured on the fingers. The differences between exposed and controls were in most cases significant. Very small and insignificant differences were found between hands for controls. For exposed there was, on average, a tendency towards larger effects on the right hand. The results for especially TPT_{NZ}, split by exposure category, indicate a

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tendancy towards an exposure-response relationship. No differences were found for TPTs measured on the foot both within and between groups.

Table 1. Mean (±Sd) thermal perception thresholds for cold, warmth and neutral zone as measured bilaterally for the index finger (LIF, RIF), index plus middle finger (LIMF, RIMF) and foot (Lfoot, Rfoot). * indicate *p*<0.5 (unpaired means comparison).

	TPT_C		TPT_W		TPT_{NZ}	
	NEXP	EXP	NEXP	EXP	NEXP	EXP
LIF	33.2 (1.4)	31.9 (1.8)*	36.3 (1.6)	36.7 (2.1)	3.0 (0.9)	4.8 (2.1)*
RIF	32.8 (1.5)	31.8 (1.6)*	36.3 (1.9)	36.9 (1.6)*	3.5 (1.1)	5.1 (2.0)*
LIMF	33.0 (1.4)	31.5 (2.1)*	36.4 (1.4)	36.9 (2.0)*	3.4 (1.0)	5.5 (2.6)*
RIMF	32.8 (1.6)	31.8 (1.8)*	36.5 (1.6)	37.4 (1.7)*	3.7 (1.2)	5.6 (2.4)*
LFoot	29.8 (2.1)	29.5 (1.9)	34.5 (2.7)	34.3 (2.7)	4.7 (2.5)	4.8 (2.6)
RFoot	29.7 (2.2)	29.3 (3.9)	34.6 (3.0)	34.0 (2.7)	4.9 (3.1)	4.6 (2.5)

Discussion

In this cross-sectional study work with hand-held power tools was associated with an increased risk of impaired thermal perception. Interestingly, the effect appeared on a young group of males and at fairly moderate vibration levels. About 90% of persons in the exposed group had a quantified personal energy-equivalent vibration exposure lower than 3.0 m/s^2. About 30% of persons in this group had TPTs, on the index fingers on both hands, classified as abnormal, i.e outside the range of the mean plus 2 Sd obtained for the controls. An exposure duration of about 30 years is in accordance with ISO 5349 required for corresponding prevalence for vascular disorders. Thus, the results indicate that thermoceptive afferents are far more sensitive to vibration exposure compared with the peripheral vascular system in the hand.

Quantitative sensory testing of thermal perception seem to offer a good possibility of assessing this specific hazard to the peripheral neurosensory system.

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Effects of acute psychological stress on autonomic nervous system in hand-arm vibration syndrome patients

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Introduction

The involvement of the autonomic centers in the brain due to exposure to hand-arm vibration has been under discussion (1, 2). It has been suggested in some studies that the autonomic nervous function, besides peripheral circulation, peripheral nervous and musculoskeletal systems, might be affected by exposure to hand-arm vibration and was previously assessed in hand-arrn vibration syndrome (HAVS) patients using time domain analysis of heart rate variability, and measuring levels of plasma catecholamines and cyclic nucleotides (3-7). It was observed that cold exposure activates the sympathetic nervous system to a higher degree in subjects with HAVS than in controls (8-12). Harada et al. investigated sympathetic response to noise, vibration and cold exposure in the healthy subjects and they observed that combined exposure to multiple stressors was more effective than a single stressor (13). In a previous study using urinary catecholamines' response we observed that the sensitivity of HAVS patients to acute psychological stress increased (14).

Recently, the frequency domain analysis of R-R intervals has been used to assess the magnitude of individual components of the heart rate power spectrum, which usually includes a high frequency (HF) component at the respiratory frequency (0.15-0.40 Hz) and a low frequency (LF) component at 0.04 to 0.15 Hz (15-19). The normalised units of the frequency domain components are used as indices of the autonomic nervous activity (LF% index of both the sympathetic and parasympathetic activity, HF% index of the parasympathetic activity and LF/HF index of sympathovagal balance) (20).

The purpose of the present study was to investigate non-invasively the effect of acute psychological stress in HAVS patients evaluating cardiac autonomic response using the frequency domain analysis of R-R intervals and measuring urinary catecholamines' responses under the same condition.

Methods

Sixteen HAVS patients (10 with vibration-induced white finger (VWF), 6 without VWF) and 14 healthy subjects (controls) volunteered in this study and gave written informed consent. The average age (SD) of the patients with VWF, patients without VWF and controls was 60.1 (7.0), 58.2 (4.7) and 56.1 (5.2), respectively. The average years (SD) exposed to vibration in the patients with and without VWF was 20.1 (11.5) and 24.3 (8.7), respectively. The patients were chain sawyers and tunnel construction workers and had been officially diagnosed with HAVS by the Japanese Ministry of Labour.

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Table 1. Characteristics of the subjects.

	Controls	Total patients	without VWF	withVWF
n	14	16	6	10
Age (yr)	56.1 (5.2)	59.4 (6.1)	58.2 (4.7)	60.1 (7.0)
Height (cm)	166.3 (5.9)	161.8 (4.9)	161.7 (2.3)	161.9 (6.1)
Weight (kg)	65.0 (7.2)	61.6 (8.0)	65.8 (6.4)	59.1 (8.0)
BMI (kg/m^2)	23.7 (3.6)	23.5 (2.6)	25.2 (2.7)	22.5 (1.9)
Smoker N / %	8 / 57.1	5 / 31.3	1 / 16.7	4 / 40
Drinker N / %	11 / 78.6	11 / 68.8	5 / 83.3	6 / 60
ETV (yr)	--	21.7 (10.4)	24.3 (8.7)	20.1 (11.5)
TT (yr)	--	2.0 (1.5)	2.9 (2.1)	1.5 (0.8)

Mean (SD). VWF, vibration-induced white finger; N, number; BMI, body mass index; ETV, exposure time to vibration; TT, time under treatment.

The patients were under treatment for HAVS and vibration exposure had been ceased in all of them. The job titles of the healthy controls were as follows: office worker, fisherman, community cleaner and farmer. There was no statistically significant difference in the mean age, body height, body weight, body mass index, percentage of smokers and drinkers among the groups as shown in Table 1. The years of exposure to hand-arm vibration and years under treatment of the patients with VWF were not different from the patients without VWF.

After an initial rest for l hour, 30 male subjects were exposed to acute psychological stress for about l hour with stressors - mirror drawing (8 minutes), watching a horror video (23 minutes) and arithmetic under intermittent noise of 90 dBA (15 minutes) (Figure 1). During the rest period every subject was allowed to drink 350 ml of soft drink.

ECG was recorded in supine position during spontaneous and deep (6 cycles/min) breathing before and immediately after exposure and was analysed using a Fast Fourier Transformation (FFT) program. The schematic outline of the frequency analysis of heart rate variability using a FFT program is presented in Figure 2. Frequency domain indices of heart rate variability, the normalised low frequency (0.04-O.l5 Hz) component power (LF%, index of both the sympathetic and parasympathetic nervous activity), normalised high frequency (0.15-0.40 Hz) component power (HF%, index of the parasympathetic nervous activity) and their ratio (LF/HF, index of sympathovagal balance) were calculated from 2 minutes electrocardiographic data during spontaneous and deep breathing, respectively.

Urine samples were collected from every subject during the before exposure rest and after exposure and urinary catecholamines (norepinephrine, epinephrine and dopamine) were analysed using high power liquid chromatography with the electrochemical detection method (21).

After exposure to the stressors and data recordings, the subjects were asked to rate the discomfort to each test they experienced on a 1 (none) to 5 (extreme) scale.

Unless otherwise indicated, data are expressed as mean (standard deviation). The intergroup differences were tested by Student t-test or Chi square test with Yates' correction. Comparison of parameters within the individual group before and after psychological test exposure was performed by paired t-test. Statistical significance was considered when $p < 0.05$.

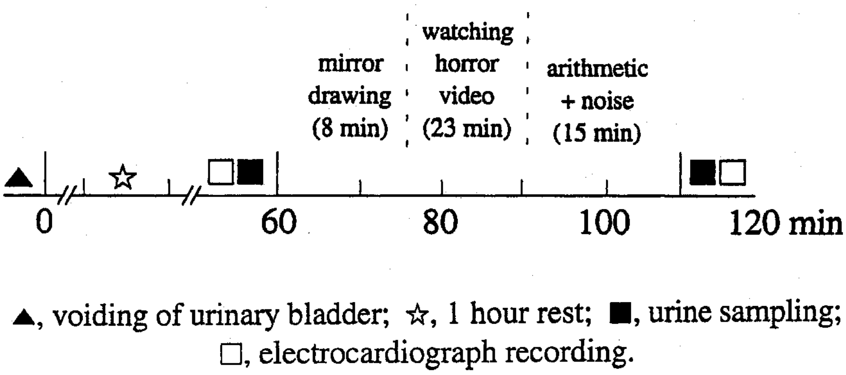

Figure 1. Procedure of the experiment.

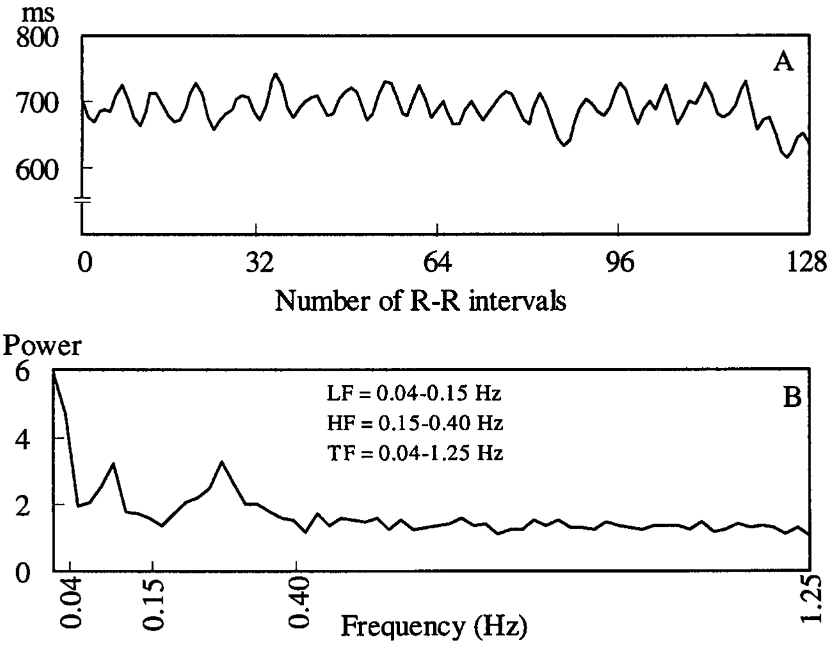

Figure 2. Schematic outline of the frequency analysis of heart rate variability using a Fast Fourier Transformation program. A, time series of R-R intervals; B, consequent power spectrum.

Results

Table 2 shows the severity of discomfort expressed in scores of subjective complaints to the stressors. The mean score of subjective complaints of the patients was larger than that of the controls ($p < 0.01$, Student t-test).

Table 2. Scores of subjective complaints to the stressors .

Controls (n = 14)	Total patients (n = 16)	without VWF (n = 6)	with VWF (n = 10)
6.4 (2.1)	9.5 (2.8)**	10.0 (3.0)**	9.2 (2.7)**

Mean (SD).**: $p < 0.01$ versus controls (Student t-test).

Table 3 shows the LF% during spontaneous and deep breathing before and after exposure to psychological stress. The LF% of the patients with and without VWF and the total patients during deep breathing after exposure was significantly larger than that of the controls ($p < 0.05$, $p < 0.01$). The LF% significantly increased after exposure during spontaneous breathing in the patients without VWF and total patients ($p < 0.01$).

Table 3. LF% before and after exposure to psychological stress.

Subjects	Spontaneous breathing		Deep breathing	
	Before	After	Before	After
Controls (n = 14)	12.6 (1.6)	13.6 (1.5)	14.8 (3.2)	13.9 (1.4)
Total patients (n = 16)	12.9 (1.7)	14.1 (1.0)##	15.0 (2.3)	15.8 (1.8)**
without VWF (n = 6)	13.2 (1.9)	14.6 (1.3)##	15.0 (2.7)	15.7 (1.3)*
with VWF (n = 10)	12.8 (1.6)	13.8 (0.8)	14.9 (2.3)	15.9 (2.1)*

Mean (SD).*: $p < 0.05$, **: $p < 0.01$ versus controls (Student t-test). ##: $p < 0.01$ versus before exposure value (paired t-test).

Table 4 shows the HF% during spontaneous and deep breathing before and after exposure to psychological stress. The HF% of the total patients during deep breathing after exposure was significantly larger than that of the controls ($p < 0.05$).

Table 5 shows the LF/HF during spontaneous and deep breathing before and after exposure to psychological stress. The LF/HF of the patients with VWF and total patients during both spontaneous and deep breathing after exposure was significantly larger than that of the controls ($p < 0.05$). The LF/HF of the patients with VWF and total patients significantly increased after exposure during both spontaneous and deep breathing ($p < 0.05$, $p<0.01$, $p<0.001$).

Table 4. HF% before and after exposure to psychological stress.

Subjects	Spontaneous breathing		Deep breathing	
	Before	After	Before	After
Controls (n = 14)	24.9 (1.7)	25.9 (2.2)	27.5 (4.3)	25.7 (2.1)
Total patients (n= 16)	25.3 (3.0)	25.6 (2.0)	27.3 (3.2)	27.8 (3.3)*
without VWF (n = 6)	24.6 (2.3)	27.0 (2.1)	27.5 (1.9)	28.1 (3.1)
with VWF (n = 10)	25.7 (3.4)	24.8 (1.5)	27.3 (3.9)	27.7 (3.6)

Mean (SD).* $p < 0.05$ versus controls (Student t-test).

Table 5. LF/HF before and after exposure to psychological stress.

Subjects	Spontaneous breathing		Deep breathing	
	Before	After	Before	After
Controls (n = 14)	0.51 (0.05)	0.52 (0.04)	0.54 (0.04)	0.54 (0.03)
Total patients (n = 16)	0.51 (0.04)	0.55 (0.04)*##	0.55 (0.05)	0.57 (0.03)*#
without VWF (n = 6)	0.53 (0.03)	0.54 (0.04)	0.54 (0.07)	0.56 (0.03)
with VWF (n= 10)	0.50 (0.04)	0.56 (0.03)*###	0.55 (0.04)	0.57 (0.04)*#

Mean (SD).*:$p < 0.05$ versus controls (Student t-test). #: $p < 0.05$, ##: $p < 0.01$, ###: $p < 0.001$ versus before exposure value (paired t-test).

Table 6. Urinary norepinephrine (µg/h) before and after exposure to psychological stress.

Subjects	Before	After
Controls (n = 14)	1.97 (1.18)	2.09 (1.26)
Total patients (n = 16)	2.65 (1.34)	3.62 (1.79)*
without VWF (n = 6)	3.03 (1.38)	3.32 (1.56)
with VWF (n = 10)	2.42 (1.33)	3.79 (1.97)*

Mean (SD).*: $p < 0.05$ versus controls (Student t-test).

Table 7. Urinary epinephrine (µg/h) before and after exposure to psychological stress.

Subjects	Before	After
Controls (n = 14)	1.05 (0.87)	1.13 (0.96)
Total patients (n = 16)	1.50 (1.01)	2.08 (1.35)*
without VWF (n = 6)	1.56 (1.49)	1.39 (1.20)
with VWF (n = 10)	1.47 (0.68)	2.49 (1.31)**#

Mean (SD).: $p < 0.05$,: $p < 0.01$ versus controls (Student t-test). # $p < 0.05$ versus before exposure value (paired t-test).

Table 8. Urinary dopamine (µg/h) before and after exposure to psychological stress.

Subjects	Before	After
Controls (n = 14)	16.70 (11.10)	15.20 (12.59)
Total patients (n = 16)	18.17 (10.74)	19.54 (9.15)
without VWF (n = 6)	18.98 (9.72)	19.10 (12.60)
with VWF (n = 10)	17.68 (11.79)	19.80 (7.15)

Mean (SD).

Table 9. Correlation coefficients between heart rate variability indices and increase of urinary catecholamine after psychological stress.

	Breathing pattern					
Urinary	Spontaneous			Deep		
catecholamine	LF%	HF%	LF/HF	LF%	HF%	LF/HF
Norepinephrine	0.43*	-0.06	0.62**	0.15	0.02	0.29
Epinephrine	0.44*	-0.03	0.59**	-0.01	-0.19	0.29

n=30.*:$p<0.05$,**:$p<0.01$.

Tables 6, 7 and 8 show the amounts of urinary catecholamines' response to the stressors. The amounts of urinary catecholamines after exposure were largest in the patients with VWF, followed by the total patients and then the patients without VWF. The after-exposure amounts of norepinephrine and epinephrine of the patients with VWF and the total patients were significantly larger than those of the controls ($p < 0.05$, $p < 0.01$). The patients with VWF indicated a significant increase of urinary epinephrine ($p < 0.05$).

Table 9 shows the correlation coefficients between heart rate variability indices and the increase of urinary catecholamines after psychological stress. The LF% and LF/HF during spontaneous breathing after exposure correlated positively and significantly with the increase of urinary norepinephrine and epinephrine ($p < 0.05$, $p < 0.01$).

Discussion

Various stressors, such as a mirror drawing test, mental arithmetic, watching a horror video, public speaking etc. are used to investigate human responses to acute psychological stress (22, 23). In a previous study we found that exposure to more than one stressor simultaneously was adequate to induce psychological responses (13). In the present study we used a mirror drawing test, watching a horror video and doing arithmetic under intermittent noise, simultaneously, and the responses to the stressors should be interpreted as combined effect. As the severity of discomfort in the patients expressed in scores of subjective complaints to the stressors was larger than in the controls, it is considered that the stressors were adequate to induce psychological responses.

The results of the frequency domain analysis of heart rate variability in this study showed that the autonomic nervous response to acute psychological stress in HAVS patients was different from the healthy controls. The LF% of the patients with and without VWF and the total patients during deep breathing after exposure was significantly larger than that of the controls. The LF% significantly increased after exposure during spontaneous breathing in the patients without VWF and total patients. These findings indicate that the cardiac sympathetic response to the psychological stress was higher in the patients than in the controls (20). The LF/HF of the patients with VWF and total patients during both spontaneous and deep breathing after exposure was significantly larger than that of the controls and also significantly increased from the corresponding before exposure value, which indicates predominance of sympathetic tone in the cardiac sympathovagal balance (18, 20).

It is well-known that circulating catecholamines are rapidly metabolised and levels of plasma catecholamines are sensitive indicators of the sympathoadrenal medullary response to acute stress (24, 25). Because a percentage of catecholamines is excreted in the urine, analysis of urinary catecholamines is used as an indicator of plasma levels over a given period of time (24-27). Norepinephrine, secreted primarily by the sympathetic nerves, increases in plasma and urine with standing, volume, cold exposure, physical activity, and exercise (24, 25). Epinephrine, secreted primarily by the adrenal medulla, is increased in plasma and urine with problem-solving, mood change, and mental stress such as flying a plane, driving in traffic, or speaking in public (24-27). As the present study is of non-invasive character, we used measurements of urinary catecholamines instead of plasma catecholamines. In the present study the amounts of urinary norepinephrine and epinephrine during exposure period were significantly larger in the patients with VWF and total patients, and urinary epinephrine of the patients with VWF significantly increased, which might indicate larger sensitivity of the sympathoadrenal medullary system to psychological stress (14).

The correlation coefficients between heart rate variability indices and the increase of urinary catecholamine after psychological stress showed that the LF% and LF/HF during spontaneous breathing after exposure correlated positively and significantly with the increase of urinary norepinephrine and epinephrine. The LF% and LF/HF during deep breathing after exposure correlated positively but not significantly. However, the differences in LF% between the patients and the controls reached significant levels during deep breathing after exposure but did not during spontaneous breathing after exposure. On the other hand, the LF% significantly increased after exposure during spontaneous breathing in the patients without VWF and total patients. Another point is that the changes in response to psychological stress were small in all groups. These may be due to contradictory influences of supine posture and deep breathing on heart rate variability responses to psychological stress.

Conclusions

It could be concluded from the findings of the present study that the sympathetic tone in cardiac sympathovagl balance predominated and sympathoadrenal medullary activity increased due to exposure to acute psychological stress, especially in HAVS patients with VWF, and should be taken into consideration when they are under medical treatment. Additional research regarding autonomic response to psychological stress in HAVS patients, under well-defined experimental protocol bearing in mind contradictory influences of different autonomic contexts on heart rate variability, should be carried out.

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Effects of vibration frequency and duration on eye-hand coordination in pointing tasks

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Introduction

Visual control of hand movement is essential in occupational activities requiring precise manipulation. The coordination of eye and hand movements is required in these tasks. Visual, proprioceptive and exteroceptive information contribute to the control of the complex coordination processes (1, 2). Hand vibration has been shown to alter continuous manual control and oculomanual coordination (3). There is evidence that these perturbations of sensory motor activities result from vibration-induced changes in sensory messages (4, 5), which deeply affect the functioning of the neurosensory mechanism underlying motor control (6, 7, 8). These alterations were found to be frequency dependent (7, 8).

The question then arises as to how alterations of manual performance and eye-hand coordination are related to vibration frequency. In particular, which vibration frequencies would have less influence on oculomanual coordination? Furthermore, as visual control may not be efficient in all situations it is of interest to assess its role in simple pointing tasks, which are frequently performed under vibration exposure while manipulating various powered hand tools.

The present study describes the changes in coordinated eye-hand pointing tasks during short term and after long term hand vibration exposure for two vibration frequencies.

Methods

Subjects

Ten right handed subjects aged 20 - 40 years participated in the experiment as paid volunteers. All subjects were in good physical condition, free from any known neurological or musculoskeletal disorders and had good vision without optical aide.

Experimental Situation

The subject was seated on an adjustable armchair in front of a display panel placed 57.3 cm from the eye (Figure 1). Eleven light emitting diodes (LED) arranged in a cross shape and spaced by 5 cm (5° viewing angle) served as visual targets. Eye position was monitored using an infrared optoelectronic device. Hand pointing position was measured by a two-dimensional sonic device fixed to the panel. The pointing device consisted of a handle with a pointer running off the top at a right angle to the axis of the handle. The handle contained a cam load vibrator. Vibration was applied to the dominant hand of the subject using either the self-contained vibrator located in the handle of the pointing device or a vertical handle fixed to an electromagnetic vibrator. In this later case, the handle was equipped with a dynamometer to display the grip force on a digital voltmeter. Sinusoidal vibration of 100 Hz and 200 Hz with displacement

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amplitude of 0.2 mm was used. The task consisted of pointing below the horizontal targets with the pointer held in the right hand. During a pointing trial each horizontal target was illuminated ten times in random order. The target was turned on for one second; three seconds separated two consecutive target presentations. A pad, on which the subject pointed, was located 7 cm below the horizontal LEDs. A mark placed under the center target indicated the starting location of all pointing movements. The subjects were instructed to simultaneously move the eye and the hand and, perform the hand motion as quickly as possible while emphasising accuracy.

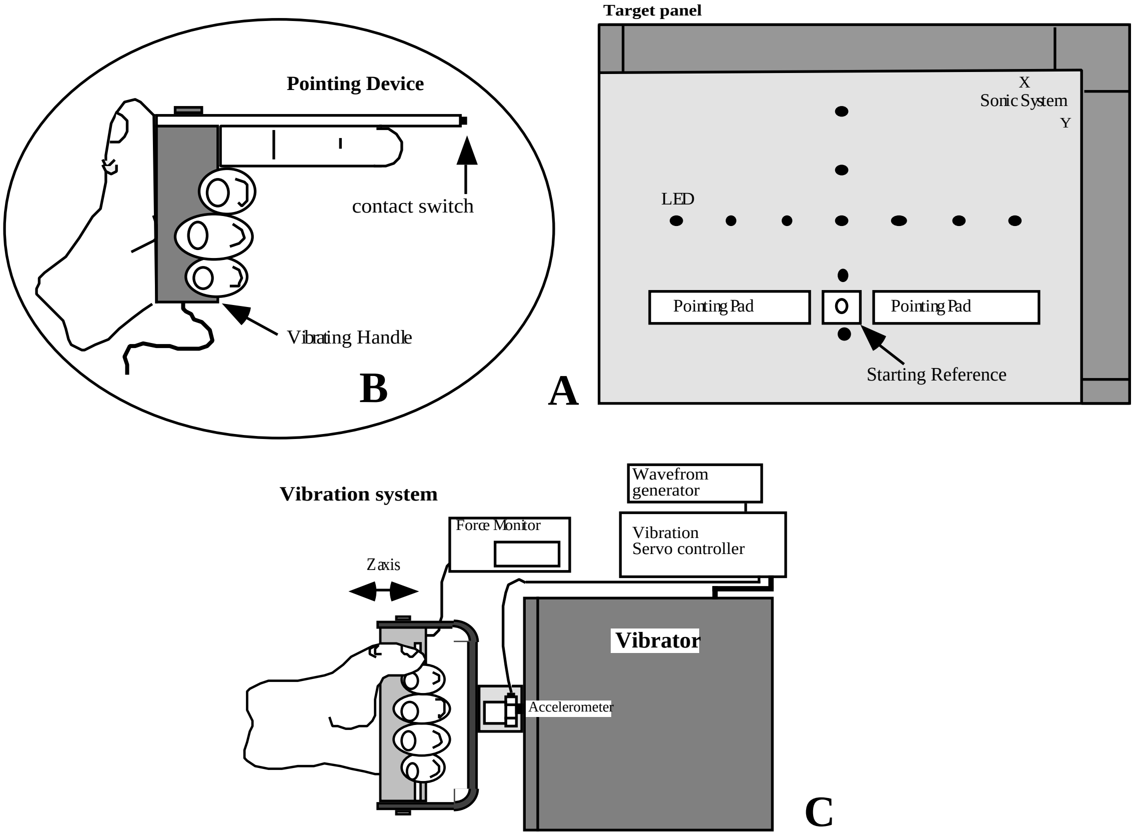

Figure 1. Experimental equipment. Punctual visual targets are presented on a vertical panel placed 53.7 cm from the eyes of the subject (A). The pointing device (B) is held in the dominant hand. The subject points below the targets, on the pointing pads. Vibration is applied to the hand using the cam load vibrator located inside the handle of the pointing device or an electrodynamic vibrator (C).

Procedure

The subject performed practice trials before the experiments. Two sets of experiments were carried out on non-consecutive days: per-vibration and post-vibration pointing. In the “per-vibration pointing” experiment the task was performed before and during hand vibration with the hand in sight or the hand out of sight, masked by an opaque screen. In this latter case, a hole in the screen allowed vision of the center mark. Data was collected for a total of eight trials (2 test situations x 2 frequencies x 2 visual conditions). A 5 minute rest period separated two consecutive trials, and a 15 minute rest period separated vibration exposures.

In the “post-vibration pointing experiment the task and visual conditions were identical to the one described above. The pointing performance was tested before (t_c), immediately after (t_0), and 5 (t_5) and 10 minutes (t_{10}) after a 10 minute vibration exposure. During the vibration period the subject grasped the handle and exerted a grip force of 5% MVC during 5 sec and relaxed for 25 seconds. Data was collected for a total of 16 trials (4 test situations x 2 frequencies x 2 visual conditions). A 15 minute rest period separated two vibration exposures.

Recording and analysis

The horizontal eye position signals were sampled at 1000 Hz and recorded by a computer. The horizontal coordinate of the pointing location and the pointing movement time were recorded simultaneously by another computer. Repeated measures analysis of covariance (ANACOVA), treating the subject as a random blocking factor, was performed on the eye and hand constant error (mean end-point from the center of a target), error variability (absolute error = |constant error| and std dev. of absolute error), and hand movement time, to characterize the effects of hand vibration on the visuo-manual task.

Results

Per-vibration pointing.

The ANACOVA performed on the hand and gaze constant errors, absolute error and hand movement time indicate that vibration, vibration frequency and visual conditions had a significant influence on hand pointing, eye gaze precision, and eye-hand coordination.

Hand movements. Figure 2 (left panels) illustrates the influence of hand vibration on the constant error for each visual condition. In the control situation (no vibration) the constant error increases when the hand is masked. In addition, the error variability also increases significantly when the hand is masked. Changes resulting from vibration exposure are as follows. Changes in the constant error were significant only for the most eccentric targets (±10°, ±15°). The average magnitude of the shift in pointing position induced by the 100 Hz vibration is 1.2 mm when the hand is visible and 3.7 mm when the hand is masked. The absolute error increases ($p < 0.05$) from 4.9 mm to 5.9 mm during 100 Hz vibration when the hand is visible. In the control situation, the standard deviation of the absolute error was larger ($p < 0.05$) for the mask (± 6.6 mm) than the no-mask condition (± 3.5 mm). Probably because of this large increase in error variability before exposure, no significant variation in error variability was observed during vibration when the hand was masked. The movement time decreases significantly only during 100 Hz vibration (Table 1). The 200 Hz vibration had no significant influence.

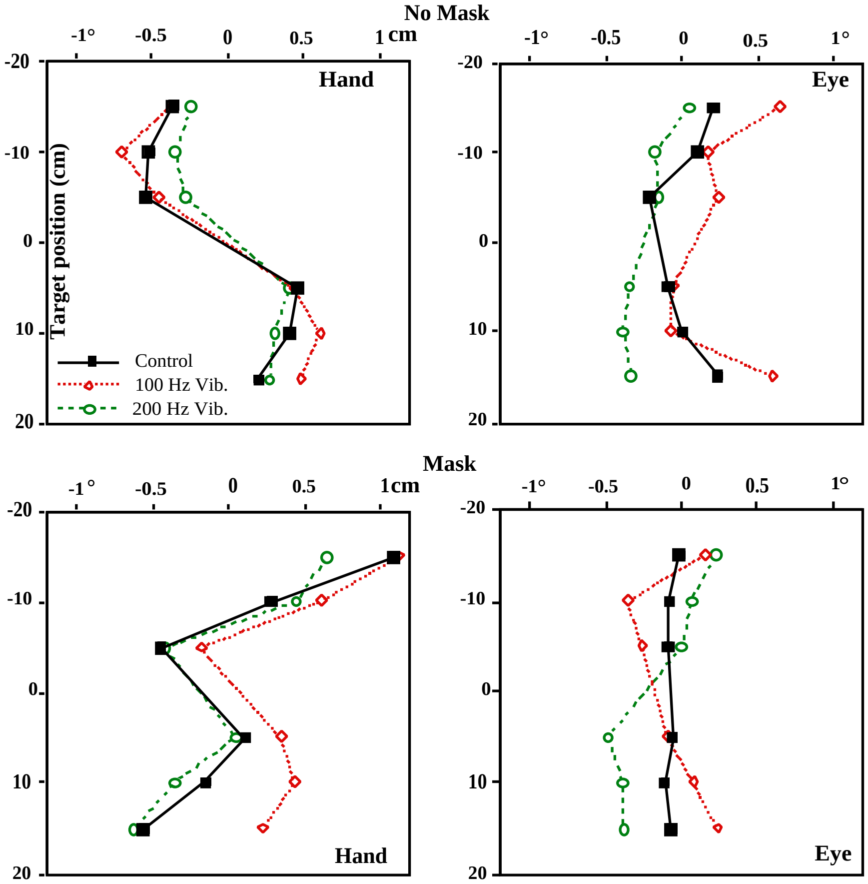

Figure 2. Hand and eye constant errors during vibration exposure. Hand not masked (upper panels), hand masked (lower panels). The errors (horizontal axis, 1cm = 1° of visual angle), are presented for each target (vertical axis). Each symbol indicates the magnitude of the error relative to the center of the target.

Table 1. Movement time.

Vibration	Hand movement time (ms)	
	No-mask	Mask
Control (no vibration)	635 ± 210	605 ± 193
100 Hz	550 ± 159*	546 ± 139*
200 Hz	645 ± 188	602 ± 187

* significant decrease ($p < 0.05$)

Eye movements. Figure 2 (right panels) illustrates the influence of hand vibration on the gaze constant error for each visual condition. Changes in the constant error (mean = 0.25° for both visual conditions) are only significant for large amplitude movements (±10°, ± 15°). The absolute error increases significantly ($p < 0.05$) by 0.2° for the 100 Hz vibration in the no-mask visual condition and is not affected by the 200 Hz vibration. In this visual condition, the error variability increases significantly from ± 0.68 (no vibration) to ± 0.78 (100 Hz vibration). No significant changes in absolute error or error variability where observed when the hand was masked. A visual analysis of the eye movement traces did not reveal a change in the saccade pattern under vibration exposure.

Post-vibration pointing

The ANACOVA indicated that vibration and visual conditions had a significant influence on hand pointing and eye gaze precision, and eye-hand coordination. Vibration frequency significantly influenced the task in specific situations.

Hand movements. Figure 3 (left panels) illustrates changes in the constant error observed immediately after vibration exposure for each visual condition. A shift in hand pointing position is observed when the hand is masked (lower left panel). This error corresponds to an undershoot of the targets. The constant error, the absolute error and error variability are not affected by the visual conditions in the control situation. Changes resulting from vibration exposure are as follows. Changes in the constant error are significant only for the most eccentric targets (±10° and ±15°). This error is significantly affected after vibration only when the hand is masked. The average magnitude of the shift in hand pointing position induced by vibration is 4.7 mm when the hand is masked. In this visual condition the absolute error increases significantly from 5.1 mm to 7.2 mm. The magnitude of the shift in pointing position observed immediately after vibration (T0) remains approximately the same up to 10 min. after vibration exposure when the hand is masked, while no significant changes are observed when the hand is visible (Figure 4).

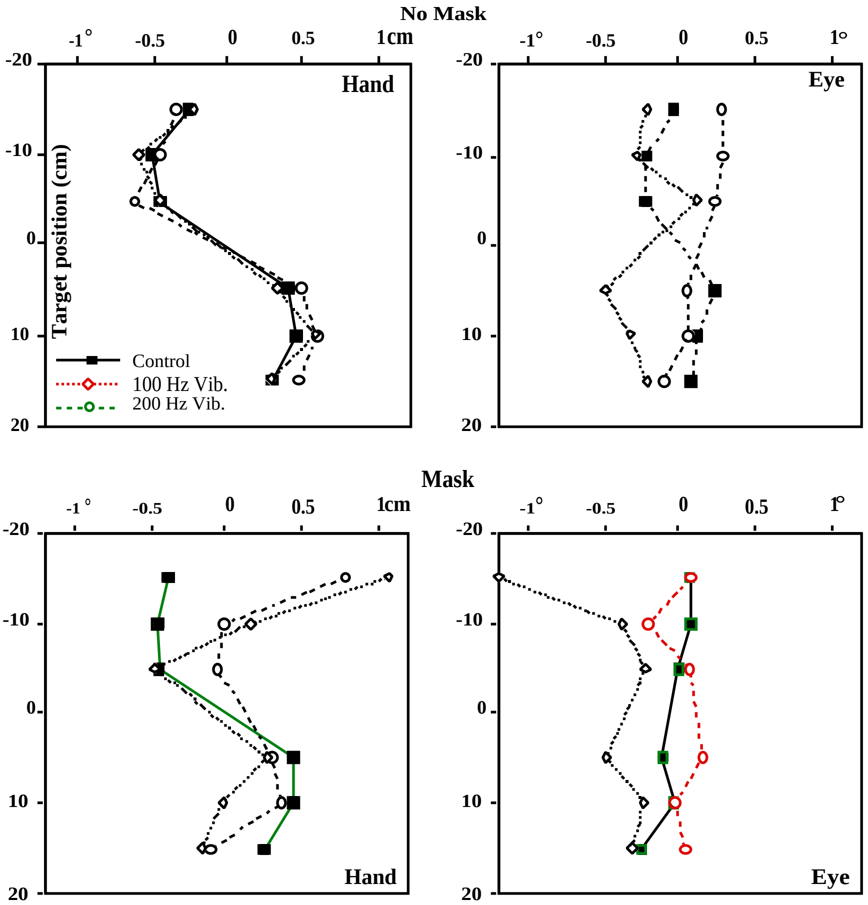

Figure 3. Hand and eye constant errors immediately after vibration exposure. Representation identical to Figure 2.

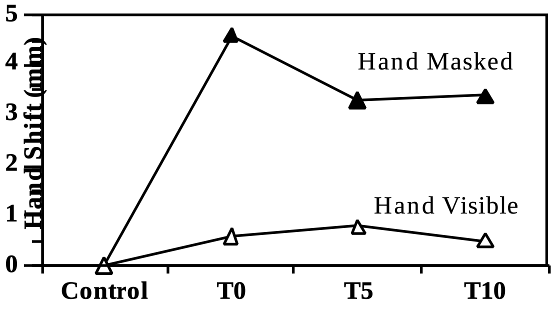

Figure 4. Average shift in hand pointing position observed after vibration exposure.

The error variability increases by more than 60% after vibration exposure when the hand is masked. This increase persists up to 10 minutes after exposure. No changes in variability are observed after vibration exposure when the hand is visible. The movement time is not significantly affected after vibration exposure.

Eye movements. Figure 3 (right panels) illustrates the influence of hand vibration on the gaze constant error for each visual condition. Changes resulting from vibration exposure are as follows. The average magnitude of gaze shift are 0.35° and 0.25° when the hand is not masked and masked, respectively. These shifts mostly correspond to target undershoot when the hand is not masked (Figure 3 upper right panel), while they are not specifically oriented when the hand is masked (Figure 2 lower right panel). The constant error was larger ($p < 0.05$) for 100 Hz than 200 Hz vibration only when the hand was not masked. The absolute error increases significantly ($p < 0.05$) by 0.17° and 0.13° immediately after 100 Hz vibration exposure when the hand is not masked and masked, respectively. Furthermore, the standard deviation also increases in the same situations. No significant changes were observed 5 minutes after vibration exposure; hence, hand vibration may not have long lasting effects on the control of eye movements.

Discussion

There were four major findings in this study. First, impairments of hand pointing and eye gaze show that hand vibration can affect the precision of hand movement and eye-hand coordination. This finding, which agrees with previous results concerning visuo-manual control, confirms the influence of hand proprioception on eye-hand coordination. Furthermore, only large amplitude movements (≥ 10°) are affected. Second, hand and eye movements are generally more strongly affected by 100 Hz than 200 Hz vibration. Third, changes in performance observed during and after vibration exposure when the hand is masked underline the role of the visual feedback in vibratory environments. Fourth, the persistence of the constant error of the hand movements 10 min after vibration exposure only when the hand is masked indicate that vibration may lead to a loss of the proprioceptive reference that is not compensated by a visual input.

Alteration of eye-hand pointing. Vibration can induce a shift in hand pointing and eye fixation, before and after vibration exposure. These errors are accompanied by an increase in error variability. The general trend indicates that 100 Hz vibration seems to produce the strongest effects. The vibration-induced alterations of coordinated hand and eye movements observed in the present context are in line with previous results showing impairments of continuous tracking movements (3). They confirm that vibration-induced alteration of sensory information issued from somesthetic mechanoreceptors can contribute to a decrease in movement precision and that frequency effects are related to the receptors sensitivity to the frequency of the vibratory stimulation. Primary muscle spindle receptors, which provide limb position information, are extremely sensitive to vibration frequencies up to 100-120 Hz (4), while cutaneous receptors, also involved in motor control processes, are sensitive to vibration up to 250 - 300 Hz (4, 9). Thus, the weaker influence of 200 Hz vibration suggests that the impairment of performance has predominantly a muscle proprioceptive origin. The alteration of eye movements indicates that vibration is able to affect the coordination of the hand and the eye in pointing tasks, despite the fact that the target was always visible. The role of hand and arm proprioceptive afferents in eye movement control, proposed by several authors (1, 3), suggests that the alteration of the information mediated by these pathways is most likely responsible for the changes in eye fixation error and error variability observed during and immediately after vibration exposure. In the present context (target visible), it can be proposed that eye gaze alterations result most probably from the sensory noise generated by the vibratory stimulus. In fact, no specific direction in fixation shift and no obvious changes in eye movement pattern were observed. Furthermore, vibration frequency had a limited impact on eye movements. We assume that the visual feedback provided by the target light counteracted most of the influence of the “distorted” hand proprioceptive information. Despite the significance of the alterations it is important to remark that fixation errors are relatively small (0.25°), which do not compromise foveal vision of the targets.

Visual feedback of the hand. The visual feedback of the hand did not totally prevent the alteration of hand aiming position during vibration exposure. This “residual” effect is probably due to the fact that the hand aiming location was 7° below the visual target. As subjects were requested to focus on the visual targets, the hand was beyond the limit of the foveal field (≈ 2°). Thus, the precision of the foveal system was not available to fully compensate the vibratory effects described above. Nevertheless, peripheral vision did play a significant role, as the alterations of hand movements were more pronounced in the absence of hand visual feedback.

Post-vibration recovery. The performance recovery time seems to be less than 5 minutes for both hand pointing when the hand is not masked and eye fixation in all visual conditions. However, the hand pointing constant error and the increase in variability of the absolute error persist throughout the observed post-vibration period. These data show that in the absence of visual feedback, the vibration-induced bias in movement amplitude is not corrected by a recalibration of the hand controller. The persistence of the error suggests that the reference is lost during vibration exposure. In the absence of visual information the subject tends to use the last available proprioceptive information. A similar effect has been observed in an earlier study of torque control under whole-body vibration without visual feedback (Gauthier et al. 1981).

Conclusions

Visual control of the hand appears to be a necessary but not sufficient condition to limit the vibration-induced degradation of manual tasks. Furthermore, pointing performances seem less affected by high vibration frequencies (200 Hz). These remarks are of particular importance in the design of the workplace and powered hand tools. First, visual control of the hand holding a vibrating tool should not be interrupted in tasks requiring aiming movements. Second, high frequency vibration (> 200 Hz) are preferable since they tend to have less influence on motor performances and are easier to attenuate.

Acknowledgement

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Shoulder and elbow musculoskeletal disorders in forest workers exposed to hand-arm vibration

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Introduction

Shoulder tendinitis and non-specific shoulder pain have been reported to be associated with highly repetitive work, (7, 9, 12) and sustained shoulder postures with more than 60 degrees of flexion or abduction (9, 12).Work tasks with continuous arm movements can generate load patterns on the rotator cuff and glenohumeral joint which may lead to muscle fatigue (12).

It has been stated that heavy work is a risk factor for shoulder tendinitis (16). More epidemiological evidence is still needed because there are several confounding factors such as age and smoking.

Few studies have associated vibration with upper limb musculoskeletal disorders (6, 15, 16). Epidemiological data is still insufficient concerning vibration-induced musculoskeletal disorders of the shoulder (11).

In our paper we report the findings of a clinical follow-up and cross-sectional study of forest workers using chain saws, which focuses on shoulder and elbow musculosceletal disorders, both on supraspinatus tendinitis, non-specific shoulder pain and lateral epicondylitis.

Methods

The investigation was carried out in Suomussalmi in northeastern Finland, in connection with a compulsory medical examination of forest workers in 1995. These forest workers have been followed for 23 years (10). 106 forest workers were examined, out of which 73 forest workers were selected who had worked over 1,500 hours in a 3 year period. The mean 3 year exposure was 2,800 h (SD 500 h), ranging from 1,540 h to 3,750 h. The mean total exposure time was 18,900 h (SD 6,100 h), ranging from 6,700 to 32,600 hours. Total exposure was established for each survey period. There have been 12 surveys conducted in Suomussalmi since 1972.

The mean age of the group was 45.5 years (SD 6.1 years), ranging from 34 to 58 years.

Detailed inquiries of sports activities and a medical history were made by questionnaire. Each subject underwent a medical interview concerning neck, shoulder, elbow and hand pain. To be accepted for inclusion in the study, pain must have lasted for weeks or for most days during 1-2 months during the previous year.

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The clinical examination was performed by specialists in physiology and otolaryngology. A radiologic examination, by x-rays, was made when needed. Routine laboratory tests and functional muscle strength capacity tests were performed as well as measurements of hand grip forces. Symptoms of peripheral sensorineural disturbances such as tingling and numbness were explored. Neck symptoms after major trauma, or due to infectious, malignant diseases or cervical nerve compression, were excluded.

The intensity of cervical pain was measured on a horizontal 100 mm visual analogue scale or VAS (17). Pain drawings were used (15). The score of a short clinical depression scale was calculated (16). The height and weight of participants were determined. Clinical diagnoses were obtained according to the criteria of Waris and Viikari-Juntura (20, 21).

Data analysis was performed by Kendall’s correlation procedure. A significance level of 0.05 was chosen for continuous data.

Results

The daily vibration exposure time of the forest workers varied from 5 to 7 h. From hygenic measurements of vibration, taken from chain saws used by professional forest workers, the mean frequency weighted acceleration was 2 m/s^2 (range 1.8-2.4 m/s^2). This allows full-time daily operation according to the threshold values published by the American Conference of Governmental Industrial Hygienists .

The prevalence rate of supraspinatus tendinitis, which included painful arch (21) and non-specific pain of the shoulder (which included pain and tenderness in the supraspinatus tendon without painful arch in isometric testing) were 18% on the right side and 8% on the left side.

The prevalence of epicondylitis was 7% on the right side. Elbow pain and tenderness locally without pain in response to resistive extension of the hand and fingers was 11% on the right side and 7% on the left side. The epicondylar tenderness and pain was thought to be a part of a continuum in elbow musculosceletal disorders. All the elbow disorders were taken into account in the results.

Tinell’s sign of diminished sensitivity to light touch in 3.5 fingers on the radial side of the hand, were not found at this examination.

The relationship between total vibration exposure time and shoulder and elbow musculosceletal disorders was examined. The occurrence of upper limb disorders increased with increasing vibration exposure time. There was a statistically significant correlation between total exposure and shoulder musculosceletal disorders, both supraspinatus tendinitis and non-specific shoulder pain on the right side (r=0.307, p=0.003, n=64) but not on the left side (r=0.184, p=0.068, n= 66).

There was no association between total exposure and elbow musculosceletal disorders on the right (r=0.117, p=0.247, n=66) or left side (r=0.084, p=0.410, n=66). It was also found that there was no association between upper limb functional tests and shoulder or elbow musculosceletal disorders.

Neck pain was reported to be 0-75/100 on the visual analogue scale, and the mean was 24.5. Two forest workers reported their neck pain as severe as 90-96/100 in VAS. Both of them had also severe low back pain.

Only two forest workers reported to have 11 points, and one man reported to have 18 points, (of a maximum of 21 points) in the short clinical depression scale, indicative of depression. There seems to be an underestimation of symptoms typical to depression in our study.

Discussion

Long term use of chain saws can lead to musculoskeletal disorders of the upper limbs (3, 8, 14). It is known that vibration can influence muscle activity by activating the tonic vibration reflex, (13) and biomechanics of the arm. Hand and wrist attenuate the mid- and high frequency vibration (5, 14).

Vibrational energy is also transmitted to the elbow and to a lesser extent to the shoulder area (14). Vibration stimulates a tonic vibration reflex and excessive forces are needed in handling tools (13). Hand-arm vibration syndrome may also involve reduced sensory perception or reduced tactile discimination (4, 5).

Forestry work also involves repetitive hand-arm motions, awkward postures and forceful exertions. It is known that both repeated and sustained postures involving over 60 degrees of abduction or flexion are associated with shoulder musculosceletal disorders (7, 9, 11, 12) There are also cross-sectional studies about the positive association betwen forceful exertions and shoulder problems, but measures of exposure and health outcome vary. More studies are still needed (1, 7, 19).

Several factors can cause upper limb complaints. Vibration as a physical workplace factor is combined with other factors.

In our study group, the mean working hours were 18,900 h, or 20.1 years working time. The exposure to vibration has been followed since 1972 with 1-5 years intervals. 29 forest workers of the present 73 workers were examined in 1992. A total of 40 men (of the present 73 men) have been followed since 1975. The prevalence of upper limb pain has been 26-31% and that of neck pain has been 33-36% throughout the years (14), consistent with the present study.

In our population, 25% were smokers, 60% were non-smokers and and 14% were ex-smokers. Smoking had a significicant correlation with upper limb disorders, but the mechanism is not known in detail.

In 1995, during the previous 6-8 weeks before the health examination, none of the men had been engaged in chain sawing. This may result in an underestimation of the strength of association between exposure and musculoskeletal disorders, especially mild symptoms and signs. The investigators were blinded to total exposure status but not to the 3 year exposure, which may bias the result.

In 75 Italian forest workers Bovenzi et al. found, that the greater the daily vibration exposure, the more musculosceletal disorders of the upper limb were observed, independently of age and body mass index (3). In Bovenzi’s et al. group the mean age was 44.0 years. The total operating time (9,196 h) was less than in our study, although the SD was very large. The prevalence of supraspinatus tendinitis was 15.4% (n=10), that of bicipital tendinitis was 9.2% (n=6) and that of epicondylitis was 29.3% (n=19). Tenosynovitis of the wrist and forearm appeared in 15.4% (n=10) of the forest workers. These observations are consistent with our results.

Stenlund (18) found an association between cumulative vibration exposure and shoulder tendinitis when he studied the frequency of acromioclavicular osteoarthrosis in vibration-exposed rock blasters and brick layers. The lifetime exposure to vibration was based on self-reported hours throughout the working lifetime. In a multivariate model, which included both the vibration exposure and sum of the lifted load, the influence of vibration on the risk of acromioclavicular osteoarthrosis was 1.05 on the right and 1.35 on the left side. The ORs were non-significant. Age, lifting and smoking were associated with the arthrosis.

Stenlund (19) also found that 32.7% (n=18) of rock blasters had signs of left-sided, and 40.0% of right-sided, shoulder tendinitis, including either pronounced pain upon palpation of the rotator cuff muscles or pain in isometric testing of the rotator cuff muscles. A significant association was found between cumulative vibration exposure and the right-sided signs of shoulder tendinitis: OR 1.66 (95%CI 1.06-2.61). On the left side, the OR was also significant, 1.84 (95%CI 1.10-3.07). Participation in sports was taken into account. There was a possibility of biases arising from the healthy worker effect and from self-estimates of the total work exposure. The work of the rock blasters involved both lifting and operating vibrating powertools. In our study, the prevalence of shoulder musculoskeletal disorders might have been greater without the period of unemployment prior to the physical examination. The data concerned the total exposure of six subjects and the right-sided shoulder symptoms of 3 subjects. This is not supposed to have influenced the result.

Burdorf (6) has examined the correlation between exposure to vibration and self reported musculoskeletal complaints in a group of riveters. Complaints were defined as disorders like pain or stiffness for at least a few hours during the past year. Cumulative vibration exposure led to increased prevalence of wrist pain (significant correlation) and, to a lesser extent, to elbow pain (almost significant correlation). When age adjusted ORs for riveters versus controls were plotted by the years of riveting, there was gradual increase in slope of OR for complaints of the elbow and shoulder (OR: between 1-2 after 10-20 years of riveting). In our study, we could partly confirm these findings by logistic regression analysis.

Elbow epicondylitis is known to be associated with forceful work (11). Chiang measured exposure to force and repetition among workers in the fish-processing industry and found a difference between the lowest and highest exposed groups in males (7, 11). Workers with short-term exposure had more complaints than those with over 60 months exposure.

Elbow epicondylitis can be related to sports activities, too. In our study, sports activities did not correlate with shoulder or elbow musculoskeletal disorders, rather, the opposite; there was a tendency for negative association. Forest workers are usually used to running or skiing, not to playing tennis and hence sports activities do not tend to increase shoulder or elbow musculoskeleletal disorders amongst them.

Conclusion

We found a correlation between the total exposure time of upper limb vibration and musculoskeletal disorders. Some specific syndromes could be characterised, such as supraspinatus tendinitis and non-specific shoulder musculoskeletal disorders, as has been found in 18% of forest workers on the right side and in 8% on the left side. Elbow musculosceletal disorders were found in a total of 18% of the forest workers on the right side.

Exposure to chain saw vibration seems to be risk factor for shoulder musculoskeletal disorders of shoulder, on the right hand side. Because vibration exposure occurs with forceful movements and repetition, vibration may be an indicator of both of these factors. Also, age is considered to be a confounding factor especially concerning shoulder musculoskeletal disorders, but it could not be confirmed in this study. Further efforts should be made to minimize the adverse effects of the vibration exposure of forest workers.

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Epidemiologic aspects of the exposure-response relationship in the hand-arm vibration syndrome

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Introduction

Prolonged exposure to hand-transmitted vibration from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the neurological, vascular and osteoarticular systems of the upper limbs. The complex of these disorders is called hand-arm vibration syndrome (HAVS). The vascular component of the HAVS is represented by a secondary form of Raynaud's phenomenon known as vibration-induced white finger (VWF); the neurological component is characterised by a peripheral, diffusely distributed neuropathy with predominant sensory impairment; the osteoarticular component includes degenerative changes in the bones and joints of the upper extremities, mainly in the wrists and elbows. An increased risk for upper limb muscle and tendon disorders, as well as for nerve trunk entrapment syndromes, has also been reported in workers who use hand-held vibrating tools. The vascular and osteoarticular disorders caused by hand-transmitted vibration are included in a European schedule of recognised occupational diseases (90/326/EEC). Several epidemiologic studies have been conducted to establish exposure-response relationships between hand-transmitted vibration and disorders of the upper extremities. The relation between white finger and vibration exposure has been extensively investigated, while there is a shortage of exposure and epidemiologic data for vibration-induced neurological and osteoarticular disorders.

Exposure-response relationships for disorders caused by vibrating tools

Neurological disorders

There is epidemiologic evidence for a greater occurrence of digital paraesthesias and numbness, deterioration of finger tactile perception, and loss of manipulative dexterity in occupational groups using vibrating tools than in control groups not exposed to hand-transmitted vibration (31). Epidemiologic surveys of vibration-exposed workers have shown that the prevalence of peripheral sensorineural disorders varies from a few percent to more than 80%, and that symptoms and signs of sensory loss can affect users of a wide range of tool types (15). Changes in finger tactile sensation have also been described in dentists and dental technicians exposed to high-frequency vibration (>1000 Hz) from high speed handpieces and ultrasonic scalers (23). Clinical and epidemiologic surveys have revealed an increase in aesthesiometric, thermal, or vibrotactile perception thresholds (VPT) of fingertips with the increase of daily vibration exposure, duration of exposure, or lifetime cumulative vibration dose (31, 33). On the basis of these findings, various authors have discussed the possible form of an exposure-response relationship for vibration-induced sensorineural disorders (13, 15, 34). In a cross-sectional study of 55 platers using grinders and chipping hammers and 54 assemblers using nut runners, Lundström et al. (24) observed an increased prevalence of sensorineural disturbances,

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staged according to the Stockholm scale (8), with the increase of individual vibration dose cumulated over the working lifetime. In a study of vibration-exposed workers at an engineering industry, the same authors reported a significant association between cumulative vibration dose and deterioration of the fingertip VPT (25), mainly in the frequency region mediated by activity from Pacinian corpuscles (63-500 Hz). In both studies, there was no clear relationship between the outcome and vibration dose on an individual basis, while a trend of increasing sensorineural impairment with the increase of vibration dose was observed on a group basis. The results of these investigations suggested a tentative proposal of exposure-response relationship in which symptoms and signs of sensorineural disorders are likely to appear earlier than vascular disorders, even though these latter seem to develop more rapidly after their onset (24). However, as pointed out by several investigators, the currently available epidemiological data are insufficient to outline the form of a possible exposure-response relationship for vibration-induced neuropathy owing to the unspecific character of the sensory disturbances, uncertainties about the clinical validity of the Stockholm scale, the cross-sectional design of most epidemiologic studies, as well as the confounding and/or modifying effects of some variables linked to individual characteristics (age, alcohol consumption, body constitution) and diseases affecting the peripheral nervous system (metabolic disorders, injuries of the cervical spine, polyneuropathies) (13).

Some cross-sectional and case-control studies have shown an increased occurrence of symptoms and signs of entrapment neuropathies, mainly carpal tunnel syndrome (CTS), in occupations involving the usage of vibrating tools (30, 31). CTS is also common in job categories whose work tasks involve high-force and repetitive hand wrist movements (18). The independent contribution of vibration exposure and physical work load (forceful gripping, heavy manual labour, wrist flexion and extension), as well as their interaction, in the etiopathogenesis of CTS have not yet been established in epidemiologic studies of workers handling vibratory tools. It has been suggested that ergonomic risk factors are likely to play the dominant role in the development of CTS (13). As a result, to date it is hard to draw a specific relation between CTS and exposure to hand-transmitted vibration.

Bone and joint disorders

Vibration-induced bone and joint disorders are a controversial matter. Various authors consider that disorders of bone and joints in the upper extremities of workers using hand-held vibrating tools are not specific in character but similar to those due to the ageing process and to heavy manual work (12). Early radiological investigations had revealed a high prevalence of bone vacuoles and cysts in the hands and wrists of vibration-exposed workers, but more recent studies have shown no significant increase with respect to control groups made up of manual workers (12, 15). An excess risk for wrist osteoarthrosis and elbow arthrosis and osteophytosis has been reported in coal miners, road construction workers and metal-working operators exposed to shocks and low frequency vibration of high magnitude from percussive tools (pick, riveting and chisel hammers, vibrating compressors) (15). On the contrary, there is little evidence for an increased prevalence of degenerative bone and joint disorders in the upper limbs of workers exposed to mid- or high-frequency vibration arising from chain saws or grinding machines. It is thought that, in addition to vibration, joint overload due to heavy physical effort, awkward postures, and other biomechanical factors can account for the higher occurrence of skeletal injuries found in the upper limbs of users of percussive tools (12). A constitutional susceptibility might also play a role in the etiopathogenesis of premature wrist and elbow osteoarthrosis. At present, there are no epidemiologic studies that may suggest, even tentatively, an exposure-response relation for bone and joint disorders in vibration-exposed workers.

Vascular disorders (white fingers)

VWF is recognised as an occupational disease in many industrialised countries. Epidemiologic studies have pointed out that the prevalence of VWF is very wide, from 0-5% in workers using vibratory tools in geographical areas with a warm climate (22) to 80-100% in workers exposed to high vibration magnitudes in northern countries (14, 32). In the general male population and control groups not exposed to hand-transmitted vibration, the prevalence of Raynaud's phenomenon or cold hypersensitivity in the fingers and hands has been reported to vary from 1.5 to 14% depending on racial and climatic differences, as well as on indoor/outdoor work conditions (27).

There is clinical and epidemiologic evidence that symptoms and signs of VWF may be reversible after the reduction or the cessation of vibration exposure (11, 21). The reversibility of VWF seems to be inversely related to age, duration of exposure and the severity of the disorder at the time the vibration exposure ceased (11).

The association between VWF and occupations involving work with vibrating tools has been clearly established in epidemiologic studies. Several investigators have reported data that indicate a trend for an increasing occurrence of VWF with the increase of the magnitude of hand-transmitted vibration, the duration of exposure, or various measures of cumulative vibration dose obtained from combining vibration magnitude (frequency-weighted or unweighted accelerations) and exposure time (years of tool usage or total working hours), (1, 14, 15, 28, 29). Despite the large number of studies published in the relevant literature, the form of the exposure-response relationship for VWF is not yet fully clarified. There are still several uncertainties connected with (a) the adoption of valid measures of vibration exposure (intensity and duration); (b) the choice of reliable clinical tests for an accurate diagnosis of VWF; (c) the possible healthy-worker effect and other selection biases associated with the cross-sectional design of most epidemiologic studies of VWF.

A relation between daily vibration exposure expressed as 4-hour energy-equivalent frequency-weighted rms acceleration ($a_{hw(eq,4h)}$) and years of vibration exposure before finger blanching (latency, T_F) for selected percentiles of an exposed population (C), was proposed in annex A to the International Standard ISO 5349, 1986 (20):

$$T_F=(9.5\ C^{1/2})/a_{hw(eq,4h)} \quad (y) \qquad [1]$$

It should be noted that the ISO proposal of exposure-response relationship was derived from a limited number of epidemiologic studies of occupational groups with high prevalence of VWF (at least 50%), short mean latencies (2-5.7 years) and exposure to high frequency-weighted accelerations (12-28 ms^{-2}). Subsequently, the basic model was used to predict the years of exposure required to produce finger blanching in 10%, 20%, 30%, 40%, and 50% of workers exposed to frequency-weighted accelerations in the range between 2 and 50 ms^{-2}. The ISO 5349 proposal of exposure-response relationship has been a matter of controversies in the last decade because of problems connected with the appropriateness of the ISO frequency-weighting curve to assess vascular effects, the lack of experimental and epidemiologic support for the daily time-dependency ("energy equivalence") adopted in the standard, and the reliability of the exposure and epidemiologic data used to construct the prediction model. Concern has also been expressed about the choice of VWF latency as a response variable as this outcome may be strongly subject to recall bias (3, 13). It has been debated that the mean latency takes into account only the exposure duration of the subjects affected with VWF, neglecting the overall vibration exposure accumulated by the worker group from which the cases of VWF arise. The findings of several epidemiologic studies have shown a poor agreement between the latencies and/or prevalences of VWF observed in various occupational groups and those predicted by the ISO 5349 model. Both overestimation and underestimation of the risk for VWF have been reported by investigators. Risk overestimation has mainly been found in worker groups using tools with a predominantly low frequency percussive action such as road breakers, rock drills and stone hammers (1, 2, 13, 32). Since the ISO frequency-weighting curve increases the importance of low-frequency vibration, it might be argued that the evaluation of such vibration according to the current standard does not reflect adequately the risk of vascular disorders. As suggested by the results of biodynamic studies, the ISO weighting method might be more appropriate for the assessment of other vibration-induced injuries such as bone and joint disorders in the upper limbs (16). Conversely, some other epidemiologic surveys have pointed out that the ISO weighting may underestimate the vascular effects of vibration containing high frequency components (13, 32). This seems to be consistent with the results of laboratory investigations which indicate that high-frequency vibration can induce a more powerful digital vasoconstriction than low-frequency vibration (4). A recent epidemiologic study has investigated the relation between alternative measures of vibration dose (derived from frequency-weighted or unweighted acceleration and duration of exposure) and the probability of occurrence of VWF in a total sample of 1557 vibration-exposed operators including dockyard workers, stone workers, and forestry workers (6). Preliminary findings from logistic regression analysis seem to suggest that when unweighted acceleration was included in the definition of vibration dose, the estimated regression models resulted in a better fitting when compared with those in which the measure of dose was expressed as total duration of exposure alone or in combination with frequency-weighted acceleration (Table 1). However, the current state of epidemiologic knowledge is still too limited to conclude that unweighted acceleration is a more representative measure of the risk for vibration-induced vascular disorders than the frequency-weighted acceleration defined in ISO 5349. It is likely that the pathophysiological responses of the various structures of the hand-arm system to vibration may depend, at a certain extent, on the frequency of the mechanical stimulus and, therefore, some frequency-weighting is required even though it may be different according to the various types of injury caused by hand-transmitted vibration. In addition to the magnitude, frequency, and duration of vibration, other exposure variables are believed to influence the development of VWF, and in particular vibration impulsiveness, direction of vibration, intermittence of exposure, work methods, contact force and posture have received attention (13, 17, 32). Current standards do not provide guidance on the possible vascular effects of such variables and there are very few epidemiologic studies that have investigated the contribution of these factors to the risk of VWF (32). These factors should be considered as additional sources of uncertainty for the comprehension of the relation between vibration exposure and finger blanching (16, 17).

There is some epidemiologic evidence that the introduction of preventive measures in the workplace for improving work conditions with vibrating tools has determined a reduction of the occurrence of VWF in some job categories, mainly in forestry workers (11, 21). The changes in the occurrence of VWF have been attributed to the use of antivibration chain saws and the adoption of administrative measures curtailing saw usage time and improving the organisation of forest work (11).

Table 1. Maximum likelihood logit estimation of the association between vibration-induced white finger (VWF) and alternative measures of vibration dose in a total sample of 1557 vibration-exposed workers including dockyard workers, stone workers, and forestry workers. Each measure of vibration dose was divided into five classes according to a quintile distribution and was included in the logistic models as a set of four dummy variables, assuming the lowest class as the reference category. The midpoint of each dose class and the prevalence of VWF in each class are shown. Age and smoking adjusted odds ratios (OR), 95% confidence intervals (CI), and the likelihood ratio (L-R) test for the measures of vibration dose are reported (from Bovenzi et al. (6)).

Dose definition	Dose classes					L-R test (χ^2,4df‡)
	1st (n=311)	2nd (n=311)	3rd (n=312)	4th (n=311)	5th (n=312)	
Σt_i (hours·10^2)	9	31	68	150	375	
VWF (%)	8.0	17.0	20.0	37.2	55.6	
OR (95% CI)	1.0 (-)	2.2 (1.3-3.6)	2.2 (1.3-3.6)	4.6 (2.8-7.6)	7.2 (4.4-11.9)	94.1*
$\Sigma a_{wi} t_i$ ($ms^{-2}h \cdot 10^3$)	6.5	23	50	127	415	
VWF (%)	10.0	15.1	22.5	33.0	58.2	
OR (95% CI)	1.0 (-)	1.2 (0.7-2.0)	2.0 (1.2-3.1)	2.9 (1.9-4.7)	6.6 (4.1-10.5)	106.2*
$\Sigma a_{wi}^2 t_i$ ($m^2s^{-4}h \cdot 10^4$)	4	14.5	42.5	183	735	
VWF(%)	10.3	21.2	26.4	29.2	51.8	
OR (95% CI)	1.0 (-)	1.7 (1.1-2.8)	2.3 (1.4-3.6)	2.9 (1.8-4.5)	5.0 (3.1-7.8)	65.3*
$\Sigma a_{wi}^4 t_i$ ($m^4s^{-8}h \cdot 10^6$)	1	6	71.5	661	3686	
VWF (%)	11.9	26.4	29.3	26.3	45.0	
OR (95% CI)	1.0 (-)	1.9 (1.2-3.0)	2.7 (1.8-4.3)	2.6 (1.7-4.2)	3.8 (2.5-5.9)	46.5*
$\Sigma a_{uwi} t_i$ ($ms^{-2}h \cdot 10^4$)	5.5	19	41.5	92.5	256	
VWF (%)	8.7	14.4	23.2	32.4	60.1	
OR (95% CI)	1.0 (-)	1.4 (0.9-2.4)	2.4 (1.5-3.9)	3.4 (2.1-5.5)	8.4 (5.1-13.8)	115.1*
$\Sigma a_{uwi}^2 t_i$ ($m^2s^{-4}h \cdot 10^6$)	3	11.5	27.5	75.5	249	
VWF (%)	10.3	16.8	23.3	29.4	59.0	
OR (95% C I)	1.0 (-)	1.4 (0.9-2.3)	2.0 (1.2-3.2)	2.6 (1.6-4.0)	6.5 (4.1-10.3)	100.2*
$\Sigma a_{uwi}^4 t_i$ ($m^4s^{-8}h \cdot 10^{10}$)	1	4.5	18	77	274	
VWF(%)	12.9	24.6	18.0	27.2	56.0	
OR (95% CI)	1.0 (-)	1.6 (1.0-2.5)	1.3 (0.8-2.1)	2.3 (1.5-3.5)	4.6 (3.0-7.1)	72.8*

awi=frequency-weighted rms acceleration of tool i; auwi=unweighted rms acceleration of tool i; ti=total time spent using tool i (h). *p<0.001, ‡df=degrees of freedom. Hosmer-Lemeshow test for the goodness of fit of the logistic models (χ^2, 8 df): range=3.6 (p=0.89) -11.8 (p=0.16)

An overview of the available epidemiologic literature seems to indicate a tendency towards a decrease in the occurrence of VWF in the last decade, at least among occupational groups who started to work with vibrating tools of new generation (3, 27). Even though the magnitude of the reduction of VWF risk cannot be precisely estimated, there are reasons to believe that the exposure-response relationship proposed by ISO 5349 in 1986 needs to be updated as it was derived from investigations carried out from 1946 to 1978. It may be supposed that the findings reported in those studies are not representative of the exposure and health conditions associated with current work with vibrating tools.

A revision of the standard ISO 5349, annex A included, is currently in preparation in an ad hoc ISO subcommittee (ISO/TC 108/SC 4/WG 3). In the revised ISO annex, the exposure-response relationship is restricted to a 10% prevalence of VWF and the probability of developing finger blanching symptoms in such a percentage of exposed workers is modelled as a function of the 8-hour energy-equivalent frequency-weighted acceleration sum, $a_{hv(eq,8h)}$ (or $A(8)$) in ms^{-2}, and the group mean total (lifetime) exposure duration, D_y in years. The new proposal of ISO exposure-response relationship is very similar to that derived from the results of a recent epidemiologic study of forestry workers in which the following power relation could be estimated (3):

$$VWF=0.354\ (A(8))^{1.05}\ (D_y)^{1.07} \qquad (\%) \qquad [2]$$

The fitted model indicates that the expected percentage of workers affected with VWF will vary roughly linearly with either $A(8)$ (with D_y unchanged) or total exposure duration (with equivalent acceleration unchanged). The findings of this study, therefore, suggests a relatively simple exposure-response relationship such that, if the vibration magnitude is doubled, a halving of the years of exposure is required to produce the same effect. It should be noted that this prediction model is restricted to specific exposure conditions (chain saw work) and the extrapolation to different occupational groups may not reflect the actual risk of adverse health effects arising from other types of vibration exposure. For instance, the findings of an epidemiologic study of operators using percussive stone-working tools suggested an exposure-response relationship in which the expected occurrence of VWF tended to increase roughly in proportion to the square root of $A(8)$ (for a particular exposure period) or in proportion to the square root of the duration of exposure (for a vibration of constant magnitude) (2):

$$VWF=2.792\ (A(8))^{0.47}\ (D_y)^{0.53} \qquad (\%) \qquad [3]$$

Thus, the two studies suggest the same time-dependency for the risk of VWF, but the magnitude of the effect for the same vibration exposure (intensity and duration) is different when the predicted prevalence of VWF in the stone workers is compared to that estimated in the forestry workers. This may be due to differences in the exposure conditions between the two groups. Such differences might be connected with the physical characteristics of vibration (tools with dominant low- or high-frequency vibration, tools producing shock-type vibration), the work method (extent of the push and grip forces exerted on tool handles), and the pattern of daily exposure (continuous or intermittent work, short or long break periods). Moreover, the current ISO 5349 frequency-weighting curve implies that the adverse health effects of hand-transmitted vibration decrease with the increase of the frequency of vibration, but this assumption may be inappropriate for certain types of vibration. The application of different frequency-weighting methods to vibration generated by specific tool types should be considered, at the least for the assessment of vibration-induced vascular disorders (17).

Other possible vibration-induced disorders

A few clinical and epidemiologic studies have reported that exposure to hand-transmitted vibration can decrease muscular strength in the hands and arms (10), aggravate the risk of noise-induced hearing loss (19), and provoke disturbances of the central nervous system (26). To date, no exposure-response relationship can be derived from the findings of the studies which have investigated these disorders in occupational groups operating vibratory tools.

Epidemiologic evidence for vibration limits

Even though a reliable exposure-response relationship is an important requirement for the definition of vibration limits, nevertheless the current inaccuracies in the relation between hand-transmitted vibration and its effects should not impede providision of guidance to restrict hazardous vibration exposures at the workplace in order to guarantee the health and safety protection of workers. The Commission of the European Union (EUC) has recently suggested exposure levels for hand-transmitted vibration within a proposed directive for the protection of workers from the risks arising from physical agents (9). In the proposal of EU directive, the exposure levels are expressed in terms of $A(8)$, and the threshold level is established at 1 ms^{-2}, the action level at 2.5 ms^{-2}, and the exposure limit value at 5 ms^{-2}. Specific provisions are indicated for exposure values above the threshold level, which is defined as "the exposure value below which continuous and/or repetitive exposure has no adverse effect on health and safety of workers". The suitability of these exposure levels was evaluated in an epidemiologic study of eight vibration-exposed worker groups (total sample=822) with observed prevalence of VWF varying from 7.4% (construction workers) to 51.6% (foundry workers), (5).

Table 2. Prevalence of vibration-induced white finger (VWF) in a total sample of 822 users of vibrating tools according to daily vibration exposure expressed in terms of 8-hour energy-equivalent frequency-weighted acceleration ($A(8)$ in ms^{-2}). The vibration-exposed worker population includes grinders (n=100, VWF=9%), shipyard workers (n=132, VWF=12.1%), caulkers (n=65, VWF=23.1%), mechanics (n=140, VWF=15%), construction workers (n=148, VWF=7.4%), quarry drillers (n=41, VWF=36.6%), foundry workers (n=31, VWF=51.6%), and forestry workers (n=165, VWF=23%). The controls are represented by manual workers not exposed to hand-transmitted vibration. VWF is given as numbers (%). Prevalence ratios (PR) and 95% confidence intervals (95% CI) are adjusted for age, smoking and drinking habits (from Bovenzi (5)).

		A (8) according to the EUC levels (ms^{-2})			
	Controls (n=455)	≤1.0 (n=82)	1.0-2.5 (n=316)	2.5-5.0 (n=313)	>5.0 (n=111)
VWF*	5 (1.1)	2 (2.4)	35 (11.1)	65 (19.5)	43 (38.7)
PR_1	1.0	2.1	9.5	16.1	32.3
(95% CI)	-	(0.4-10.8)	(3.7-24.3)	(6.7-41.5)	(12.8-81.9)
PR_2	-	1.0	4.5	7.9	15.5
(95% CI)	-	-	(1.1-18.9)	(1.9-32.5)	(3.7-64.1)

*Raynaud's phenomenon in the controls

PR_1, reference category: controls

PR_2, reference category: A(8) ≤1.0 ms^{-2}

After adjustment for age and smoking habit, the prevalence of VWF was found to be significantly associated with the EUC vibration exposure levels. It is noteworthy that the prevalence of white fingers in the category of workers with $A(8)$ ≤1 ms^{-2} (2.4%) was similar to and not significantly different from that observed in a control group of 455 manual workers (1.1%). The point estimate of VWF prevalence was 11% for *A*(8) between 1 and 2.5 ms^{-2}, 20% for *A*(8) between 2.5 and 5 ms^{-2}, and 39% for *A*(8) >5 ms^{-2}, i.e. approximately a twofold increase in prevalence with each increment of vibration exposure level. A cold test was also performed in the vibration exposed workers and the results of cold provocation were expressed as the change in finger systolic blood pressure at 10°C as a percentage of the pressure at 30°C ($FSBP\%_{10°}$), (Table 3). A significant pattern of decreasing $FSBP\%_{10°}$ with increasing levels of *A*(8) was observed in the vibration exposed workers. The occurrence of the closing phenomenon in the digital arteries during finger cooling to 10°C (i.e. $FSBP\%_{10°}=0$) was found to increase with the increase of daily vibration exposure (p<0.001).

Table 3. Finger systolic blood pressure at 10°C as a percentage of the pressure at 30°C ($FSBP\%_{10°}$) in a total sample of 822 users of vibrating tools according to daily vibration exposure (*A*(8) in ms^{-2}). Values are given as means (SD). The number (%) of workers showing the closing phenomenon in the digital arteries at 10°C (zero systolic blood pressure, FSBP(0)) is also reported (from Bovenzi (5)).

	A(8) according to the EUC levels (ms^{-2})			
	≤1.0 (n=82)	1.0-2.5 (n=316)	2.5-5.0 (n=313)	>5.0 (n=111)
$FSBP\%_{10°}$ (%)	86.6 (18.9)	84.5 (27.5)	74.2 (31.1)	61.9 (38.2)*
FSBP(0) (n)	1 (1.2)	17 (5.4)	28 (8.9)	23 (20.7)†

F test: *p<0.001; χ^2 test for trend: †p<0.001

The clinical and epidemiologic findings of this study seem to suggest that the EU exposure levels are sufficiently representative of the current risk of vascular disorders in occupational groups with various patterns of exposure to hand-transmitted vibration. This conclusion is also confirmed by the results of the previously mentioned study of forestry workers (3). Table 4 reports the number of years of vibration exposure that are expected to cause VWF in selected percentiles of the forestry worker population according to the EU exposure levels.

Table 4. Number of years of exposure for the onset of VWF in various percentages of forestry workers according to the vibration exposure levels of the directive for physical agents proposed by the Commission of the European Union (EUC). Years of vibration exposure before VWF were estimated by equation [2], (from Bovenzi et al. (3)).

EUC level	$A(8)$ (ms^{-2})	Percentage of forestry workers affected with VWF				
		10	20	30	40	50
Threshold	1	22.5	42.9	>45.0	>45.0	>45.0
Action	2.5	9.2	17.5	25.5	33.3	41.1
Exposure limit value	5	4.6	8.9	12.9	16.9	20.8

The estimated magnitude of the risk of VWF among workers exposed to $A(8)$ of 5 ms^{-2} indicates that the exposure limit value proposed by the EU directive is not too conservative.

Conclusion

This paper has reviewed the current state of epidemiologic knowledge about the relation between exposure to hand-transmitted vibration and disorders of the hand-arm system. The exposure-response relationship included in ISO 5349 is thought to cover *all* biological effects of hand-transmitted vibration. Actually, this review points out that to date the available epidemiologic data are insufficient to outline an exposure-response relationship for both sensorineural disturbances and bone and joint disorders caused by hand-transmitted vibration. The association between white finger and exposure to hand-transmitted has been clearly established in both cross-sectional and longitudinal studies of workers operating a great variety of power tools. The form of the relation between vibration exposure and VWF is not yet fully understood. Some uncertainties concern the relative importance of different vibration frequencies to produce adverse health effects in the hand and arm. The results of various epidemiologic studies seem to indicate that the current ISO frequency-weighting may be unsuitable for all types of vibration and for all kinds of vibration injury. Alternative exposure-response relations for VWF have been suggested in recent epidemiologic studies. Further biodynamic and physiological research is required to determine how the response of the hand and arm depends on the physical characteristics of vibration (frequency, magnitude, direction) and other relevant variables connected with vibration exposure (contact force, posture). Epidemiologic studies are essential to investigate the contribution of exposure duration, cumulative exposure indices, and some environmental and individual variables to the development of the chronic disorders produced by occupational usage of vibrating tools. The epidemiologic information used to construct current exposure-response relationships for vibration-induced injuries is primarily derived from cross-sectional studies. It is recognised that the cross-sectional design may suffer from many shortcomings as it is subject to several sources of bias. Future epidemiologic research should be based on prospective cohort studies because the design characteristics of such studies permit the study of cause-effect relationships and the formulation of aetiologic hypotheses. Surveillance programs including exposure and medical monitoring of occupational groups exposed to hand-transmitted vibration could be practical applications of the prospective cohort design.

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A follow up study on the consequences of VWF patients in the workers using chain saws.

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Introduction

There is still some debate as to whether or not vibration induced white finger (VWF) is reversible. However, there were a small number of observational studies which have presented the relationship between vibration exposure, severity of VWF and reversibility of VWF. Earlier studies had suggested that stage 3 of VWF was irreversible, and this may prove to be correct (1,2). The authors carried out 14 years of follow up studies of VWF from the time the use of chain saws ceased (3,4). According to those studies the reversibility of VWF depended on its severity. The current status of those subjects who had been affected by VWF was observed to clarify the changes in VWF at more than 20 years after the use of chain saws had ceased.

Methods

A total of 496 workers (31.3% of the total number of chain saw operators) who were affected by VWF during the period 1955-82 were followed up to observe the consequences of VWF. These subjects were selected from a total of 1,586 chain saw operators who had used a chain saw as a professional operator during some of the years from 1955-82 in the state forest of Kyushu Island, Japan. VWF and other consequences were certified by asking each person to complete a questionnaire. Answers were verified by comparing them with inquiries and medical records made by the regional forest office and with the results of compulsory annual medical examinations conducted by physicians beginning in 1965. The work history of the subjects was confirmed by examining routine production records kept by the regional forest office. In 1997 the authors had verified the current status and the course of VWF in 496 workers by direct interviews (a small number by mail). A life table Product Limit method analysis of the VWF prevalence was carried out to describe the consequences of VWF from the time the use of chain saws ceased. For each worker it was determined whether or not VWF had disappeared. The observation time then ran from the starting time to the date of disapperance or, if VWF did not disappear, to the end of the corresponding follow up period. The statistical significance of the percentage prevalence curves was assessed by the difference in the chi-squared goodness of fit statistic using the Mantel-Haenzel procedure. Furthermore, a case-control study was undertaken to evaluate some factors affecting the prognosis of VWF. The case group consisted of 35 workers who had had severe VWF and whose VWF remained at the same severe stage at the time of examination in 1977 after the use of chain saws had ceased, and the control group was 35 members who had had severe VWF but whose VWF had disappeared by 1977. The difference of prevalence of the related factors between the two groups was evaluated using the chi-squared test.

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Results

Out of a total of 496 workers it was possible to follow 488 workers (98.4%) to ascertain their current states. Four-hundred eighty one (96.6%) workers had retired from national forest work and 124 workers (25.4%) had died by the beginning of 1997.

Table 1 shows the cause-specific standard mortality ratio (SMR) in the death cases from 1975 to 1996. The difference in SMRs for all causes of death was not shown. Significantly higher SMRs in the patients with VWF were found for leukemia, including lymphatic neoplasma and suicides, while the SMR for cerebrovascular diseases and diseases of heart were not different from the controls.

Table 1. Cause-specific standardised mortality ratio in the patients with VWF.
Underlying causes of death: 1975-1996.

causes of death	observed number	expected number	SMR	(95% C.I.)
All causes of death	198	199.7	99.2	(86.3 - 114.0)
1. Malignant neoplasmas	75	67.7	110.8	(88.3 - 138.9)
1) Stomach	8	13.5	59.4	(29.7 - 118.8)
2) Liver	13	12.7	102.4	(59.5 - 176.4)
3) Trachea . Bronchi & Lung	13	13.2	98.8	(57.4 - 170.1)
4) Oesophagus	7	3.4	205.9	(98.1 - 431.9)
5) Colon	2	2.5	79.1	(19.8 - 316.1)
6) Pancreas	6	4.1	148.1	(66.6 - 329.8)
7) Blood & Lymph	9	1.9	476.2	(247.8 - 915.2)**
2. Cerebrovascular diseases	24	26.6	90.4	(60.6 - 134.8)
3. Diseases of heart	33	33.0	100	(71.1 - 140.7)
4. Pneumonia	18	10.7	169.0	(106.5 - 268.3)*
5. Liver diseases	11	9.8	112.4	(62.2 - 202.9)
6. Accident , Poisoning and suicide	15	14.6	102.6	(61.9 - 170.2)
1) Death from drowning	3	1.6	184.0	(59.4 - 170.2)
2) Asphyxia	9	3.3	269.5	(140.2 - 517.9)*

The rate of prevalence of VWF fell continuously after the use of chain saws ceased, from 31.3% to a final value of 18.8% after more than 20 years observation. The changes of the Stockholm Workshop Scale from the time the use of chain saws stopped to the last observation period are shown in Table 2.

Table 2. Change in severity of VWF during study period.
(Stockholm Workshop Scale)

	the time the use of chain saws stopped (1955-1982)		the latest observation period (1982-1997)		at the beginning of 1997 (except death cases)
VWF 0	1 122	(70.7%)	1 288	(81.2)	unknown
1	28	(1.8)	54	(3.4)	51
2	325	(20.5)	184	(11.6)	146
3	111	(7.0)	60	(3.8)	44

Figure 1 shows the changes in prevalence of VWF from the time that exposure to vibration ceased for different levels of severity of VWF at the point when the use of chain saws ended. It was observed that the percentage prevalence depended significantly on the severity: 12.8% for the cases with stage 3 and 40.3% of those with stage 1-2 had disappeared after 25 years observation. Among stage 1-2 of VWF cases, 6% disappeared during the period of chain saw operating, 56% had disappeared within 5 years after cessation of vibration exposure, and a further 9% had disappeared by 15 years from time of cessation. On the other hand, among stage 3 of VWF cases, no case disappeared during the chain saw operation period. Only 17% disappeared within 5 years after cessation of vibration exposure, and 35% had disappeared after 15 years from time of cessation. The time course of the recovery rate of VWF differed between moderate VWF cases and severe ones.

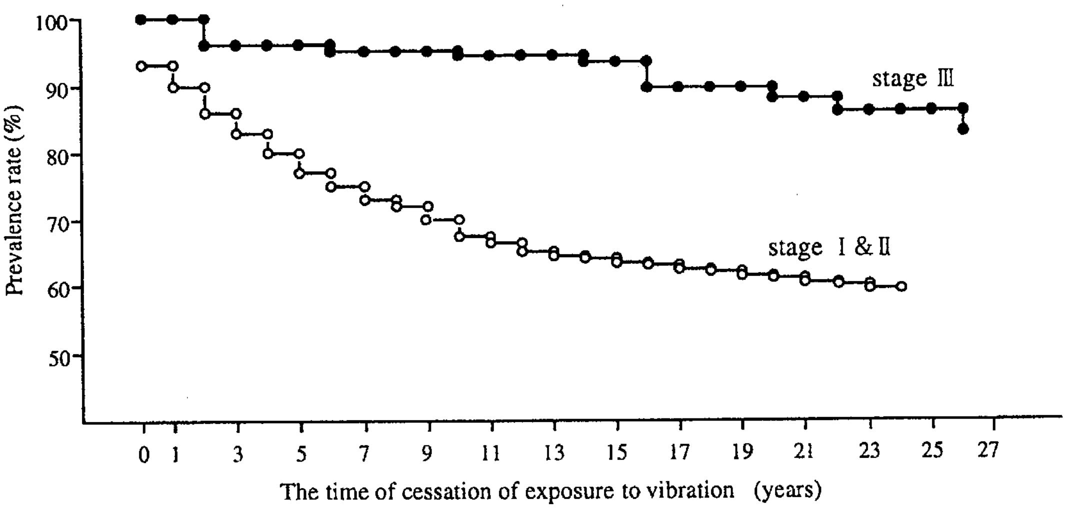

Figure 1. Prevalence of VWF from time exposure to vibration ceased by VWF severity.

Table 3 shows the course of VWF at the latest observation period from 1982 to 1997. Of all the subjects who had been affected by VWF, 47.0% showed improvement, 46.3% were unchanged, and 6.7% were aggravated at the latest observation period.

Table 3. Change in severity of VWF at the latest observation period

VWF 1	improvement	49	(16.4%)	ù
	unchanged	5	(1.7)	ú 54 (18.1)
	aggravated	0		û
VWF 2	improvement	90	(30.2)	ù
	unchanged	88	(29.5)	ú184 (61.7)
	aggravated	6	(2.0)	û
VWF 3	improvement	1	(0.4)	ù
	unchanged	45	(15.1)	ú 60 (20.2)
	aggravated	14	(4.7)	û

It was noteworthy that 60 (3.8% of the total subjects) severe cases of VWF remained even 20 years after the use of chain saw had ceased.

Figure 2 shows the prevalence rate of VWF from the time of cessation of exposure to vibration according to the cohort group for time when chain saw use was begun. There was a tendency that the prevalence among those who began chain saw use before 1960 was larger than that after 1965. This result suggests that the dose of vibration exposure effects the VWF prognosis.

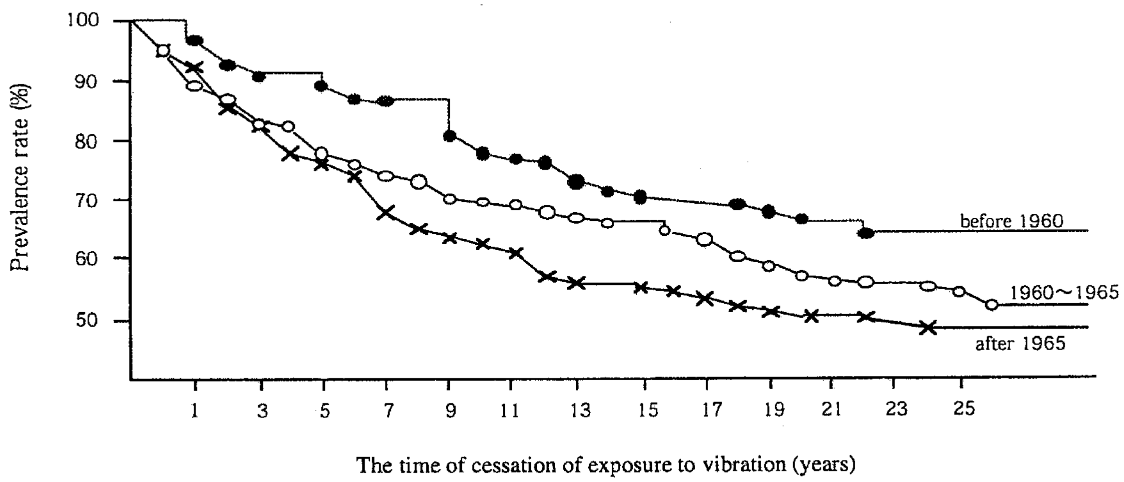

Figure 2. The prevalence rate of VWF from time exposure to vibration ceased accord to the cohort group for time when chain saw use was begun.

Table 4 shows the results of a case control study. There were no significant differences except for the time of the beginning of exposure, which is the same as results seen in figure 2. There were no differences in the duration of exposure, exposure period after the onset of exposure, history of smoking and alcohol drinking and clinical complication such as hypertension, as shown in Table 4.

Table 4. Frequency of exposure and related histories between case and control group.

	case		control	
Beginning of exposure (before 1960)	13	(37.1%)*	7	(20.0)
Duration of exposure (>9 years)	13	(37.1)	10	(28.6)
Exposure period after the onset of VWF (>6 years)	8	(22.9)	9	(25.7)
Age when the VWF occurred (>50 years)	5	(14.3)	7	(20.0)
Smoking (>20 cigarettes)	11	(31.4)	12	(34.3)
Alcohol consumption (everyday)	18	(51.4)	14	(40.0)
Complication (Hypertension etc)	7	(20.0)	6	(17.1)

*p< 0.1 compared with control group

Discussion

Earlier studies had suggested that stage 3 of VWF was irreversible and this may still be correct, but there is still some debate as to whether or not earlier stages of VWF are reversible. Agate reported that in 36% of workers who already had VWF, the vascular disturbances appeared to have progressed rather than to have improved after the cessation of work (5). Jepson reported that there was no abatement once symptoms occur even after stopping work with vibrating tools (6). Stewart and Goda observed that five years after work involving exposure to vibration ceased, 30% of the workers no longer experienced attacks of VWF (7). Among forestry workers using chain saws in Sweden, a six year follow up showed that prevalence of VWF had decreased from 48% to 38% (8). In England, a similar study indicated improvement among forestry workers in 1975 (9). Pyykkö et al. observed that in 1972, 40% of the lumberjacks in one forestry district had VWF, but in 1980 the prevalence had decreased to 5%. They suggested that the recovery period was similar to the latent interval (10).

In the present study the authors confirm that the reversibility of VWF seems to depend on its severity. A fairly large number of stage 3 cases of VWF are irreversible and continue to experience almost the same white finger symptoms more than 20 years after the use of chain saws ceased. The reversibility seems not to be affected by age related factors, smoking habits or by environmental factors such as cold exposure. On the other hand, in more than half of those who recovered, VWF had disappeared within 5 years after the use of chain saws had ceased, whereas only 5% of the recovered cases disappeared more than 15 years after the cessation of exposure to vibration. The time course of the recovery rate of VWF was very different among moderate cases of VWF and severe ones as shown in figure 1. We conducted pathophysiological examinations in 13 cases of severe stage VWF. Twelve cases showed peripheral neuropathies in the upper extremities and cervical spondylosis deformans (C3-7) was clearly found in 7 cases. Also, 7 cases showed suspected sympathetic disturbances in the peripheral circulation according to the Laser-Doppler blood flow meter. Carpal tunnel syndrome was found in one case and collagen disease (anti-centromere antibody 640 positive) was found in one case. In any case, the reason why severe stage VWF is irreversible remains unclear, and further pathophysiological studies will be needed to clarify this question.

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Vibration syndrome among Swedish workers: a follow-up study from 1989-1995

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Introduction

It is well known that the use of hand-held vibrating tools can cause circulatory disturbances resulting in white fingers and neurological disturbances such as carpal tunnel syndrome and peripheral neuropathy in hand/fingers (1). In spite of increasing knowledge about risk factors resulting in protective measures and improved equipment, this patient group is still a significantly large proportion of those referred to the Department of Occupational Health. Several studies have previously shown that by minimising continued exposure to vibration, the development of injuries might be arrested and in some cases the symptoms improved, even if it can take several years (2,3,4). Operative decompression of the median nerve in the case of carpal tunnel syndrome can reduce the symptoms (5). According to this, we have worked out a policy at the Department of Occupational Health which we have followed for several years. When only vibration-related white fingers are diagnosed, the patient is recommended to minimise the exposure to vibrating tools and terminate the use of nicotine (cigarettes, snuff). If carpal tunnel syndrome (here defined as symptoms in the median nerve and/or nocturnal paraesthesiae, a neurophysiological involvement of the median nerve and a nonobligat Tinel sign or a positive Phalen’s test to support the diagnosis) or other neurological disturbances in the hands are diagnosed, the patient is recommended to discontinue using vibrating tools even if this means a change of job. If carpal tunnel syndrome is diagnosed, the patient is also referred to a hand surgeon to discuss whether or not an operation can improve the symptoms. The patient is informed about the results of the examinations with diagnoses and recommendations (both oral as well as written) for how to avoid further damage. This information is also given to the patient’s ordinary doctor as well as to the social insurance office. After that we usually cease contact with the patient. Over the years a number of patients have returned to our clinic some years later with progressive deterioration of their symptoms. It has then become evident that they have continued to work with vibrating tools to the same extent as before the diagnosis and have not been able to follow our recommendations.

The purpose of this investigation was to study (i) if the subjects had followed the recommendation to reduce or stop vibration exposure (ii) the progression of symptoms and functional disturbances in relation to continued or ceased work with vibrating tools and (iii) what type of support is needed in connection with diagnosis to make the prognosis as good as possible.

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Methods

The study was initiated with a questionnaire about vibration exposure and symptoms, sent out to all 79 patients that were diagnosed during 1989 for vibration syndrome with white fingers and/or neurological disturbances at the Department of Occupational Medicine at Huddinge Hospital. Of these patients ,(all male), three were deceased, six had changed address and could not be reached and four did not answer. Of the 66 (84%) that answered, 37 still worked with hand-held vibrating tools and 28 described symptoms with white fingers and/or numbness. 49 of the 66 that answered (29 still working with hand-held tools) reported their interest in a follow-up examination. Among the 17 not interested in this follow-up, two reported working with vibrating tools and symptoms of white fingers. Of the 15 unexposed subjects, 13 reported symptoms of white fingers and/or numbness. An invitation to this follow-up examination was sent out to all the 49 who had earlier reported interest in a follow-up examination, the four that did not answer the questionnaire and one that could not be reached earlier but now had moved back to Stockholm. 14 subjects in the first group (six still exposed to vibrating tools, of whom five reported symptoms of white fingers and/or numbness) changed their mind due to difficulty getting time off from work or due to medical reasons not connected to vibration exposure. Three out of the four in the second group were not interested in participating in this follow-up study. A total of 37 out of the 79 patients (46%) that were diagnosed in 1989 for vibration syndrome were still interested in a follow-up examination by a clinician, which was performed in 1995 at the Department of Occupational Health. The patients were asked about their present symptoms in the hands in comparison with earlier symptoms and compared to earlier documentation in the journal from the previous examination. Vibration exposure, as well as nicotine habits were explored in detail for the time after the previous examination 1989. A physical examination was performed including, for instance, Tinel’s and Phalen’s test, grip force, sensitivity, reflexes, palpation of hand arteries and general blood pressure. This was followed by a repeated neurophysiological examination including temperature thresholds (6) and vibrotactile sense (7) in 35 subjects (two declined for personal reasons). For those who did not already have the diagnosis of white fingers, a cold provocation test was planned (8). All subjects were interviewed by a social therapist to reveal the effect that the vibration diagnosis had on the patient’s professional and social life, and whether or not changes had been implemented following the diagnosis and the recommendations given as a consequence thereof.

Results

Exposure

The interview revealed that 12 of 37 subjects (32%) had followed the recommendation and discontinued working with hand-held vibrating tools in connection with the first examination 1989. Eight subjects (22%) had reduced the exposure for vibrating tools to at least half the time within three years after the diagnosis. Five subjects (14%) continued working with vibrating tools 4-5 years after the diagnosis (to the same extent as before the diagnosis) and then ceased vibration exposure, i.e. 1-2 years before follow-up. As many as 12 (32%) were still working with hand-held vibrating tools to the same extent that had caused disturbances earlier. In the following tables all subjects with at least four years of unchanged continued vibration exposure after diagnosis are considered to have a continued exposure (5+12subjects=46%).

Table 1. Number of subjects with an impairment in hand nerve symptoms (numbness), hand status and in the result of neurophysiological examination (carpal tunnel, temperature thresholds and vibrotactile sense) 1995 compared to 1989 in correlation to vibration exposure.

Vibration exposure	Total number of subjects	Numbness	Status	Carpal tunnel	Temp. thresholds	Vibrotactile sense
Continued	17	7	13	9	13	4
Decreased	8	3	3	3	6	1
Ceased	12	0	2	4	4	4

Nicotine use

At this follow-up 21 of the subjects admitted regular use of nicotine by smoking cigarettes, using snuff or both. Three subjects had followed the recommendation and stopped smoking at the time of the diagnosis, but one of these had started smoking again one year later. Eight subjects had stopped using nicotine before 1989. Six subjects had never used nicotine.

Neurological symptoms

At the time of this follow-up ten subjects reported increased numbness at room temperature (Table 1) and six subjects reported unchanged symptoms. Four subjects reported improved symptoms and 17 claimed that they never had experienced any numbness or sensorineural symptoms in the fingers. No correlation was seen between nicotine use and the degree of neurological symptoms in the hands.

Physical examination

As shown in Table 1, the status of the hands had became worse in 18 subjects compared to the examination 1989, i.e. in 13 with a continued exposure, in three with decreased exposure and in two with ceased exposure to vibrating tools. The status had improved in four cases (Table 2), all in the group that had ceased vibration exposure in connection with the first examination 1989. In the remaining 18 subjects, the status was pathological and unchanged compared to 1989, whereas four subjects still had no objective pathological signs (two with continued exposure, one with decreased and one with ceased exposure).

Neurophysiological examination

At the time of this follow-up, signs of previously unknown median nerve involvement in the carpal tunnel was discovered in 16 subjects (Table 1). In nine of these subjects no sign of median nerve involvement was seen in 1989, whereas the other seven had not undergone a neurophysiological examination previously. In five subjects the result showed the same grade of disturbance now at this follow-up in 1995 as compared to 1989. In 12 of the 16 subjects with a newly diagnosed median nerve involvement and in three out of the five subjects with unchanged disturbance, pathological temperature thresholds were seen in fingers, hands and feet. Five subjects with a newly diagnosed median nerve involvement fulfilled the criteria for carpal tunnel syndrome as described in “Introduction” (four with continued exposure and 1 with decreased exposure) and all five also had pathological temperature thresholds at all levels. In two subjects an improvement of previously diagnosed carpal tunnel syndrome was seen, in one subject who had an operation had continued exposure and in one unoperated subject that had ceased exposure to vibration (Table 2).

Table 2. Number of subjects with an improvement in hand nerve symptoms (numbness), hand status and in the result of neurophysiological examination (carpal tunnel, temperature thresholds and vibrotactile sense) 1995 compared to 1989 in correlation to vibration exposure.

Vibration exposure	Total number of subjects	Numbness	Status	Carpal tunnel	Temp. thresholds	Vibrotactile sense
Continued	17	1	0	1	0	3
Decreased	8	1	0	0	0	1
Ceased	12	2	4	1	2	1

The neurophysiological examination also showed disturbances in small and large nerve fibers. In 17 subjects a small fiber polyneuropathy was diagnosed, in nine subjects signs of both small fiber as well as large fiber polyneuropathy were diagnosed and in five subjects only signs of large fiber polyneuropathy were diagnosed. The temperature thresholds, mediated in small nerve fibers, were impaired in 23 subjects, of whom 17 subjects showed disturbances in both fingers and hands and all but one of these also showed disturbances in the feet. Five subjects showed increased temperature thresholds in the fingers only, one subject showed pathological values for the hands only and all of these also showed pathological thresholds in the feet. The temperature thresholds were unchanged in three subjects and were still pathological for fingers, hands and feet. In two subjects that had ceased vibration exposure the temperature thresholds had improved and were now normal in fingers and hands. The vibrotactile sense, mediated in large nerve fibers, was impaired in nine subjects, unchanged pathological in two subjects and had improved in five subjects , of whom two subjects now showed normal values at all levels (Table 1 and 2). No subject showed a perfectly normal result of the neurophysiological examination. No correlation could be seen between nicotine use and result of neurophysiological examination.

Circulatory symptoms

In 32 out of 37 subjects white fingers were already diagnosed in 1989. Most of them reported unchanged or subjective impairment of symptoms at the time of this follow-up. Only five subjects reported an improvement of the symptoms (Table 3). No correlation was seen between nicotine use and the degree of circulatory symptoms in the hands. Five subjects had a normal cold provocation test in 1989, of whom four still reported no white fingers and no increased cold sensitivity.

Cold provocation test

One subject that had a normal cold provocation test in 1989 and reported unchanged cold sensitivity now showed a pathological test result . Three out of the four subjects with a normal test in 1989 declined a repeated cold provocation test. The one that accepted a repeated test showed a circulatory disturbance in the fingers with a cold related fall in finger blood pressure. All these four were nicotine users.

Table 3. Reported symptoms of VWF 1995 compared to 1989 in correlation to vibration exposure.

Vibration exposure	Total number of subjects	Improved	Impaired	Stationary	No symptoms
Continued	17	0	8	5	4
Decreased	8	1	4	3	0
Ceased	12	4	3	5	0

Social therapist interview

20 out of 37 patients had changed something in their work-situation due to the work-related injury either in connection with the diagnosis 1989 or within three years. Most of them still worked for the same employer but had changed their area of work and had new tasks and several had gone over to indoor work, seven had changed work completely. Fear of loosing their job resulting in unemployment or getting a dull job with less pay were reasons why some did not try to change the work situation. Difficulty in accepting the risk with continued exposure to vibration, since the impairment develops slowly and difficulty predicting the outcome of the injury, were reasons why so many continued to work to the same extent with hand-held vibrating tools after the diagnosis. These fears, however, did not come true for those who managed to change assignment. No one became unemployed due to the diagnosis. Twelve thought that the change had resulted in more interesting work and only one thought that the new work was dull and more stressful. Seven got a better salary and only for two had the change resulted in less pay. Many of these would not admit that the change was due to the diagnosis and they would rather say that they took the opportunity to change assignments when there was a change in the organisation at work. Most subjects (12 out of 20 subjects) that had minimised or ceased the exposure to vibration reported support from the doctor associated with the firm and all but one was satisfied with this support. The employer was involved in the change of work task for 12 subjects and 75% were satisfied with the support received. The social insurance office was involved in the change for two subjects, who were satisfied with this. In seven cases the subjects succeeded in changing job without any support. In eight cases the trade union and in two cases the general practitioner were involved in the change. Of those that continued their exposure to vibration, nine had had contact with their employer, the doctor associated with the firm or someone else resulting in no change, maybe because the subject himself did not see any need for a change. All but one of the eight subjects still working with vibrating tools to the same extent as before diagnosis did not want to change work assignment. Only one had started to look for a new job but was not interested in any support.

Discussion

To continue working with hand-held vibrating tools after the diagnosis of vibration syndrome results in the development of new, and a progression of existing symptoms, as well as increased disturbances in neurological function and hand circulation. Many had developed neurophysiological signs of median nerve involvement, as in carpal tunnel syndrome, but considerably fewer had a manifest carpal tunnel syndrome. This strengthens the suggestion that median nerve involvement may result from the vibration-induced injury and not only from compression, and this is probably one of the reasons why not all become symptom-free after operation with decompression of the median nerve in the carpal tunnel (9,10). The most common disturbance seen with neurophysiological examination was increased temperature thresholds in fingers and hands as a sign of vibration induced injury of small nerve fibers. This is in accordance with earlier studies showing that increased temperature thresholds are often the first signs of vibration related nerve injury (11). Surprisingly often, increased temperature thresholds were also seen in the feet suggesting the possibility of a central mechanism in the pathogenesis. The symptoms of white fingers showed a tendency to improve among those who had stopped working with vibrating tools. Twentyone subjects still used nicotine, which might explain why so many reported impaired symptoms among those with ceased or decreased exposure to vibration. Only three had managed to stop using nicotine, at least for a year. In many work places the majority use nicotine, which is why it is difficult for an individual to stop.

Many of the subjects had not been able to minimise or cease their exposure to vibration in spite of the diagnosis of vibration related injuries. It seems to be a major change to be forced to change work due to health aspects, especially if the change is of preventive nature and the symptoms not yet are so great that the patient feels that a change is necessary. For many, the decision to change work assignment is a process that takes time. It also takes time to find a replacement for the present task. There are modern tools that vibrate less. The problem is that they are expensive and as long as the old tools can be used, no new tools are bought. No statistical analyses have been made on the material of this study since there were only 46% of the subjects that were diagnosed during 1989 for vibration syndrome that participated. We still think that the subjects that participated are representative of the group and that the conclusions below can be made.

Conclusions

It is important to minimise or cease exposure to vibration if disturbances in circulation and/or nerve function are diagnosed. Patients often have difficulty changing their work situation themselves and is not acceptable to put the responsibility for the change on the patient alone. Many patients have difficulty taking the threat of impaired health seriously resulting in continued exposure for vibrating tools, as well as for nicotine. The patients need motivation with repeated information and support from doctors and technicians at work who can affect the work situation. All of the subjects that managed to stop or minimise exposure to vibration by changing work tasks or by changing job thought that the social effects were better than expected. With a well motivated patient and the right support the chances are quite good that the symptoms will diminish, as well as the signs of objective injuries, by minimising or stopping the exposure to vibration. Many have had support from the doctor associated with the firm, which has been a positive factor for them. This type of health care system has been successively reduced and the question arises as to whether we will notice the effects of this in the future.

Acknowledgements

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A report for Japanese mailmen who used motorbikes daily

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Introduction

In Japan about 80 000 mailmen use motorbikes for mail delivery. They have been exposed to the vibration of the handle grips of motorbikes. They constitute good examples of exposure to long-term, low intensity vibration in an occupational group. Since 1982 health examination has been conducted for the effects of vibration. The fourth examination was carried out in 1995. This report presents the relationship between the incidence of white finger and the amount of vibration exposure in a certain group having simple histories of vibration exposure.

Methods

Measurement of Vibration exposure

Vibration measurements were conducted since 1978 (l). Field surveys on the amount of vibration exposure per day from motorbike deliveries were carried out in 1978, 1979, 1992 and 1993. The subjects of the survey were 59 carriers serving 59 areas in 8 cities. The motorbikes used were 41 of the older, pre-anti-vibration models and 18 of the latter anti-vibration models which have been used since 1979. In the 2 earlier surveys, the left handle vibration was sampled at 3 second intervals and recorded by a semiconductor memory along with running speed. In the latter 2 surveys, vibration in three axes, engine revolution and speed were recorded on magnetic tape continuously. These data were fully recorded from the time when the mailmen left the post office until the time of return thereto.

For this report, the data of an anti-vibration model was studied again to analyse the details of vibration exposure and the vector sum of the three axes of vibration.

Subjects

The data analysed in this study were obtained from the fourth survey conducted in 1995, comprising 111 696 mailmen who used motorbikes. Only data from the latter carriers, who started the use of motorbikes after 1979 at the age of between 18 to 22 years, is included in the analysis. The number of these subjects was 16 319.

These subjects had only used the single type of motorbike (anti-vibration model), while the other older letter carriers had experienced use of several models of motorbike.

Their average age was 26.9 years. Age effects regarding the appearance of White Finger were clear above about forty years old when it could be thought to have less effect.

Typically, the subjects drove motorbikes 5-6 days per week, about 2 hours a day, and the distance ranged from 20 km to 60 km travelled.

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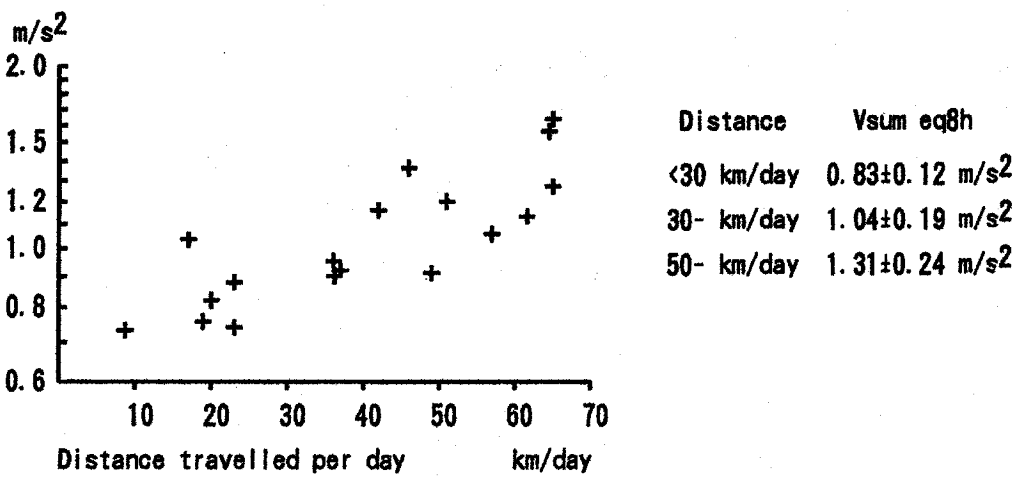

Figure 1. Daily vibration exposure and distance travelled.

Results

The vibration at the handle grips was composed of three main factors. One component was from the unbalanced revolution of the crankshaft. The second component was caused by contact between tyres and the road surface. The last component was shocks while shifting gears and parking motorbikes by using kick stands.

Vibration exposure of the carrier is very often interrupted. With many delivery sites, the carrier must stop and mount and dismount often, taking his hands off the handles frequently to insert mail into post boxes. For example, one carrier travelled 42.0 km in a day with 385 separate runs, and delivered 1 440 letters and parcels.

Daily vibration exposure was closely related to actual driving time and also to distance travelled. The subjects could answer their daily distance correctly because they recorded distances as a part of their jobs. Figure 1 shows the relationship between distances and the vibration exposure in equivalent value through 8 hours (m/s^2) of the vector sum of three axes in the anti-vibration model motorbikes. The vibration exposure of the subjects in this report could be thought below 2.0 m/s^2 in $8_{h,eq}$ vector sum.

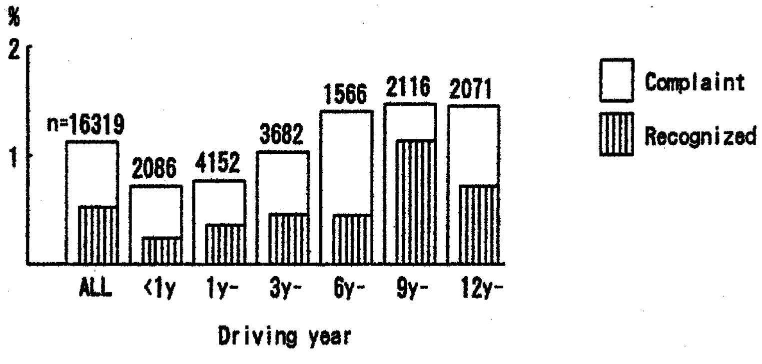

Figure 2. Rate of white finger and driving year.

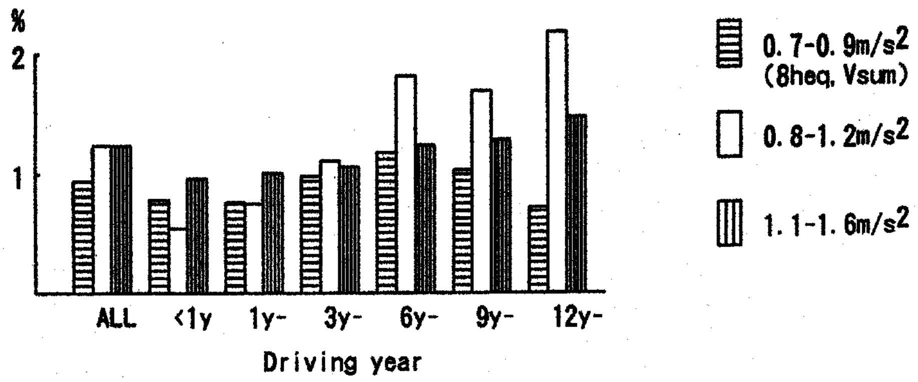

Figure 3. Vibration exposure and white finger.

One hundred and eighty three subjects 1.1% of the subjects, complained of White Finger. The relationship between the prevalence rate of White Finger and driving year was shown in Figure 2. In Figure 2 the rate of recognition of WF is also shown. Recognition means appearance of WF in both sides of the fingers, having a clear boundary. Figure 3 shows the rate of complaints of WF according to the amount of daily vibration exposure. The rate of WF did not correlate with the vibration exposure. The experience of motorbike use before the job also did not correlate with White Finger.

In the rates of White Finger, about two thirds of subjects complained of WF in thumbs and/or symmetrical fingers (Figure 4). Among the White Finger recognised, the ratio reached to 80%. Even in the youngest subjects who complained of WF after short use, less than one year, WF in thumbs or symmetrical fingers was found in half of them.

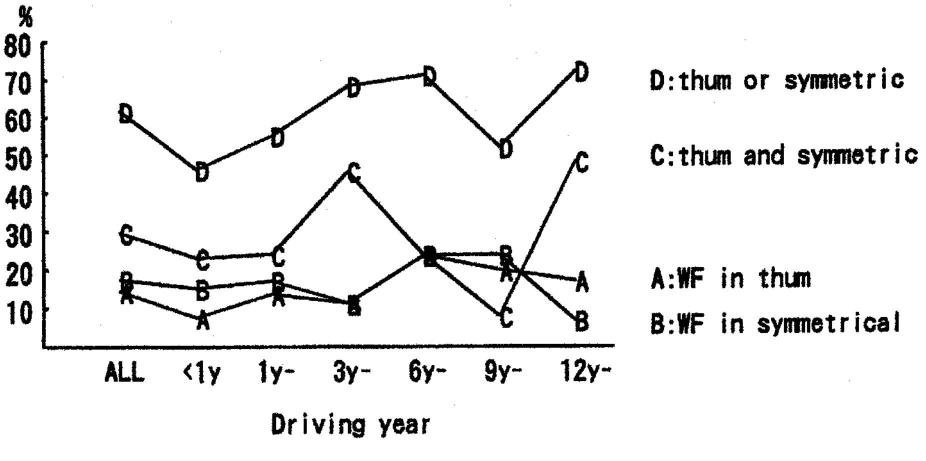

Figure 4. White finger in thumbs and/or symmetric finger.

Discussion

In the previous health examination conducted in 1982 to 1987, the rate of complaints of white finger symptoms correlated with factors related to exposure, number of years of riding a motorbike and distance travelled per day. A correlation between White Fingers and age could also be seen, especially for those about 45 (2-4).

The rate of WF shown above was similar to the rate among non-vibration exposed people from the primary Raynaud's phenomenon or other type of non-vibration induced White Finger (5). About two thirds of the subjects who complained of WF had White Finger in thumbs or symmetrical fingers. It was known that white fingers were found frequently in thumb or symmetric fingers in the primary Raynaud's phenomenon. Then their white finger symptoms could not be thought of as a vibration-induced white finger phenomenon. If they had no exposure to vibration, a similar rate of WF could be found.

In the previous study, letter carriers who had used the pre-anti-vibration model of motorbikes for 10 years or more and had been exposed to relatively strong vibration, about 3 m/s^2 in 8 hours equivalent vector sum value, showed 3% or more rate of WF.

Conclusion

The effects of vibration were not visible in a certain group of mailmen who had been exposed to less amounts of vibration at most 2.0 m/s^2 in 8 hours equivalent value of vector sum of frequency weighted acceleration according to ISO 5349.

The vibration exposure limit for WF was considered to be in the range of between 2-3 m/s^2 in 8 hours equivalent value vector summed.

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Vibration white finger and finger systolic blood pressure after cold provocation in chain saw operators: a follow up study

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Introduction

Some epidemiologic studies have shown that symptoms of vibration-induced white finger (VWF) may reverse if vibration exposure is reduced or stopped. Subjective improvement of the extent and frequency of finger blanching attacks or complete remission of vascular complaints have been reported in both active and retired forestry workers (5, 9, 12). Investigations of vibration-exposed worker groups other than chain saw operators have produced contrasting results: VWF symptoms were reported to improve, not to change, or deteriorate after the cessation of vibration exposure (1, 2, 8, 13). Most of the follow up studies of the reversibility of VWF, however, are based on anamnestic findings. Only a few investigators have monitored the natural course of VWF by means of objective clinical tests, in addition to health history (4, 10, 11). The aim of the present study was to investigate the occurrence of VWF and the cold response of the digital vessels in a group of chain saw operators who underwent a first clinical examination in 1990 and then were re-examined in 1995.

Methods

In February and March 1990, the prevalence of VWF and the cold response of digital vessels were investigated in four groups of chain saw operators working in the district of Amiata (Siena, Italy). The overall study population included 92 vibration-exposed workers. In January 1995, 68 of the previously studied chain saw operators (74%) participated in a follow up study. Of the 24 subjects lost during the five year follow up period, 8 had changed their place of residence, 8 refused to participate in the follow up, and 8 could not be identified. Among these workers, 16 were asymptomatic, 6 complained of sensorineural disturbances in the fingers and hands, and 2 were affected with VWF at the time of the first examination. The subjects lost at the follow up did not differ significantly from the participants in the study with respect to age, smoking and drinking habits, and indices of vibration exposure. The chain saw operators underwent a medical interview, a complete physical examination and a cold provocation test, which were performed by the same occupational health physicians in both 1990 and 1995.

To study the course of VWF symptoms and signs, the subjects were divided into three groups according to the allocation design used by other researchers (10): group A (n=27): active workers without VWF in 1990 and continuing to use chain saws; group B (n=29): workers without VWF in 1990 and retired before 1995; group C (n=12): active (n=8) or retired (n=4) workers with VWF in 1990. The chain saw operators were interviewed about their work history, state of health, and consumption of tobacco and alcohol. No subject was found to be affected with metabolic, cardiac or occlusive arterial diseases at either examination. None used medicines. The anamnestic diagnosis

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of VWF was based on the following criteria: a) positive history of cold provoked episodes of well demarcated blanching in one or more fingers after excluding primary Raynaud's phenomenon; b) first appearance of finger blanching after the start of occupational exposure to hand-transmitted vibration and experience of VWF attacks during the last two years. VWF symptoms were staged according to the Stockholm scale (6). Table 1 reports the characteristics of the study population at the surveys conducted in 1990 and 1995.

Table 1. Characteristics of the study population. Values are given as medians (lower and upper quartiles), numbers (%), or dates.

	Year of survey	Group A (n=27)	Group B (n=29)	Group C (n=12)
Age (y)	1990	41 (35-47)	45 (34-50)	47 (40-56)
Smokers (n)	1990	16 (59.3)	22 (75.9)	9 (75.0)
	1995	10 (37.0)	12 (41.4)‡	6 (50.0)
Drinkers (n)	1990	20 (74.1)	24 (82.8)	11 (91.7)
	1995	17 (63.0)	20 (69.0)	11 (91.7)
Duration of exposure (y)	1990	8 (7-13)	6 (4-10)	12 (10-19)
	1995	13 (12-18)	9 (6-14)	16 (12-24)
$A(8)$ (ms^{-2})	1990	3.9 (2.7-4.9)	4.0 (3.7-5.0)	4.0 (3.3-5.2)
	1995	3.8 (2.6-4.9)	3.9 (3.1-5.1)	3.6 (3.1-4.8)*
Lifetime vibration dose ($m^2s^{-4}h \cdot 10^5$)	1990	3.3 (1.4-7.6)	3.2 (1.9-5.0)	4.9 (3.4-8.1)
Use of AV saws only (n)	1990	22 (81.5)	28 (96.6)	8 (66.6)†

Wilcoxon matched-pairs signed-ranks test: *p=0.02, χ^2 test: †p<0.05; exact McNemar test: ‡p<0.01

The cold test consisted of strain-gauge plethysmographic measurement of finger systolic blood pressure (FSBP) during local cooling to 30°C and 10°C. A double inlet plastic cuff for both air filling and water perfusion was placed on the middle phalanx of the third left finger. In the subjects with subjective symptoms of VWF, the most affected finger was cooled. The test finger was warmed and cooled with water circulating at 30°C and 10°C with a digit cooling system. Two air filled cuffs were applied, one to the proximal phalanx of the test finger (for ischaemia during cooling), and one to the middle phalanx of a reference finger of the same hand (usually the fourth finger). The cold test was performed by pressurising the air cuffs to a suprasystolic level (210 mmHg) and perfusing the water cuff with water initially at 30°C and then at 10°C. After five minutes of ischaemic cooling, FSBP was measured by a strain gauge in the distal phalanx of the test and reference finger. The result of the cold test was expressed as the change of systolic blood pressure in the test finger at 10°C ($FSBP_{t,10°}$) as a percentage of the pressure at 30°C ($FSBP_{t,30°}$), corrected for the change of pressure in the reference finger during the cold test ($FSBP_{ref,30°}$ - $FSBP_{ref,10°}$):

$$FSBP\%_{10^\circ} = (FSBP_{t,10^\circ} \cdot 100)/(FSBP_{t,30^\circ} - (FSBP_{ref,30^\circ} - FSBP_{ref,10^\circ})) \qquad (\%)$$

To avoid nicotine induced vasoconstrictive effects on the digital vessels, tobacco users refrained from smoking for at least two hours before testing. The cold test at the first and second survey was performed by the same method and apparatus (Digitmatic 2000, Medimatic A/S, Copenhagen, Denmark).

In the first study in 1990, the cold test was also performed in 99 manual workers not exposed to vibration. In the control subjects, $FSBP\%_{10^\circ}$ averaged 93.8% (SD 12.1%). For epidemiologic purposes, the finding of $FSBP\%_{10^\circ}<70\%$ (mean-2·SDs in the controls) was considered to be an abnormal response of the digital vessels to cold provocation.

Triaxial vibration measurements were made on the front and rear handles of the antivibration (AV) chain saws currently used by the forestry workers. To assess previous exposure to hand-transmitted vibration in elderly forestry workers, vibration from a sample of non-AV chain saws used in the past was also measured. From the one third octave band frequency spectra (6.3-1250 Hz), the root-mean-square (rms) of the frequency-weighted acceleration (a_{hw}) was obtained according to the ISO 5349 procedure (7). The root-sum-of-squares of the frequency-weighted rms acceleration values for the x-, y- and z-axes $[a_{hv}=(a_{hwx}^2+a_{hwy}^2+a_{hwz}^2)^{0.5}]$ averaged 6.4-8.6 ms^{-2} in the AV chain saws, and 16.7-23.0 ms^{-2} in the non-AV chain saws. The results of vibration measurements are reported in detail elsewhere (3). Daily vibration exposure was assessed in terms of 8-hour energy-equivalent frequency-weighted acceleration sum: $A(8)=a_{hv}(T/T_0)^{0.5}$, where T is the daily duration of exposure to vibration a_{hv} and T_0 is the reference duration of 8 h. A measure of vibration dose cumulated over the working lifetime was derived from the following formula: $\sum(a_{hvi})^2 t_i$, where a_{hvi} is the frequency-weighted acceleration sum of chain saw i (ms^{-2}) and t_i is the total time spent using chain saw i (h).

Data analysis was performed with the software Stata 5.0 and StatXact 2.0. Continuous variables were summarised as medians and quartiles. The Mann-Whitney rank sum test and the Kruskal-Wallis one way analysis of variance were used to compare two or more independent groups. The difference between paired observations was tested by Wilcoxon's signed-ranks test. The McNemar test was used to test the equality of response rates in paired dependent data. The χ^2 statistic was applied to data tabulated in $2 \cdot k$ contingency tables. The relation between repeated measures of $FSBP\%_{10^\circ}$ and several individual and exposure variables was assessed by the generalised estimating equations (GEE) method for longitudinal data in order to account for the within subject correlation.

Results

In group A, of seven active workers without VWF symptoms but with abnormal $FSBP\%_{10^\circ}$ (<70%) in 1990, three subjects improved, two were stationary, and two deteriorated at the cold test in 1995. One of the latter complained of white fingers (stage 3 of the Stockholm scale) at the second examination. In group B, two retired workers with abnormal $FSBP\%_{10^\circ}$ in both 1990 and 1995 reported finger blanching symptoms (stage 2) at the medical interview in 1995. The two subjects experienced Raynaud attacks before the retirement from saw work. Four retired workers without VWF symptoms had an abnormal cold test in 1990: of these, three were stationary and one improved in 1995. In group C, six subjects (four active and two retired) recovered from VWF symptoms and showed FSBP%$_{10^\circ}$>70% in 1995, while the remaining six men with VWF (four active and two retired) did not worsen, but were still affected with finger blanching attacks and showed an abnormal cold test in 1995 (exact McNemar test: $p<0.05$). The two retired workers who recovered from finger blanching had been classified as VWF stage 3 in 1990. The percentage of workers who had used non-AV chain saws in the past was significantly greater in group C (33.4%) than in group A (18.5%) and B (3.4%), ($p<0.05$). As a result of preventive measures curtailing daily sawing time in the VWF workers, the estimated $A(8)$ in group C (Table 1) was found to be lower in 1995 than in 1990 ($p=0.02$). Table 2 reports the changes in FSBP during the follow up period in the three groups of chain saw operators.

Table 2. Results of the cold test in the controls and the forestry workers. Values are given as medians (lower and upper quartiles) and dates. The p-values of the Wilcoxon signed-ranks test for paired comparisons within groups are also shown.

	Year of survey	Controls (n=99)	Group A (n=27)	Group B (n=29)	Group C (n=12)
FSBP$_{t,30^\circ}$	1990	120	131	132	142
(mmHg)		(107-140)	(125-145)	(121-146)	(137-152)
	1995	-	139	140	146
			(130-150)	(125-160)	(121-160)
			p=0.36	p=0.40	p=0.81
FSBP%$_{10^\circ}$	1990	97.2	85.6	79.2	47.2**
(%)		(89.2-100)	(76.5-95.8)	(70.9-92.4)	(41.4-56.0)
	1995	-	89.1	94.4	67.8*
			(82.8-100)	(78.3-103)	(44.5-92.9)
			p=0.45	p<0.001	p=0.16

Kruskal-Wallis test for the difference between groups: *$p<0.02$, **$p<0.001$

No significant change in FSBP$_{t,30^\circ}$ was found within any group. In group A, no change in FSBP%$_{10^\circ}$ was observed at the end of the follow up ($p=0.45$). An improvement in the cold response of digital vessels (i.e. increase in FSBP%$_{10^\circ}$) was observed in group B ($p<0.001$). In group C, FSBP%$_{10^\circ}$ increased in 1995 compared to 1990, but the difference was not significant ($p=0.16$). All groups showed a significant reduction of FSBP%$_{10^\circ}$ at the first cold test in 1990 when compared to the controls ($p<0.001$), and the cold response in group C was stronger than in groups A and B ($p<0.05$). At the second cold test in 1995, FSBP%$_{10^\circ}$ in group B was not significantly different from that measured in the controls at the first examination. The relation between the changes in FSBP%$_{10^\circ}$ during the follow up and several independent variables (age, smoking habit, finger blanching symptoms, lifetime vibration dose, and a term for either the follow up time in the active workers or the time from the cessation of work in the retired workers) was assessed by the GEE method for longitudinal data in order to account for the correlation between repeated measures of FSBP%$_{10^\circ}$ (Table 3).

Table 3. Marginal linear regression of FSBP%$_{10°}$ on individual and exposure variables in the forestry workers divided into two groups according to employment status at the end of the follow up: active forestry workers (n=35, observations=70), retired forestry workers (n=33, observations=66). Estimates of marginal regression coefficients (robust standard errors) by the GEE method are shown.

Variable	Active forestry workers (n=35)	Retired forestry workers (n=33)
Intercept	76.4 (15.6)	128.8 (14.6)
Age at entry (y)	0.12 (0.35)	-0.95 (0.37)*
Lifetime vibration dose ($m^2s^{-4}h \cdot 10^5$)	-0.57 (0.75)	-2.95 (1.43)*
Smoking (no=0/yes=1)	2.99 (7.43)	1.79 (5.20)
VWF symptoms (no=0/yes=1)	-40.4 (8.31)***	-31.2 (8.09)***
Follow up time (y)	1.75 (1.06)	-
Time from retirement (y)	-	4.31 (1.42)**

*p<0.05, **p<0.01, ***p<0.001

In the group of all active chain saw operators (n=35), only FSBP%$_{10°}$ showed a significantly inverse relation with VWF symptoms (p<0.001). In the group of all retired workers (n=33), FSBP%$_{10°}$ was negatively related to age, lifetime vibration dose and VWF symptoms (0.001<p<0.05), and positively related to the time from the cessation of work with chain saws (p<0.01).

Discussion

The results of this follow up study are consistent with those of previous investigations which suggested that VWF may be reversible in chain saw operators (5, 9, 10, 12). It has been reported that the prevalence of VWF in Finnish chain saw operators has gradually decreased from 40% in 1972 to 5% in 1990 (9). A retrospective cohort study of 1551 Japanese forestry workers showed a reduction of the prevalence of VWF from 31% in 1973 to 17% in 1988 (5). In both investigations, a decrease in the incidence of VWF was also reported among active forestry workers. The changes in the occurrence of VWF were attributed to the use of lighter AV chain saws and the introduction of administrative measures curtailing saw usage time and improving the organisation of forest work. In our study, the subjects with VWF in 1990 showed a significant decrease in the occurrence of symptoms and signs of vascular disorders at the end of the follow up. These findings may be due to the cessation of vibration exposure in the retired workers and to the reduction of daily exposure time in the active workers. There were three new cases of VWF during the follow up, corresponding to a five-year cumulative incidence of 5.4%. Moreover, some subjects without subjective symptoms of finger blanching showed an exaggerated digital arterial response to cold at both examinations. Most of these workers (85%) had only operated AV chain saws. At the end of the follow up, the prevalence of VWF was 14.3% in the active forestry workers and 13.2 % in the overall study population. These figures are similar to those reported in previous epidemiologic studies of forestry workers whose work experience was limited to AV chain saws (3, 12). These findings, as well as the results of the cold test, suggest that medical monitoring should be maintained for forestry workers who use modern chain saws as AV saw vibration can still induce damage to the vasoconstrictor mechanisms in the digital vessels.

A major finding of this study was the beneficial effect of the cessation of vibration exposure on the cold response of digital vessels in the retired forestry workers. After controlling for the influence of individual and exposure variables, the increase in FSBP%$_{10°}$ averaged about 4% per year of removal from vibration exposure. As expected, subjective white finger symptoms were the most important predictor of digital arterial hyperresponsiveness to cold in both the active and retired forestry workers. The adverse effects of age and lifetime vibration dose on FSBP%$_{10°}$ among the retired workers may be explained taking into account that these latter were older and had a more prolonged vibration exposure than the currently active chain saw operators ($p<0.05$). In both groups, changes in smoking habit did not influence the cold response during the follow up period.

When combined with reliable work and health histories, FSBP measurement after finger cooling is considered to be one of the most accurate laboratory testing methods to detect cold-induced digital vasospasm and confirm VWF symptoms objectively. In the available literature there are three follow up studies of vibration-exposed workers in which the vasoconstrictor response to cold was assessed by measuring FSBP (4, 10, 11). Two of these studies reported the changes of FSBP%$_{10°}$ in a series of VWF cases who had been exposed to vibration from a great variety of hand-held tools (4, 11). One study of these found no change in FSBP%$_{10°}$ at two consecutive examinations in VWF patients reporting subjective improvement or stationary symptoms, while an increased cold reaction was observed in those with subjective impairment (4). The second study reported an improvement in FSBP%$_{10°}$ in nearly half of 102 patients with moderate to severe VWF after one to 13 years of follow up (11). Owing to the study design, neither investigation could assess the relation between the changes in FSBP%$_{10°}$ and exposure variables. The third study is a five year prospective survey of the cold response of digital vessels in a group of 37 Danish forestry workers with and without VWF symptoms (10). The findings of this study are broadly in agreement with those of the present investigation and in particular an improvement in the subjective symptoms of VWF and in the vasoconstrictor response to cold was observed in the workers who were found to be affected with vascular disorders at the first examination. The improvement in these workers was ascribed partly to a shift from non-AV saws to AV saws and partly to stopping the use of chain saws.

Conclusion

The findings of this follow up study of forestry workers indicate that the reduction or the cessation of exposure to vibration may have a beneficial effect on finger blanching symptoms and the digital arterial response to cold. However, a few new cases of VWF occurred during the follow up period in workers who had only used AV chain saws and this indicates the need for the maintenance of health surveillance of workers who handle chain saws of the new generation. On a group basis, the length of time after stopping the use of chain saws was the major predictor of the improvement in the cold response of the digital vessels in the retired workers.

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Standards for the evaluation of hand-transmitted vibration and the prevention of adverse effects

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Introduction

The risks of developing disorders caused by hand-transmitted vibration are currently predicted using ISO 5349 (1986), British Standard 8642 (1987) and similar standards and guidance. This paper considers the assumptions in the current International Standard and some implications to the prevention of the effects of hand-transmitted vibration.

Standards and guides can define methods of *measuring* vibration (to obtain a numerical indication of the vibration), or a means of *evaluating* the vibration (so as to obtain a measure of the vibration severity), or a means of *assessing* the severity (to predict the likely consequences of exposure). With uncertain knowledge of human responses to vibration, the wording of standards requires care: they could offer assistance in the form of clear guidance on methods without implying certainty of knowledge, or they could add to confusion by defining relationships which are unsupported by knowledge. It is suggested that attention is required to avoid the misdirection that could arise from firm guidance based on consensus which is not firmly supported by understanding.

Current standards, guides and directives

International standard 5349

ISO 5349 (1986) and other current standards use one frequency weighting to evaluate the severity of hand-transmitted vibration in each of the three axes of vibration: from 16 to 1000 Hz the ‘effective acceleration’ is inversely proportional to the vibration frequency. An ‘energy’ concept is used so that any exposure pattern during the day can be represented by the equivalent continuous r.m.s. acceleration over 8 hours (4 hours in ISO 5349, 1986): the ‘energy-equivalent acceleration’ is proportional to the ‘effective acceleration’ and proportional to the square root of the daily exposure duration (2, 10).

In ISO 5349 (1986), assessments of vibration severity are based on the expected occurrence of finger blanching (i.e. vibration-induced white finger, VWF); it might be assumed that the prevention of VWF may also tend to prevent some other disorders. The predicted prevalence of finger blanching is: (i) proportional to daily exposure duration, (ii) proportional to the square of the years of exposure, (iii) proportional to the square of the acceleration magnitude, (iv) inversely proportional to the square of the vibration frequency (from 16 to 1000 Hz).

The evaluation method assumed in ISO 5349 (1996) might be considered to be a general overall representation of how some responses of the hand approximately depend on vibration frequency and other variables: it has not been evolved from an understanding of how the different frequencies, axes, durations, etc. in vibration exposures cause damage to the peripheral vascular system, or the neurological and articular systems. The guidance on the assessment of hand-transmitted vibration offered in an annex of ISO

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5349 (1986) is based on the assumed evaluation method and further interpolation, extrapolation and simplification of available dose-effect information. Consequently, the percentage of persons exposed to hand-transmitted vibration who develop disorders will not necessarily match closely to that predicted by the standard. The guidance in ISO 5349 (1986) was based on consensus within committee more than scientific observation: other methods could represent current knowledge equally well.

A revised version of ISO 5349 is under development and Committee Drafts have been made available for public document in 1996 and 1997 (12). The principal changes currently proposed are: (i) the evaluation of vibration severity based on the root-sums-of-squares of the frequency-weighted acceleration in all axes, rather than the vibration in only the ‘dominant’ axis; and (ii) the restriction of the dose-effect guidance to only 10% prevalence of vibration-induced white finger. In an annex providing dose-effect guidance, the weighted accelerations required to produce finger blanching have been increased by a factor of 1.4 to allow for the change from single (dominant) axis evaluation to the use of root-sums-of-squares summation over all three axes. If vibration is measured in only the dominant axis, current drafts of the revised standard advocate that the measured value is multiplied by 1.7 before being compared with the guidance in the annex. The proposed revision also provides increased guidance on the measurement of hand-transmitted vibration and additional information on the variety of disorders produced by hand-transmitted vibration.

An additional part to ISO 5349 (ISO 5349-2), now in preparation, offers guidance on a strategy for conducting measurements at the workplace and how to perform the measurements.

Various other standards (e.g. the Machinery Directive and a proposed Physical Agents Directive of the European Community) are currently based on ISO 5349 (1986).

Machinery Safety Directive of the European Community

The Machinery Safety Directive of the European Community requires that instruction handbooks for hand-held and hand-guided machinery specify the effective acceleration if it exceeds a stated value (2.5 ms^{-2} r.m.s.) (4). This magnitude applies to the tool when tested in a defined way and is independent of the duration of use of the tool in work.

Figure 1 shows that according to ISO 5349 (1986), an 8 hour daily exposure to 2.5 ms^{-2} r.m.s. would result in 10% of persons with finger blanching after about 8 years and 50% with blanching after about 18 years. However, less blanching is predicted with shorter daily exposures: a 1 hour daily exposure is not expected to produce 10% of persons with finger blanching until after about 24 years. If the dose-effect information in the currently proposed revision of ISO 5349 were used, the apparent severity of the vibration will either rise or fall, compared with the implications of ISO 5349 (1986). The magnitudes required for 10% blanching will rise if the 1.4 increase in magnitude in the annex is used without changing the values measured. The magnitudes required for 10% blanching will fall, if the measured values are obtained in only the dominant axis and are multiplied by 1.7 before being compared with the values in the annex.

Proposed Physical Agents Directive of the European Community

A proposed Directive of the Council of the European Communities suggests that hand-transmitted vibration should be reduced to the lowest achievable level, with the aim of reducing exposure to below a threshold level (3). A threshold level ($a_{hw(eq,8h)}$ = 1.0 ms^{-2} r.m.s.), an action level ($a_{hw(eq,8h)}$ = 2.5 ms^{-2} r.m.s.), and an exposure limit value ($a_{hw(eq,8h)}$ = 5.0 ms^{-2} r.m.s.) are defined. For exposures exceeding the ‘threshold level’, it is proposed that workers must receive information concerning potential risks. The ‘action level’ identifies conditions in which training in precautionary measures is required, an assessment of the vibration is to be made, a programme of preventative measures is to be instituted, and workers have the right to regular health surveillance, including routine examinations designed for the early detection of disorders caused by hand-transmitted vibration. If the ‘exposure limit value’ is exceeded, health surveillance would be required by Member States to control the harmful effects.

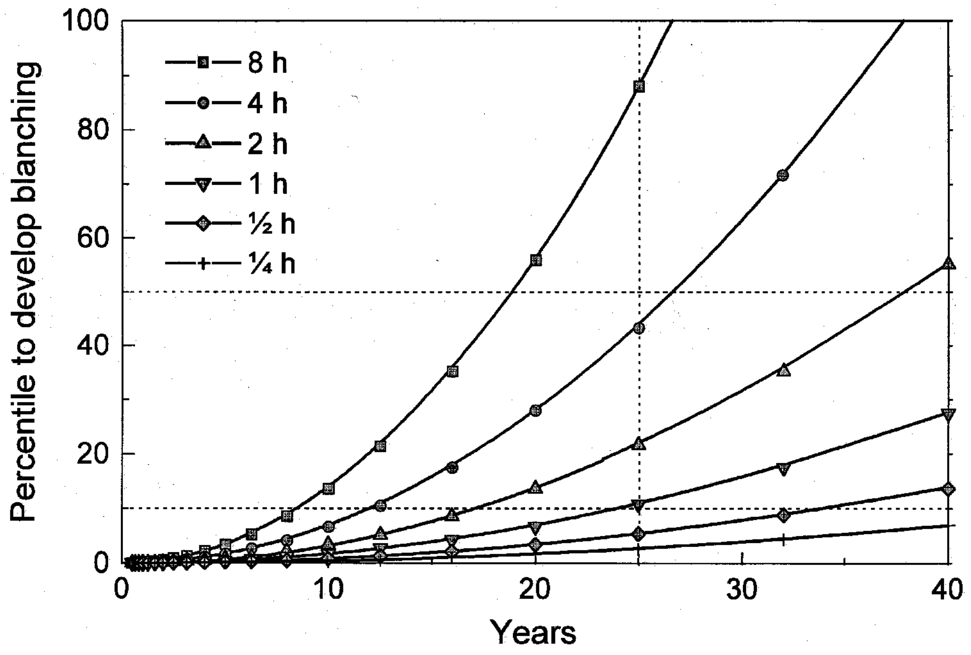

Figure 1. Predicted percentile to develop finger blanching at the 2.5 ms^{-2} r.m.s. level defined in the Machinery Safety Directive (calculated from ISO 5349, 1986).

Figure 2 shows that according to ISO 5349 (1986), the threshold level would produce 10% of persons with finger blanching after about 20 years. The action level would produce 10% of persons with finger blanching after about 8 years and 50% with blanching after about 18 years. The exposure limit value would produce 10% of persons with finger blanching after about 4 years and 50% with blanching after about 9 years. The comparisons in Figure 2 are strictly only applicable when the vibration occurs in only one axis, as ISO 5349 (1986) requires the assessment of vibration in the worst axis and the proposed Physical Agents Directive is based on a summation over axes. If the dose-effect information in the currently proposed revision of ISO 5349 were used, the apparent vibration severity (i.e. the predicted number of persons with finger blanching) would fall.

Some of the problems with the current standards

There are problems with all of the physical variables associated with the evaluation of hand-transmitted vibration: frequency, direction and duration. In addition, the area of contact with vibration, the force of contact, the thermal environment and individual variability are believed to influence susceptibility to the effects of hand-transmitted vibration.

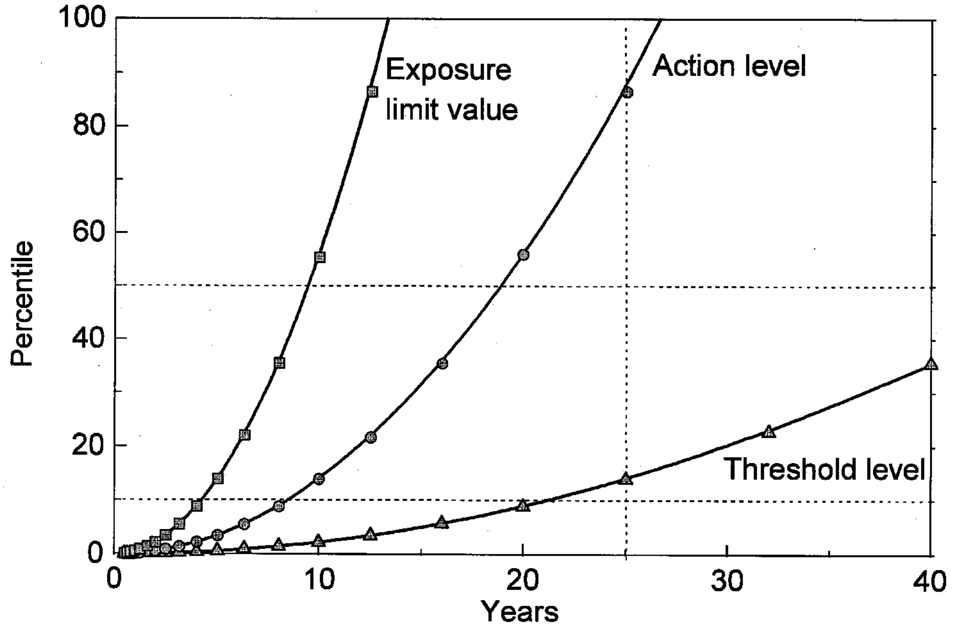

Figure 2. Predicted percentile to develop finger blanching at the three levels defined in a proposed Physical Agents Directive of the EC (calculated from ISO 5349, 1986).

Vibration frequency

The frequency weighting, called W_h in some standards, is not well supported by epidemiological or experimental studies of physiological or pathological changes. The weighting is loosely based on subjective sensations at low and medium frequencies and has been extrapolated to higher frequencies (5). However, subjective sensations (thresholds and discomfort) depend on the contact conditions and other factors. So, at best, the weighting gives only a very approximate indication of how vibration magnitudes should change with vibration frequency so as to maintain a similar degree of sensation. Although the standards suggest that with increases in frequency between 16 Hz and 1000 Hz the acceleration should be doubled for every doubling of frequency so as to maintain the same severity, this is unlikely to be appropriate over all frequencies. The frequency-dependence will certainly depend on what effect is to be predicted: vibration perception, vibration discomfort, or vascular, neurological, articular and other disorders.

The standards tend to be coy about the disorders that might be predicted or prevented by the use of frequency weighting W_h. The dose-effect data in Annex A of ISO 5349 (1986) uses the weighting to predict conditions causing finger blanching. However, the introduction to ISO 5349 seems to imply that weighting W_h is the best available for predicting the risk of disorders to the ‘blood vessels, nerves, bones, joints, muscles and connective tissues’. It seems likely that the different injuries are associated with different frequencies of vibration; for example, perhaps some types of damage to the articular system are more likely with low frequencies of vibration while vibration-induced white finger may be more common with intermediate frequencies.

The frequency weighting ‘allows’ very high magnitudes at high frequencies, where it has been extrapolated beyond the range the subjective data on which it was based. Figure 3 shows how the accelerations required to produce 10% of persons with finger blanching from 4-hour daily exposures depend on vibration frequency and years of exposure. The high accelerations at high frequencies have not been proven to be safe. However, because they rarely occur, the precise nature of the weighting at high frequencies often has little affect on the weighted value (6). In practice, the high attenuation of high frequencies by the weighting means when using frequency weighting W_h it is often likely to be sufficient to restrict the measurement of vibration to frequencies below about 250 Hz. Without the frequency weighting (i.e. equal weighting to acceleration between 16 and 1000 Hz), many tools have significant vibration at frequencies above 250 Hz, but only a few would be greatly under-estimated by using an upper limit of 500 Hz rather than the current 1000 Hz limit (6). A low upper-frequency limit would have appreciably assisted the method of measuring hand-transmitted vibration, or even changed the manner in which this is performed.

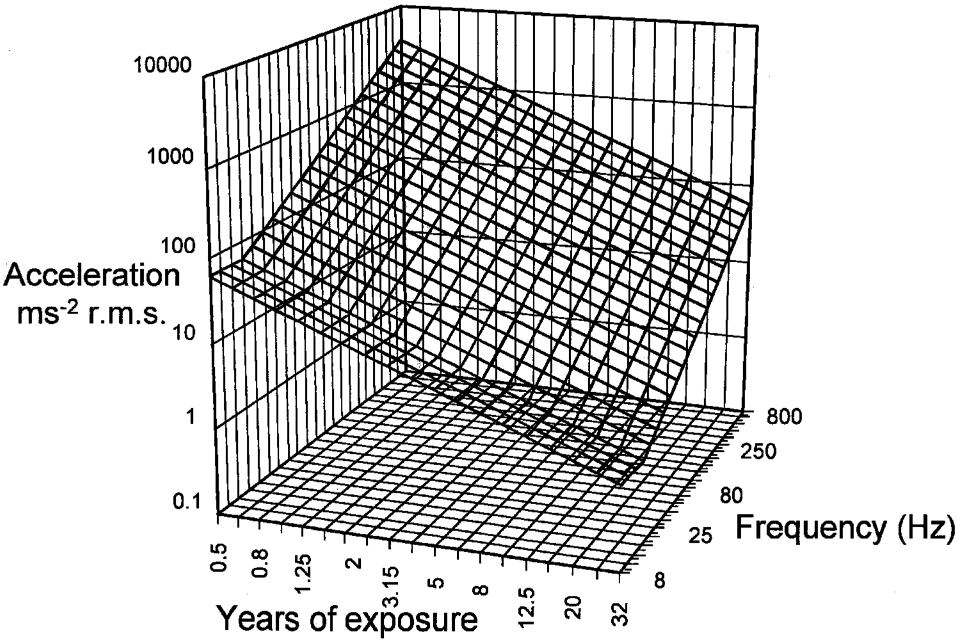

Figure 3. Accelerations required to produce 10% finger blanching from 4 hour daily exposures according to ISO 5349 (1986).

At low frequencies there are arguments for excluding frequencies below about 20 Hz, especially when attempting to predict the vascular effects of vibration (6). The current frequency weighting seems to give two types of problem at low frequency: (i) vibration-induced white finger has not been shown to be caused by low frequencies (although they may cause other disorders); (ii) voluntary movements of some tools result in significant levels of vibration at low frequency and can artificially raise the weighted levels.

Considering the nature of the vibration on many tools, and currently available epidemiological data relating to vibration-induced white finger, it is difficult to see a justification for the current combination of the frequency range (8 to 1000 Hz) and the frequency weighting, W_h. It seems that either the frequency range should be reduced or the measurements should be obtained without this frequency weighting: epidemiological and experimental studies are required to determine the appropriate combination of the frequency range and the frequency weighting.

Standardised methods of measuring vibration should anticipate that weighting W_h will eventually be replaced by other weightings giving better guidance on the severity of vibration at different frequencies. The reporting of frequency spectra is therefore highly desirable (14).

Vibration direction

It seems obvious that a vibration exposure will be more likely to cause injury if the vibration occurs in all three axes rather than in only one direction. The problems are: (i) how to identify the axes of vibration, (ii) whether the same evaluation method (e.g. frequency weighting) is applicable in all three directions, and (iii) how the vibration in the different axes should be combined to form one value.

The identification of the axes of vibration is sometimes easy, but often difficult. It may be possible to refer to the geocentric axes (e.g. vertical and horizontal), or tool-centred axes (e.g. parallel or perpendicular to the percussion direction), or basicentric axes (e.g. normal and perpendicular to the surface of the handle), or anatomical axes (e.g. parallel to the third metacarpal bone). In practice, the axes are often decided for each tool or workpiece and no method is universally applicable. With some tools and work-pieces there is not a constant relation between the four types of axis as the tool is moved through space or the hand is moved to different locations on the tool.

With the axes not defined in a universal manner for all tools, it is difficult to decide on a universal method of evaluating vibration which differs between the axes. Consequently, while it might be hypothesised that at some frequencies the vibration in the shear directions is less harmful than vibration transmitted normal to the surface of the body, this is not easily implemented in a standardised method applicable to all tools. Although there are data showing a different biodynamic and subjective response for the different axes, there are no epidemiological data showing whether such differences affect the development of disorders. Hence, the standards assume that one method of evaluation is applicable to all three orthogonal axes, irrespective of how they are defined and orientated.

Even if all axes are treated equally for the evaluation of the vibration, they are not treated equally for the assessment if it is assumed that only the worst axis dominates the response. Not only does this result in the exclusion of lower magnitudes from other axes, it also allows the measurement of vibration in only one direction on some tools (e.g. percussive hammers).

ISO 5349 (1986) required that vibration was assessed in the dominant axis only. Measurements and evaluations would often be required in all three axes so as to determine the dominant axis, but the method was assumed to be simpler than requiring an assessment based on all three axes. The method also avoids having to decide how to combine the evaluations in three axes so as to determine one value for the assessment. Following the same ideas used with whole-body vibration, the currently proposed revision of ISO 5349 specifies that the root-sums-of-squares (i.e. r.s.s.) of the weighted values in the three axes should be the basis of the assessment.

The use of the r.s.s. gives a higher value than the dominant axis, by up to a factor of 1.73. Any ‘limits’ prepared for dominant axis measurements will be more likely to be exceeded if they are used with r.s.s. measures. Although measurements show that the differences between r.s.s. and worst axis measurements are usually less than 1.73, the difference varies between tools so that a single correction between ‘worst axis’ measurements and ‘r.s.s.’ measurements is not possible without treating some tools unfairly. It has been suggested that typical ratios between the r.s.s. values and the worst axis values are 1.2 for percussive pneumatic tools, 1.3 for rotary pneumatic tools, and 1.5 for tools powered by internal combustion engines (9, 12, 13).

The currently proposed revision of ISO 5349 compensates for the use of the r.s.s. in preference to the dominant axis by raising the values in the dose-effect guidance by a factor of 1.4. This will tend to decrease the rated severity of percussive pneumatic tools, which have dominant components in one axis, and increase the rated severity of tools powered by internal combustion engines, which often have significant components in all axes. There is a risk that the change of method may result in values being reported in four ways: (i) uncorrected dominant axis measures (as in ISO 5349, 1986); (ii) r.s.s. measures obtained over three orthogonal axes; (iii) measures in the dominant axis multiplied by 1.7; (iv) measures in the dominant axis multiplied by either 1.2, 1.3 or 1.5 according to the type of tool.

The value of 2.5 ms^{-2} r.m.s. mentioned in the EU Machinery Safety Directive is currently often interpreted as applying to the worst axis. The proposed Physical Agents Directive mentions that the values are expected to be the ‘vector sum’, meaning the root-mean-square of the frequency-weighted values in all three axes.

The use of r.s.s. results in higher magnitudes where there is significant vibration in more than one axis and prevents the reporting of artificially low values by the judicious orientation of an accelerometer. However, if only r.s.s. measures are reported, it will not later be possible to separate the differential effects of vibration in different axes. It is therefore to be hoped that, just as vibration spectra should be retained, the magnitudes in each axis will be reported in addition to the r.s.s. value over all three axes. Epidemiological studies might recognise that the method of quantifying multi-axis vibration is another assumption that may result in differences between jobs but might be avoided by the development of tool-specific dose-effect guidance.

Daily exposure duration

For practical convenience, the time-dependency (i.e. duration weighting) used to assess the importance of daily exposure duration in ISO 5349 is based on r.m.s. averaging. This so-called ‘equal energy’ concept allows any simple or complex exposure pattern of any duration during the day to be represented by the equivalent magnitude for an exposure of 8 hours (4 hours in ISO 5349, 1986). For example, an exposure of duration, t, to a frequency-weighted r.m.s. acceleration, a_{hw}, the 8 hour energy-equivalent acceleration, $a_{\mathrm{hw(eq,\ 8h)}}$, is given by:

$$a_{\mathrm{hw(eq,\ 8h)}} = a_{\mathrm{hw}}\ (t/T_{(8)})^{0.5}$$

where $T_{(8)}$ is 8 hours (in the same units as t). The value of $a_{\mathrm{hw(eq,\ 8h)}}$ is sometimes denoted by $A(8)$. On this principal, any exposure can be expressed in terms of an energy-equivalent frequency-weighted acceleration (e.g. as $a_{\mathrm{hw(eq,\ 8h)}}$ or $a_{\mathrm{hw(eq,4h)}}$).

The ‘equal energy’ concept has not been justified by epidemiological or experimental research but might be justified as being, for a while, the only practical method commonly available. The method encourages reductions in vibration duration, but indicates that a similar reduction in vibration magnitude is far more beneficial: the vibration severity is halved by either halving the vibration magnitude or by decreasing the exposure duration by a factor of four.

This ‘energy’ time-dependency allows fairly high magnitudes of vibration at short durations (see Figure 4). Although the dose-effect guidance in Annex A of ISO 5349 is restricted to weighted accelerations below 50 ms^{-2} r.m.s., there is no specification of the measurement period over which this value should be determined. It is probably assumed that the 50 ms^{-2} r.m.s. applies to the average acceleration over the full measurement period, which may contain short periods at higher magnitudes and long periods at lower magnitudes. Often, exposures with an average weighted acceleration exceeding 50 ms^{-2}

r.m.s. might be considered of little interest since they could always be considered hazardous.

ISO 5349 (1986) may not prevent exposure to short periods of very high magnitude vibration, or repeated shocks, when these form only a short part of the exposure period. On an ‘equal energy’ basis, the 2.5 ms^{-2} r.m.s. 8 hour ‘action level’ proposed by the EU, corresponds to 54.7 ms^{-2} r.m.s. for a 1 minute exposure. In recognition of the high levels possible for short durations, the draft Physical Agents Directive of the EU identifies exposures ”*for a short term (a few minutes) equivalent acceleration equal to or greater than 20 ms^{-2} r.m.s.*” as ”*activities with increased risk*” which must be declared to the ‘authority responsible’: Member States would be required to ensure that appropriate measures are taken in order to control the risks associated with these activities. It is proposed that equipment which ‘transmits to the hand-arm system’ a short-term (a few minutes) equivalent acceleration equal to or greater than 20 ms^{-2} r.m.s. must be marked. For lower magnitudes of vibration, the proposed Directive says: ”*Where the activity involves the use of work equipment which transmits to the hand-arm system a short-term (a few minutes) equivalent acceleration exceeding 10 ms^{-2} r.m.s., increased efforts shall be made to reduce the hazard, with priority to the use of low-vibration equipment and processes, including the revision of product design and work practice. Pending the effective implementation the duration of continuous exposure shall be reduced.*” The ambiguous references to ‘short-term’ and ‘equivalent acceleration’ leave these as unsatisfactory means of assessing vibration. Vibration exposures are not always statistically stationary: work often includes transient exposures to vibration (and repeated shocks) and variable intermittent periods without exposure to vibration. Any specification of average vibration magnitudes must always make it clear how the averaging period is to be decided.

The evaluation method in ISO 5349 (1986) implies that it is applicable to intermittent vibration (with no allowance for breaks in exposure) and to repeated shocks. However, this seems unlikely and some other methods may need evolution for this purpose. It is to be hoped that any new method introduced for this purpose is based on evidence that it will give a better prediction of injury than the existing method. Otherwise, even if committee consensus can be reached on some method, it will impose complications to the evaluation method not shown to be necessary. Meanwhile, it would be helpful to define a method of reporting the time-varying characteristics of intermittent exposures and repetitive shock motions so that information can be gathered before, rather than after, standardisation in this area.

Lifetime exposure duration

The variation in vibration severity with lifetime exposures is only included in the Annex to ISO 5349 (1986) concerned with vibration-induced white finger. Hence, it forms part of the method of assessing vibration severity with respect to vibration-induced white finger rather than part of the method of evaluating vibration exposures. Even so, the general severity of exposures is sometimes assessed by considering the years of exposure.

Figure 5 shows that in order to protect most workers from finger blanching, the frequency-weighted acceleration must be well below 10 ms^{-2} r.m.s. if exposures continue for 10 or more years. The ‘weighting’ for years of exposure in ISO 5349 (1986) assumes that a given percentage reduction in the years of exposure is equivalent to the same percentage reduction in vibration acceleration magnitude. This differs from the weighting used for hours of exposure in the day. Hence, the method encourages reductions in years of exposure in preference to hours of exposure: the vibration severity is halved by either halving the years of exposure or by decreasing the daily exposure duration by a factor of four (see Figure 6).

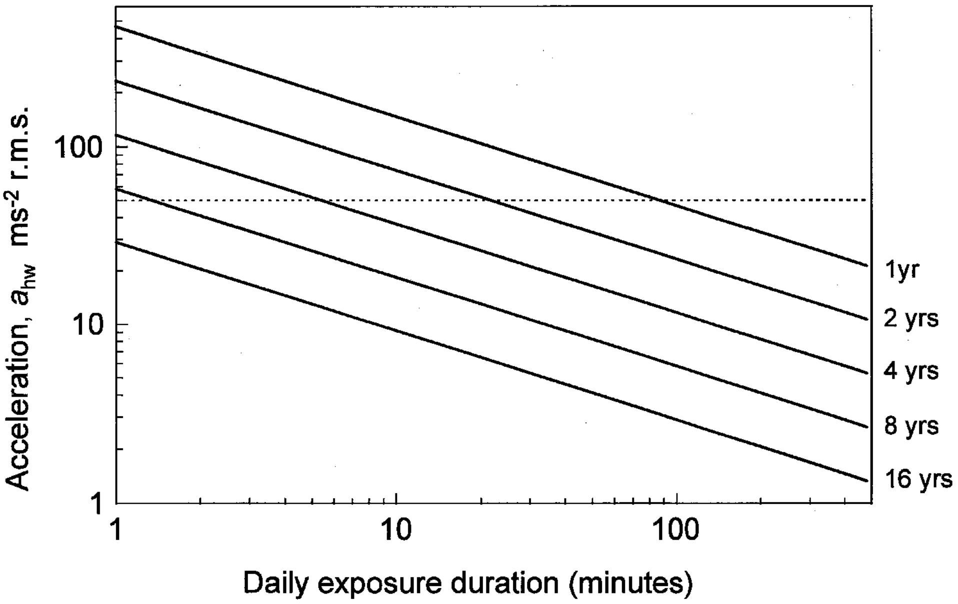

Figure 4. Effect of daily exposure duration on the frequency-weighted acceleration required for 10% finger blanching according to ISO 5349 (1986).

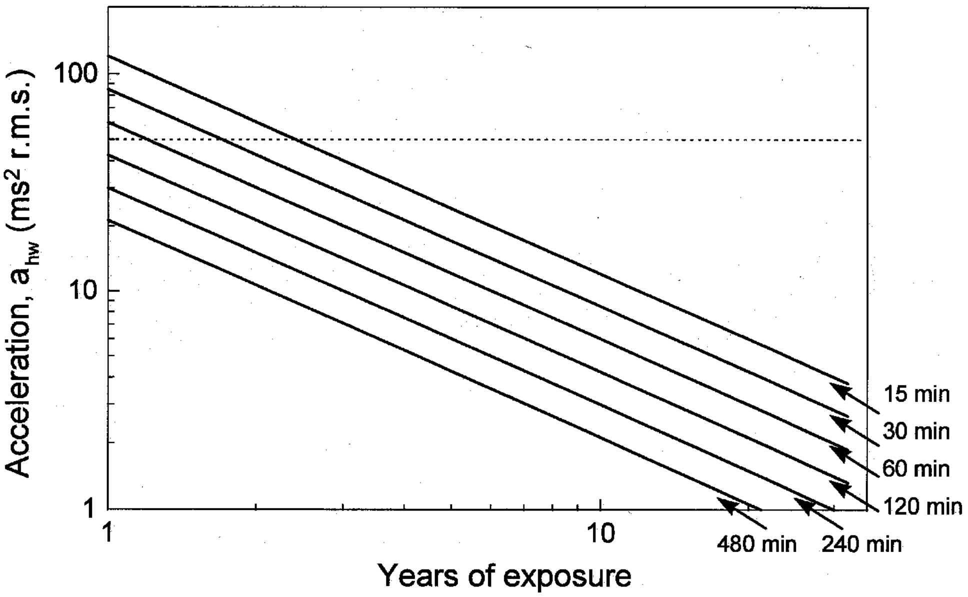

Figure 5. Effect of lifetime exposure duration on the frequency-weighted acceleration required for 10% finger blanching according to ISO 5349 (1986).

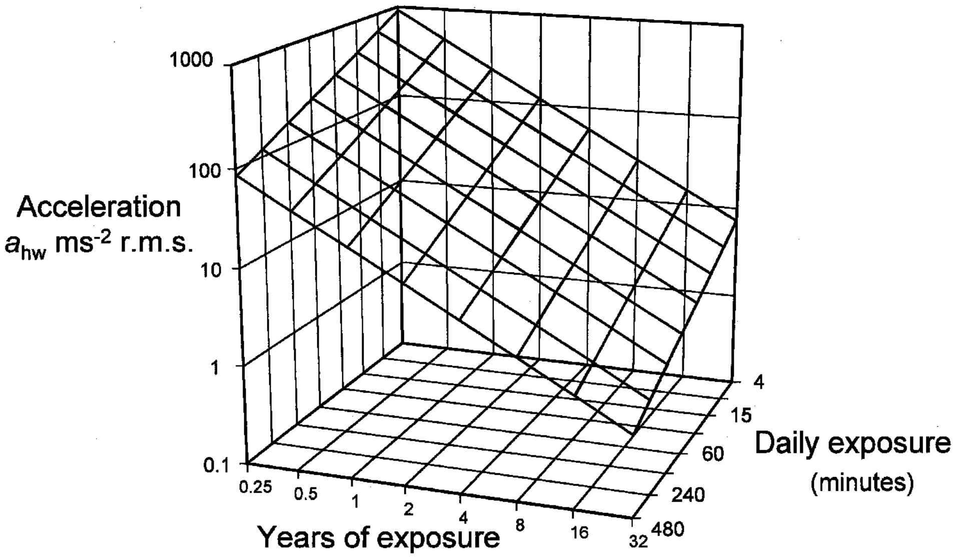

Figure 6. Comparison of effect of daily exposure duration and lifetime exposure duration on the frequency-weighted acceleration required for 10% finger blanching according to ISO 5349 (1986).

The weighting for years of exposure was originally based on the 'mean latency' for the onset of finger blanching in early epidemiological studies. The different weighting for hours and years means it is not possible to simply sum hours of tool use over the years during which exposure has occurred so as to determine exposure severity according to the standard. If the daily summation used the same duration 'weighting' that is used for years (i.e. magnitude inversely proportional to duration), it would allow even higher magnitudes for short durations, or restrict tool magnitudes to lower values for long daily exposure durations, or both. For example a 1.0 ms^{-2} r.m.s. 8 hour exposure would be equivalent to a 1 minute exposure to 480 ms^{-2} r.m.s. This may seem unacceptable in the light of current understanding and it is likely to be inconsistent with the subjective assessment of vibration severity if this changes with duration in a manner broadly similar to whole-body vibration, where a fourth-power relation between vibration magnitude and exposure duration currently seems reasonable for both subjective sensation and the prevention of injury. If the yearly summation used the same duration 'weighting' currently used for hours of exposure (i.e. 'energy' summation), it would be more restrictive of high magnitudes for durations of only a few years, or allow higher tool magnitudes with greater years of exposure, or both. For example, currently, a 25 year exposure to 2 ms^{-2} r.m.s. is equivalent to a 1 year exposure to 50 ms^{-2} r.m.s., whereas the energy time-dependency would place a 25 year exposure to 2 ms^{-2} r.m.s. equivalent to a 1 year exposure to 10 ms^{-2} r.m.s. It is less obvious that this is unacceptable. Available epidemiological data do not appear to allow a comparison of the consequences of using various alternative daily and yearly time-dependencies, although one study implies that the product of average acceleration magnitude and total hours of tool use gives a better estimate of finger blanching than the product of hours of tool use and the square of the acceleration magnitude (1).

In the context of ISO 5349 (1986), the assessment of exposure severity in an annex brings together the daily and yearly exposure durations to predict the prevalence of finger blanching. The prevalence is doubled by doubling the daily exposure duration or by a √2 increase in either the years of exposure or the vibration magnitude. This tends to emphasise the importance of years of exposure over hours of exposure. Although the draft revision of ISO 5349 only defines conditions expected to produce 10% finger blanching, the greater importance of reducing years of exposure rather than hours of exposures is retained.

There is currently no agreed way of allowing for intermittent exposures, either variable tool use over a week, over a month or over years. This means that severe short-term exposures might be rated lower by, for example, averaging the exposure over a year. Suggestions that persons exposed for 2 days per week over 52 weeks, or those exposed for only 6 months of the year, could be allowed double the vibration magnitude during their periods of ‘full-time’ work may not be clearly excluded from all possible interpretations of the current standard.

Area of contact with vibration

Standards do not usually allow for any differences caused by the area of contact. For example, they do not distinguish between vibration transmitted to the fingers and vibration transmitted to the hand. It seems that with some tools the effects of vibration are localised to the area in contact with vibration, so presumably an exposure to one or two fingers may not have the same severity as an exposure to all fingers. Further, it might be suggested that exposure to vibration on one hand could be considered less severe than the exposure of two hands.

Standards for hand-transmitted vibration and standards for whole-body vibration have been developed separately and little consideration has been given to avoiding apparently inconsistent guidance (8).

Contact force

The grip force and push force may be expected to affect the transmission of vibration to the hand and arm. They may also affect local blood circulation. Consequently, vibration severity may depend on grip force and push force yet there is no specific incentive to reduce these in current standards.

Environment and posture

The ambient temperature and the temperature of the handle or workpiece may affect finger blood flow. With vibration, and possibly the contact force, already causing a reduction in finger blood flow, this may be assumed to be undesirable, but current methods do not allow for any differences in the vibration severity. Other aspects of the environment may also be undesirable (e.g. noise and chemicals) but their effects on the disorders caused by hand-transmitted vibration are largely unknown and not allowed for in current standards. Some postures, such as overhead work, are also likely to reduce circulation to the upper limbs and may be best avoided, but this has rarely been suggested.

Subject variability

Subject variability is reflected in the dose-effect guidance in an annex of ISO 5349 (1986). Assuming a normal distribution of latent intervals, the exposure duration required for a given percentile to develop blanching was predicted from the mean and standard deviation of the group latency. This was then approximated by a squared relation between the percentile affected by blanching, C, and the years of exposure, E: $C \quad E^2$. The other relationships assumed in ISO 5349 (1986) (i.e. between years of exposure and frequency-weighted acceleration, and between frequency-weighted acceleration and hours of exposure, see above) allowed the formulation of an equation relating all four variables:

$$C = \left[\frac{a_{hw} \; E}{9.5}\right]^2 \frac{t}{T_{(4)}}$$

where:

C = prevalence of VWF (expressed as a percentage);
a_{hw} = frequency-weighted acceleration (ms^{-2} r.m.s.)
E = years of regular exposure to vibration;
t = daily exposure duration (in same units as $T_{(4)}$);
$T_{(4)}$ = 4 hours (in same units as t).

Figure 7 shows how the predicted prevalence increases with years of exposure and with acceleration magnitude; the squared approximation is clearly not appropriate at prevalence rates much above 50% and is also inappropriate below 10%. The guidance in the annex of ISO 5349 (1986) was limited to prevalence rates in the range 10 to 50%. The proposed revision of ISO 5349 does not include a relationship between prevalence and the years of exposure, hours of exposure or acceleration magnitude: it is restricted to 10% finger blanching *"in order to limit the potential for inappropriate use of the relationship"*. The quantification of subject variability is therefore excluded from the currently proposed revision of the standard.

The biodynamic, physiological and pathological variables may explain some of the large variability between individuals. Possibly, with better understanding of their roles, it may be appropriate to select out persons more likely to suffer the adverse effects of hand-transmitted vibration. There may also be causes of intra-subject variability that could allow the avoidance of circumstances more likely to cause injury.

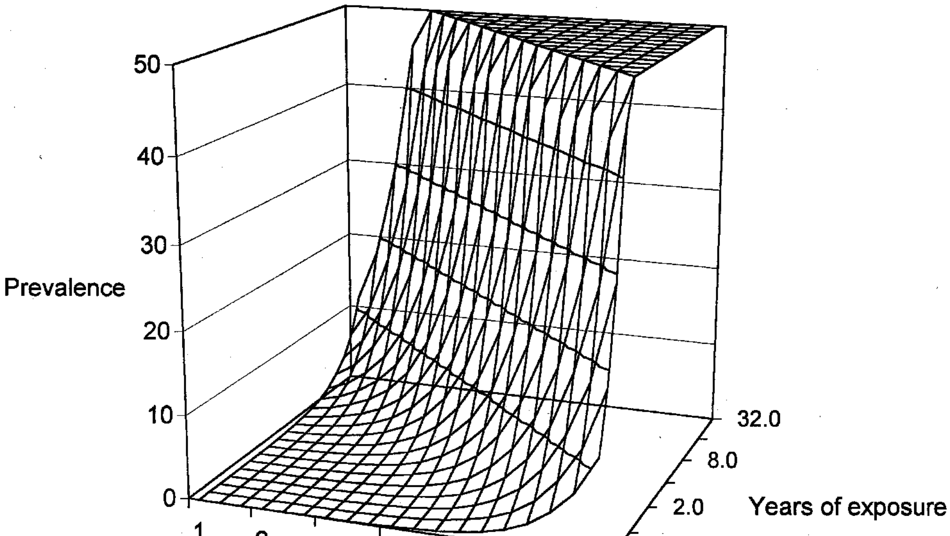

Figure 7. Predicted prevalence of finger blanching as a function of frequency-weighted acceleration and years of exposure according to ISO 5349 (1986). Assuming 4 hour daily exposures.

Prevention

To minimise the risks of vibration injuries, the vibration magnitude and exposure duration should be minimised, and warning, education and medical monitoring of those exposed may be required.

The method of evaluating vibration exposures in current standards defines the means of reducing vibration severity. Changes to only three variables (magnitude, frequency and duration) determine the assessed severity of exposures. However, in a qualitative manner, the standards also mention other matters that might affect the risks of injury.

Doubts, about the method of allowing for the effects of vibration frequency and exposure duration, and doubts over the importance of other variables, can have major implications to the organisation of work, the selection of optimum tools and the use of ‘anti-vibration’ devices, such as suspensions and gloves (7). For a preventative measure to be attractive, it must reduce the apparent severity of vibration exposures. If ISO 5349 contains an incorrect allowance for the effects of a vibration variable (e.g. frequency, direction or duration) it could wrongly imply that a means of protection is beneficial when it is not, or imply that protection is ineffective when benefit can be obtained.

Anti-vibration gloves

In the past, few scientists have advocated ‘anti-vibration gloves’ as a useful solution to the effects of hand-transmitted vibration. Gloves may attenuate high frequencies of vibration but do not attenuate the low frequencies. It has been argued that the vibration on most tools is dominated by low frequencies at which gloves have little beneficial effects. In part, this arises from the influence of the frequency weighting W_h in ISO 5349 (1986).

The term ‘glove isolation effectiveness’ has been used to indicate the extent to which a glove attenuates the effective vibration on a handle (7):

$$\text{Glove isolation effectiveness (\%)} = \frac{\text{weighted acceleration at hand when wearing glove}}{\text{weighted acceleration at hand without glove}} \times 100$$

The glove isolation effectiveness indicates the extent to which a specific glove decreases (or increases) the severity of vibration on the handle of a specific tool. In International Standard 10819 (1996), it is recommended that gloves are tested using only two spectra, M and H, so as to calculate values of $\overline{TR}_M$ and $\overline{TR}_H$; these are the ‘glove isolation effectiveness’ when using spectrum M and spectrum H and the currently standardised frequency weighting, W_h.

Figure 8 illustrates the predicted values of glove isolation effectiveness of a glove when exposed to the vibration from 20 tools and the two test spectra (spectra M and H) (more complete data will be found in reference 7). Figure 9 shows the glove isolation effectiveness calculated without the frequency weighting, W_h.

With the frequency weighting, substantial attenuation of vibration (i.e. a glove isolation effectiveness much less than 100%) is only seen when the glove is used with two tools. The predicted values using spectrum M (90%) and spectrum H (60%) may be compared with the range of values obtained for specific tools. Using 10 different gloves, it was found that with spectrum M, the values fell in a narrow range from 90% to 103%, compared with a wider range of values for individual tools from 64% to 114%. With spectrum H, 4 gloves gave values lower than that achieved with the spectrum for any tool, while 5 gloves gave values higher than that achieved with any tool. It is therefore difficult to see any value in the results obtained by using spectrum M and spectrum H.

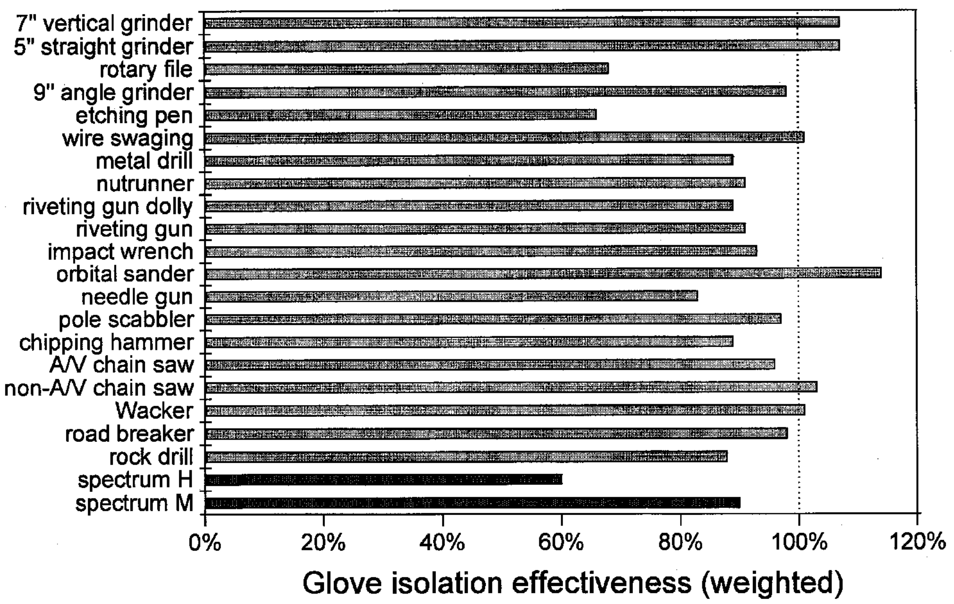

Figure 8. Predicted ‘glove isolation effectiveness’ for one glove tested with the spectra from 20 tools and the spectra M and H from ISO 10819 (1996). Values obtained using frequency weighting W_h.

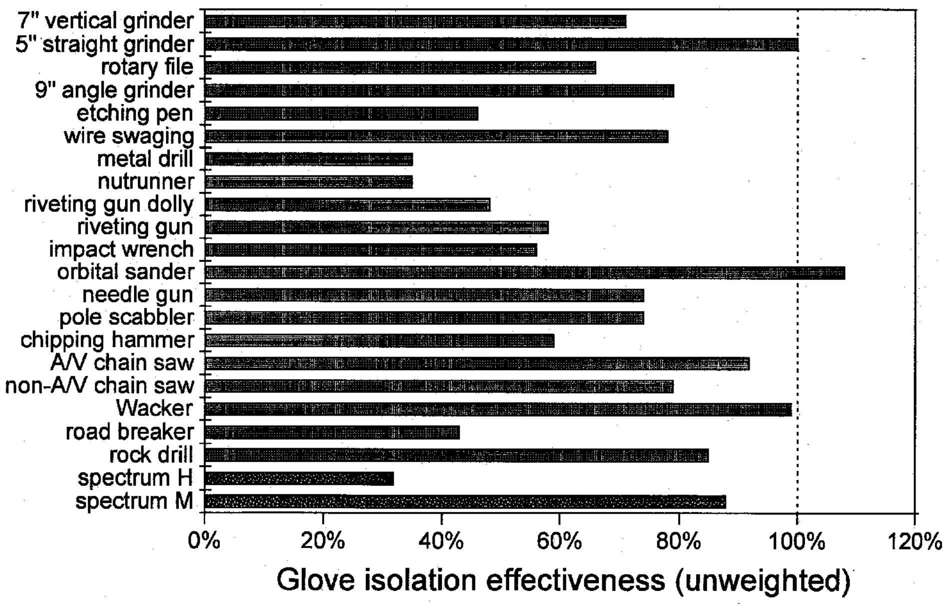

Figure 9. Predicted ‘glove isolation effectiveness’ for one glove tested with the spectra from 20 tools and the spectra M and H from ISO 10819 (1996). Values obtained without using frequency weighting W_h.

Without the frequency weighting (i.e. equal gain for all acceleration between 8 and 1000 Hz), the vibration on many tools was usefully attenuated by the example glove Figure 8. On the basis of the unweighted data, the glove could be advocated for use with all except about 3 of the 20 tools. There are several cases in which the unweighted acceleration predicted at the palm of the hand is halved by the wearing of the glove.

The glove isolation effectiveness shows that the effects of a glove used with a particular tool are not well predicted by assuming that all tools have the same spectra.

Furthermore, it can be seen that the frequency weighting has a large effect on the perceived effectiveness of gloves in attenuating the vibration. It seems that it is the frequency weighting that decides whether anti-vibration gloves can be an effective means of reducing the hazards of hand-transmitted vibration.

The use of unweighted acceleration over the range 8 to 1000 Hz tends to increase the perceived effectiveness of gloves (and some other anti-vibration techniques). An extension of the frequency range to frequencies above 1000 Hz (or raising the low frequency limit to, say, 20 Hz) could further increase the apparent value of gloves. While new standards for anti-vibration gloves (e.g. ISO 10819, 1996) make use of the current frequency weighting, their future evolution should include consideration of the consequences of changes to the frequency weighting (7).

Discussion

With the mechanisms of the injuries caused by hand-transmitted vibration still unknown, and the full range of injuries not agreed, methods of predicting the effects of vibration from measures of exposure to vibration have significant uncertainties.

The evaluation of vibration exposures according to current standards will usually form a significant and useful part of a programme to prevent injury. However, intelligent use of standards requires understanding of where they are based on knowledge and where they are based on guesswork or convenience.

Measurement and evaluation methods should allow, assist and encourage the collection of improved data on human exposures to hand-transmitted vibration. This requires the standardisation of methods of collecting and reporting the spectral, axial and temporal characteristics of vibration exposures, and other variables, over a wide range of conditions.

A lack of knowledge has allowed the production of standards for the measurement, evaluation and assessment of vibration based largely on committee consensus. The basis of this consensus, and the support for the standardised methods is sometimes hidden from users of the standards. It is to be hoped that future standards will identify the foundations on which they are offered and that this will include information published in scientific, medical and engineering journals that has been available for peer review. Where the limitations to knowledge are insufficient for conclusions to be based on such foundations, it seems reasonable to ask that the basis of consensus should be declared. In all cases, methods proposed by standardisation committees would benefit from trial application and thorough analysis before they are offered for ritual approval by member countries.

The ISO sub-committee responsible for ISO 5349 has recently been invited to approve two resolutions concerning the quality control of its standards. The first resolution concerned the provision of information on the basis of proposed standards: "*ISO TC108 SC4 agrees that in future the sub-committee and its working groups will insure that simple explanatory justifications for the principal technical content of its proposed standards will be documented prior to their circulation for vote by member countries. The justifications may appear in resolutions of working groups or in other traceable documents in which the justifications are easily accessible to experts of member countries. Where a justification can be expected to significantly affect the interpretation or application of a standard it should be included in the standard in the Foreword or in notes or in an annex.*"

The resolution was approved ‘subject to editorial changes’ which included limiting the action to the encouragement of working groups and the removal of the final sentence so as to leave only: “*ISO TC 108/SC4 agrees to encourage its working groups to insure that the basis for the principal technical content of its proposed standards is documented prior to its circulation for vote by member countries. This information may appear in resolutions of working groups or in other traceable working group documents which are easily accessible to experts of member countries.*”

A second resolution concerned the verification of proposed test methods prior to their publication: “*ISO TC108 SC4 agrees that in future when a proposed standard defines a test method there must be documentary evidence that the test method has been successfully applied, and found to be sufficiently repeatable and valid, before it is circulated for final vote. Where appropriate, the standard should indicate the repeatability and validity of the test method.*”

This resolution was rejected! The rejection of the second resolution and the reduction of the first resolution will inevitably lead the reader to doubt the confidence that the committee has in its standards. If justifications that can affect the application of a standard are excluded, and test methods can be standardised when they have not been shown to be satisfactory, there are potential dangers to those affected by such standards. Further, knowledge that standards could be produced in this way casts doubt on the applicability of all standardised methods of measuring, evaluating and assessing vibration with respect to human responses and the associated methods of preventing unwanted effects.

Conclusion

It is desirable that standards should be understood, and not promulgated, accepted or applied without comprehension. It is suggested that the basis of all guidance in a standard should be indicated and that quantitative guidance should be accompanied by a statement of the possible error; test methods should have been proven to provide repeatable and useful results before they are standardised. With limited supporting evidence for currently standardised methods of measuring, evaluating and assessing hand-transmitted vibration, changes may be anticipated as research reveals the mechanisms of the various effects of vibration on the human body.

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Certified safety by European co-ordination and co-operation of notified bodies for machines and personal protective equipment

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Introduction

The harmonised internal market of the European Union is closely related to the requirement of product safety. In the past manufacturers of machinery and personal protective equipment were held to observe the national safety regulations of each single Member State in which they wished to sell their products. This large variety of safety regulations with different contents and varying safety levels - sometimes supplemented by national construction requirements - was replaced in 1993 by Directives applying to all EU Member States and those countries which have entered the European Economic Area. Safety aspects relating to vibration emission are dealt with in the Machinery Directive (1) and the Directive on Personal Protective Equipment (2).

The large number of machines causing hazardous vibration exposure of the operator makes it impossible to include in EU-Directives - which in fact have legal status - detailed stipulations in terms of vibration reduction and vibration measurement. Directives are therefore restricted to the definition of essential health and safety requirements. The European Standardisation Committee CEN was commissioned by the European Commission to further specify the legal framework; the standards thus elaborated are examined by the Commission in view of their compliance with the basic health and safety requirements of the Directive and, in case of a positive result, published as so-called “harmonised standards” in the Official Journal of the European Union.

In general, compliance with these basic health and safety requirements has to be verified by authorised test and certification bodies, which are notified by the Member States. Type test certificates issued by these bodies are valid everywhere in the European Economic Area. The presentation of national safety certificates, which was required before, is therefore no longer necessary. The manufacturer of a machine affixes the CE label to any of his products available on the European internal market, thus signalling to the purchaser that the basic health and safety requirements of the applying Directive are fulfilled.

Method

Everyone involved in this process was aware of the fact that the introduction of a harmonised regulatory and testing system for the safety of machinery and personal protective equipment would cause some difficulties. Particular problems were encountered in connection with the short-term elaboration of European safety standards for the design of machinery and personal protective equipment. On the one hand, all concerned parties, i.e. manufacturers, test laboratories and national authorities, had to develop a large number of standards in very little time; on the other hand, it was

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necessary to synthesise a generally accepted harmonised European standard out of the numerous independent national safety and test regulations.

As there was not enough time for exhaustive interlaboratory trials to evaluate the proposed test and assessment procedures, the standardisation committees agreed that standards should nevertheless be adopted; the idea was to collect experiences in the following application phase and to include them at a later point in time in a revised version of the standard.

As, at the same time, compliance with the relevant safety requirements would be checked by the market surveillance authorities of the Member States, it was indispensable to develop suitable structures of co-ordination, especially between the notified test and certification bodies; this is still done by organising interlaboratory trials and by documenting any agreed changes to or deviations from the standardised procedures.

For this purpose, a refined network of co-operation between the notified bodies from the EU Member States has been established during the last few years. In parallel, the EU Commission set up a Standing Committee of national experts from the Member States for each of the safety-relevant Directives. Whenever the notified bodies agree that an existing standard should be applied differently, this decision is notified to the member states via the competent Standing Committee so that market surveillance can be carried out accordingly. A similar information flux exists between the notified bodies and the European Standardisation Organisation CEN; this is to make sure that the competent Technical Committees of CEN are informed of any modification proposal too.

As far as safety requirements for machinery are concerned, testing and certification of product samples by a notified body are not always compulsory. In most cases the manufacturer is simply held to take account of the state of the art in anti-vibration technology and to measure and indicate the vibration emission of his products without referring to a notified body.

In the case of personal protective equipment, however, type testing and certification by a notified body are required for nearly all products. In the following, the field of anti-vibration gloves will be taken as an example to illustrate the necessary co-ordination and co-operation between test and certification bodies, which exist both for personal protective equipment and machinery.

Implementation of EN ISO 10819:1996

Despite many open questions, the test laboratories adopted the test and certification standard for anti-vibration gloves (EN ISO 10819:1996 (3)) - result of a close co-operation between ISO and CEN - with the intention to gather the necessary experience in the course of application and to revise the standard accordingly at a later point in time. Since applying the standard would also mean issuing test certificates for products meeting the standard requirements and the basic health and safety requirements of the EU-PPE-Directive, it was also necessary to take account of the rules of market surveillance. In the beginning, contradictory tests results were produced due to the fact that it took the test laboratories in the different countries quite a while to establish a co-operation and co-ordination group in which the test procedures for anti-vibration gloves could be agreed in detail. Chaired by the HSE Vibration Laboratory (United Kingdom), the test laboratories, which were all accredited at national level but - with the exception of one - had not been reached the status of notification to the Commission, decided to found a working group for co-ordination and co-operation and organise interlaboratory trials based on commonly agreed criteria. Until there is a revision of the test standard EN ISO 10819:1996, they will be able to use the existing network structures set up by the bodies notified under the terms of the Directive on personal protective equipment; these structures will help agree modifications and keep the Commission, the market surveillance authorities of the member states and the competent Technical Committees of CEN informed.

As far as anti-vibration gloves are concerned the competent co-operation group is Vertical Group 5 “Protective clothing, hand and arm protection” of the Horizontal Committee of notified bodies for personal protective equipment. This is where modification proposals concerning the applying European harmonised test standard are put forward as a question in the so-called “Proposal for Enquiry” (example see annex 1) and mailed to the other members of the working group together with the initiator's recommended solution. The proposals are discussed by exchange of letters or in a working group meeting, and a commonly agreed solution is adopted. The result, normally a further specification of the standard requirements, is then made available to all participating test and certification bodies as a “Recommendation for Use” (example see annex 2), counselling harmonised application. On condition that these “Recommendations for Use” deal with details of a product standard only, the Secretariat of the Horizontal Committee gives them to the attention of the national representatives Standing Committee. What was agreed by the test and certification bodies thus comes to the knowledge of the market surveillance authorities too. The competent Technical Committee of CEN is also informed; there, the documents are collected as standard proposals of which account can be taken when the standard will be revised. It is in the standardisation committees that manufacturers and other parties concerned with product safety have the possibility to comment on the bodies’ agreements.

The Secretariat of the Horizontal Committee of notified bodies for personal protective equipment receives financial support from the EU Commission for this practical and necessary co-ordination. The working documents “Proposal for Enquiry” and “Recommendation for Use” have become commonly accepted tools ensuring the functional application of harmonised European safety regulations.

Conclusion

With the establishment of a European co-ordination and co-operation in the context of the EU Directives for PPE and machinery, the notified bodies succeeded in furthering the harmonised application of European standards. Agreements relating to divergence from standardised test procedures or to lacking test details are laid down in the so-called Recommendation for Use sheets and are made available both to the European Commission and the market surveillance authorities of the Member States. It is thus possible to ensure the best possible application of standards in the period preceding the standards’ revision which will allow for an inclusion of all modifications agreed so far.

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Annex 1

	CO-ORDINATION OF NOTIFIED BODIES **PPE-Directive 89/686/EEC + amendments** **Annex 1** **PROPOSAL FOR ENQUIRY**	CNB/P/05.001(AVG) Revision 00 Language : E

Number of pages : 1	Date : 03/06/98	Approval by : ☑ Vertical Group .... ☐ Horizontal Committee............. ☐ Standing Committee...............	Approved on :
Origin : VG5 Protective Clothing, Hand and Arm Protection			

Question related to : Annex : Article :	EN/prEN : EN ISO 10819:1996 Clause : [(pr)EN] 5.2.2.2 and 6.3.3	Other :

[redacted]

Annex 2

CO-ORDINATION OF NOTIFIED BODIES
PPE-Directive 89/686/EEC + amendments
Annex 2
RECOMMENDATION FOR USE

CNB/P/05.209
Revision 00
Language : E

Number of pages : 1

Date : 97-03-02

Approval by :

☑ Vertical Group 97/04/07
☐ Horizontal Committee.........
☐ Standing Committee............

Approved on :

Origin : VG5 Protective Clothing, Hand and Arm Protection

Question related to :
Annex :
Article :

EN/prEN : 420

Other :

Clause : [(pr)EN]

Key words : Fitting of gloves, Glove circumference and length of fingers

Question :

In EN 420 the size of glove is given only with the measurement of length of the glove. On the other side it is demended the glove fits the hand correctly. How can we verify the glove fits the hand correctly just using the length?

Recommended solution :

We propose to take into account at least the circumference of glove in order to verify this circumference is upper or equal than the circumference of the hand it has to fit.

Sent for information to :
☑ members of the VG ☐ other(s) VG ☐ HC (2) ☐ TC (3)
☐ SC (4) ☐ other (5)

(1) Essential safety requirement
(2) HC = horizontal committee
(3) N° of CEN/TC (Secretary & Chairman)
(4) EEC Standing Committee 89/392
(5) To be specified

How to transfer knowledge from the laboratory to the field: training factory inspectors for the measurement of vibration in the workplace

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Introduction

Despite the sale on the French market of anti-vibration power tools such as some models of rammers, grinders, sanders, etc., the protection of operators against vibration hazards progresses slowly in factories, in comparison to the forest workers which are today generally equipped with suspended chain saws and medically followed. This is because of the absence of regulation or limit in France on hand transmitted vibration and ignorance by most users and employers about the risk associated with the use of traditional power tools (only 25 VWF compensated cases per year are claimed, compared to several thousands in the UK or hundreds in Italy or Sweden). At the beginning of the 90's INRS came to the conclusion that low vibration tools will not be widely bought (and used) as long as users and associates are not aware of the vibration hazards and relays trained to transfer the information (1). The following strategy into three points was therefore elaborated to reach that level:

(a) Information to users on hazards associated with the use of vibrating tools and methods to reduce the hazards of repeated exposure
(b) Training of intermediaries
(c) Help to manufacturers for the development of low vibration tools.

INRS actions on points (a) and (c) were previously presented in various articles (2, 3). The purpose of this paper is to report the method developed for training specialist factory inspectors.

Method

In France there are height laboratories (CMP) which make physical measurements (noise, light, ventilation, etc.) for the twelve Regional Sickness Insurance Funds (CRAM). Five to seven specialist factory inspectors work in each laboratory. A three day training session on how to measure human vibration was organised at the beginning of the 90's for them, but this action was too isolated to be efficient.

In 1994 a group of ten specialist inspectors convened by INRS experts was created with the purpose to elaborate three guides on the vibration measurement at the workplace (whole-body, hand-arm and building vibration) (4, 5). Firstly, the three days training sessions were repeated and many measurements on hand held power tools were made in the laboratory. Each inspector was then asked to prepare one chapter of each guide, the proposals were then discussed by the group and the revisions made by another inspector. In parallel, joint measurements with INRS were realised in about 30 different working sites for different purposes: comparison to select low vibration tools, exposure assessment for epidemiological research, survey of the different tools used in one factory

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to identify the main vibration hazards, etc. The different laboratories were equipped with similar measurement and analysis equipment and a common calibration system was bought.

Content of the guide

The guide was designed to be practical on the site. It is based on standard prEN 25349-2 and the HSE book on Hand Arm Vibration (4, 5) It follows the action chronology:

- *What should be known before visiting the working site?* Chapter 1 is a synthesis of present knowledge on hand-arm vibration (effects, standardisation, sources and exposure). Chapter 2 is devoted to the metrology of vibration, chapter 3 to the preparation of the field measurement (information to be asked at the factory, choice and check of equipment).
- *What should be done during the visit of the working site?* Chapter 4 regards the examination of the working place, chapters 5 and 6 the organisation of the vibration measurements and exposure time assessment.
- *What should be done after the visit?* Chapters 7 and 8 report respectively on the analysis of measurements, calculation of the daily vibration exposure and life dose. Finally, chapter 9 briefly presents measures for vibration hazards reduction. This chapter is completed by an appendix which provides information on low vibration tools.

What should be known before visiting the working site?

Before visiting the working site it is essential to make an analysis of the demand so as to determine the real need for measurements: who is asking and why? The demand will generally come from a working site (employer, union or hygienic group), an occupational physician, a factory inspector or a manufacturer. They are many reasons for asking: user complaint, estimation of a potential hazards, information of employer or operator, compensation of an occupational disease, choice of new tools, development of a new working place, social problems. Altogether we can distinguish three main objectives for the measurements as it follows: (a) exposure assessment, (b) comparison of vibration emitted by different machines, (c) characterisation of vibration signal emitted by some machine.

The guide also recommends looking for information on the working place (task, tools, process, duration, physical parameters, etc.) and previous measurements on similar machines. This information can partly be obtained by phoning to the working site but also consulting data banks, scientific reports and manufacturer technical literature. It is also important to know the conditions of the visit: if the employer or user are not aware of the problem, or if the working equipment is rarely free, measurements must be organised in such a way as not to disturb the work process.

The knowledge of the purpose of measurements will impose the type of analysis to be made and consequently the equipment to be prepared. We should never forget that in most cases:

- the operator, the process and the assembly line should not be disturbed,
- there is no room for the equipment and no power plug at proximity,
- nobody in the factory has time to assist the measurement,
- inspectors will not be offered a second chance to repeat the measurement.

Therefore, it is preferable to check the equipment twice rather than once before the visit. The use of a compact measurement chain with a battery is recommended. It is often quite clever to borrow, if possible, the main power tools to be measured so as to instrument them in advance in the comfort of the laboratory.

What should be done during the visit of the working site?

Examination of the workplace

To assess the vibration risk and organise the measurement procedure it is first necessary to examine the workplace at the following three levels:

- the operator activity to identify the operations (tasks, process, work cycle, duration, etc.) which are likely to produce the important vibration exposures,
- the power tools and accessories characteristics,
- the operator loads (posture, forces, temperature, noise and solvent).

It is often helpful to ask the workers directly which situations they believe produce the highest vibration magnitude. When this is safe and possible, the inspector will get information by trying the different tools himself.

Organisation of vibration measurements

The way the measurements are carried out to assess the operator's exposure depends on the type of operation:

- Where the operation time is long enough to take representative measurements over a period of at least one minute, measurements can be made during normal working over a section of the operation or a complete operation.
- Where the duration of the operation or the time the operator has his hands in contact with the vibrating surface is not sufficiently long, the operation may be artificially simulated so as to get a longer measurement period of at least 8 to 15 seconds without breaks.
- Where the operation exposes the worker to multiple single shocks, the task may be organised so as to cover several shocks with as little time as possible between shocks.

When the purpose of the vibration measurements is to compare different machines, it is preferable to design simulated work procedures which will give representative and repeatable results.

Assessment of vibration exposure duration

The assessment of daily exposure duration must be made to calculate the vibration exposure which is based on the measurement of the actual exposure time of tool normal use during a complete work cycle or a typical period, multiplied by the work rate, such as the number of cycles per day.

Exposure duration assessment is often delicate because the operators tend to overestimate the duration (they will normally give an estimate of the period of time for which a tool is held, including pauses in operation). Estimates of usage time, which include breaks in tool operation, may be used provided that the vibration measurements are made over equivalent periods.

Moreover the amount of time may be highly variable from one day to the next; in this case the assessment is based on weekly or monthly estimates and an equivalent daily exposure deduced by calculation.

What should be done after the visit?

The analysis of measurements and calculation of vibration exposure are made in accordance to the standard ENV 25349 (8), the application of which is generally not a problem. Unfortunately, in the absence of legal or standardised limits of safe vibration exposure in France, inspectors have difficulty providing incisive conclusions regarding vibration hazards.

An important part of inspector job is to propose solutions to improve the work situation. Standard CR 1030-2 (9) should constitute a reference document in the future but requires practice for it’s usage.

Examples of applications

Figure 1. Measurement of vibration emitted by a rotary file being used to fettle a component.

The CMP and INRS guide was tested under different conditions of application, e.g. to estimate the vibration life dose of operators working in a factory repairing railway wagons (10). In this factory three different jobs (welders, iron mongers and grinders) involved exposure of 40 workers to hand arm vibration (see Figure 1). The weighted acceleration of 16 different hand held power tools (grinders, rotary files, nailers, pick hammers and needle guns) were measured. The daily vibration exposure ($A_{eq,8}$) and life dose (D is calculated from the square of 8 hour energy equivalent vibration total value multiplied by the number of years of exposure) of each exposed persons were assessed. $A_{eq,8}$ ranged from 1.3 to 13.9 m/s^2 and D from 28 to 4231 (m/ s^2)^2 x year. It was found that the highest values were associated with the use of needle guns. A new model of low vibration needle gun was recommended after it was successfully tested by the factory.

A second example was the case of a factory which was buying new rotary files to fettle turbine components made of titanium (11). We were asked to compare the vibration emitted by four different tools selected by the factory. A simulated task was organised which consisted of using a rejected titanium component which could be ground at length without extra cost. The tools were tested for several speeds and with different accessories. The equivalent acceleration values were 3 m/s^2 for two of the files and 2 m/s^2 for the others.

Figure 2. Measurement of vibration on the operator finger nails when sewing shoes.

In some cases the metrology may be a problem. This was the case for measuring vibration transmitted to operators of a sewing machine used to manufacture safety shoes (see Figure 2) (12). The only solution was to glue the accelerometers directly on the workers' nails. The measured equivalent acceleration values varied between 4 and 6 m/s^2. In addition this operation required the operators to exert an important pinch force to grip the different shoe leather parts. The solution came one year latter when the shoe factory discovered it was easier to work leather once it has been previously heated to 100°C.

Conclusions

The three years training program organised for the specialist factory inspectors enabled them to become aware of the problem of hand-arm vibration and to be able to assess vibration exposure for most conditions.

The next step is for them to act for the reduction of vibration hazards by promoting low vibration tools or modifying the working process. They are also encouraged to train other intermediaries in the factories to assist these latter INRS in collaborating with a manufacturer to develop a basic and cheap vibrometer, which, it is hoped, will simplify hand-arm vibration measurements in the future. The final step of the inspector training program will be the preparation of a French brochure on practical ways to reduce the vibration risk (12).

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Progress in persuading British industry that effective management of exposure to hand-arm vibration results in good health and good business

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Introduction

The Health and Safety Executive (HSE) advises and enforces standards of health and safety in British industry. HSE's health risk review in the early l990's showed that improvements were possible in industry's management of occupational health risks. In response to these findings HSE launched the 'Good Health is Good Business' campaign designed to raise awareness of occupational ill-health issues and publicise accepted good practice for their control and draw attention to the financial and other rewards that good management of occupational health risks can bring. Phase 3 of the campaign was launched on 22 May 1998 and added hand-arm vibration to a portfolio of occupational health risks including noise, dermatitis and musculo-skeletal disorders.

The campaign capitalises on publicity to raise awareness of health risks and means of their prevention through trade and national press, radio and television, and through intermediaries such as trade associations, trade unions, and employers associations. HSE's inspectorates have industry specific campaigns for awareness and, where necessary, enforcement action. Inspection of risks from exposure to hand-arm vibration has focussed on those industries where VWF and latterly HAVS have been reportable diseases in the UK. Activity has been notable in foundries, heavy fabrication and forestry, amongst others. These inspection activities have been widely supported by guidance leaflets addressing the particular problems of specific industry sectors and trades, e.g. foundries information sheets.

HSE recommends a programme of preventive measures and health surveillance if daily exposures to hand-arm vibration regularly exceed 2.8 ms^{-2} A(8). Guidance for employers and others has been published (1,2) including: advice on the nature and causes of HAVS; methods of reducing the risk of injury; procedures for measuring vibration and assessing risk; methods for clinical diagnosis and health surveillance; and many case study examples of action taken by companies to reduce the risk of HAVS in a range of industries. Free leaflets summarising the content of this guidance on hand-arm vibration for employers and employees have been updated and extended and relaunched at the start of the campaign.

For employees and others, a video - Hard to handle - has been launched introducing the consequences of excessive exposure to hand-arm vibration and what can reasonably expected of employers to achieve control of risk.

Methods

For over a decade HSE has applied the results of research to investigate the risks arising from exposure to hand-arm vibration to the preparation of guidance to industry, the

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development of enforcement policy, and negotiation of Standards and proposals for legislation. Research interests have included; where people are exposed, the consequences of exposure, and means of preventing or reducing exposure. The findings of research have been developed into campaign material providing practical advice on good practice to achieve control of health risks from hand-arm vibration. In particular, the campaign seeks to make the main points that:

- there is risk of crippling injury
- the risk can be controlled
- action to reduce risk is cost effective.

The HAV initiative will inform works managers and supervisors, health and safety advisers/consultants, and occupational medics of the nature of HAVS injuries and the consequences of injury on lifestyle. Many workforces are aware of vibration white finger and other HAV injuries, and public awareness is increasing through national press coverage of recent successful compensation claims. However, there are still many companies where the cause of injury and it's consequences are not appreciated. Even where the risk of injury is recognised inspection experience suggests there is little knowledge of best practice for its prevention.

HSE's inspectors have been trained in hand-arm vibration and the number of interventions and number of enforcement actions regarding hand-arm vibration is expected to increase as a result of the campaign. Priority has been given to training for inspectors specialising in industries long associated with vibration injury - heavy engineering, moulten metals, construction and agriculture - but all inspectorates have had opportunities to train.

Inspectors and other HSE staff have been equipped with a speakers' pack in readiness for providing seminars and workshops to raise awareness of means of controlling risk of hand-arm vibration syndrome. Information covered at seminars and workshops is covered by a CD-ROM to be published during the campaign.

HSE's campaign in industrial premises is coordinated with the inspection activities of local authority inspectors in minor industrial and retail premises.

The legislative framework

Failures to meet the minimum workplace standards required by general harmonised European legislation will be subject to enforcement action. HSE's guidance is underpinned by legislation implementing European Directives. The principle legislation (3,4) applies to supply of work equipment by manufacturers (the Machinery Directive) and the provision of work equipment by employers to their employees (the Framework and daughter Directives) but other legislation also addresses issues relevant to hand-arm vibration.

Supply legislation sets out essential health and safety requirements (EHSRs) for equipment supplied for use at work. There are a number of EHSRs for hand-arm vibration (paraphrased):

- to design for low vibration emission
- to report the vibration emission under Standard test conditions
- to warn of any risks (such as vibration) which may not be immediately apparent.

Employers are required, amongst other things, to ensure that equipment supplied for use at work is suitable and in good repair and that the users have received training.

Personal protective equipment is covered by separate legislation (5,6). HSE recommends that gloves are worn to keep hands warm. Employers should not provide anti-vibration gloves as personal protective equipment against risk of HAVS unless they have data to show that risk is likely to be reduced, i.e. they can show that the vibration reaching the hand is likely to be reduced by the anti-vibration glove in the particular work situation.

The campaign promotes a four point plan of action:

- find out if you have a problem
- decide what action to take
- take action
- check what you have done.

Results

Find out if you have a problem

Employers have a legal duty to assess risk with sufficient accuracy for the purpose of identifying preventive measures. In practice many regular users of powered hand-held or hand-guided equipment are widely exposed to between 4 and 10 ms^{-2} A(8) and in some cases up to 20 ms^{-2} A(8) (2), i.e. well in excess of the HSE recommended action level of 2.8 ms^{-2} A(8) and HSE would expect management of vibration exposure.

HSE identifies several means of deciding if there is a need for action including knowledge of a history of injury in the industry, reference to published emission or exposure data, use of databases, or measurement of personal exposure. A suggested ‘rule of thumb’ is that investigation of excessive exposure to vibration should be made if power tools, or other hand-held, hand-fed or hand-guided equipment are regularly used for 2 or more hours per day, or in the case of percussive equipment, for l/2 hour or more per day.

Manufacturers’ declared vibration emission data should not be assumed indicative of risk but other manufacturers’ data warning of vibration injury risks may be helpful.

Decide what action to take

Once the likelihood of risk is established it becomes important to know what can reasonably be done to reduce the risk - indeed, in some cases employers may first want to establish that more could be done and at what cost before considering the legal duty to act. It appears that much can be achieved to reduce risk at minimal cost in many factories because of the low level of knowledge of control measures seen in much of industry - an observation the campaign seeks to change. Once the simple steps to control risk have been taken employers might want to consider risk of vibration injury a little more carefully especially once the cost of quantifying exposures becomes comparable or small compared with the cost of control action.

An early step in deciding appropriate control action is to decide if the process requiring exposure to vibration is absolutely necessary or could be substituted by an alternative process eliminating the need for exposure. Vibration exposure is often dictated by specification of the product and production process. Vibration exposure can often be avoided or reduced if the production processes to be used are considered at the design stage. For example, exposure is reduced if a simplified product is compatible with mechanised production, or a required finish is achieved by chemical instead of mechanical means.

If it is established that exposure cannot be eliminated, it is necessary to look at vibration reduction measures. The campaign promotes reduction of vibration exposure first by reduction of vibration magnitude and second by reduction of exposure time. Techniques encouraged include: selection of reduced vibration equipment - the employers assessment of risk should have determined the likely daily usage periods which, to achieve exposures below HSE’s recommended action level, will suggest a corresponding (though not always achievable) acceptable vibration emission from the tool during use; ensuring the maintenance programme is adequate to prevent exposure to unnecessary vibration; and vibration reduction by modification of equipment - usually best tackled by manufacturers but retrospective action may be possible in a few cases, e.g. pedestrian controlled equipment.

Where sufficient reduction in vibration magnitude cannot be achieved employers should reduce exposure time. Limiting exposure time is an effective interim, and sometimes sole means of controlling the risk of vibration injury.

Other actions such as provision of training are essential. The ergonomics of the workplace and workstation should be considered against the risk of vibration injury. When tackling a vibration problem it is often advantageous to consider the impact of controlling exposure to vibration on other risks of injury such as those from noise or dust - a combined benefit may be achievable.

Check what you have done
Given that some exposure to HAV will always occur, and given the difficulty in reducing exposures to safe levels, e.g. in ship repair where recommended usage of some tools is only a few minutes per day, the campaign will stress the need for monitoring the effectiveness of risk control measures. This will be achieved in part by review of the risk assessment and in part by health surveillance.

Health surveillance may be required when vibration exposures remain relatively high. Health surveillance does not prevent injury but it can prevent significant handicap. It is a valuable tool for both identifying individuals most susceptible to HAVS and, when linked into the risk control programme, indicating weak or ineffective control measures and priorities for further action. The use of questionnaire techniques is promoted but information and guidance on objective test techniques is available.

Discussion

HSE’s knowledge of the health risks presented by excessive occupational exposure to hand-transmitted vibration is sufficient for enabling guidance to be published on the prevention of injury and for enforcement action to be taken on the basis of proven risk. However, increased knowledge is always welcome and research is continuing into issues, including: the accuracy of assessing risk of injury; the performance of anti-vibration gloves; the correlation of manufacturers’ declarations of equipment safety with risk of vibration injury; and review of the number and distribution of workers exposed.

Accuracy of assessing risk of injury
The purpose of assessing risk of vibration injury is to guide what could and should be done to control the risk. Quantification of exposure can be difficult, costly or inaccurate and its relative performance in risk assessment against simpler methods of assessing risk

is of interest. The achievable accuracy in quantifying exposure becomes increasingly important as criterion values are proposed to prescribe action or limits, as by HSE or in the EC proposed Physical Agents Directive. A small HSE project to investigate accuracy of evaluation of industrial exposure using common instrumentation in laboratory and real workplaces is continuing, including evaluation of the performance of various common vibration instruments, the determination of exposure time, the effect of different operators, the effect of applying a tool to several similar but different tasks, etc. The value of improvements in the accuracy of evaluating exposures is ultimately limited by the accuracy of the dose-response information that might be used to predict risk. Guidance on the accuracy of evaluating industrial exposure to vibration will be published for British industry.

Performance of anti-vibration gloves

Anti-vibration gloves are being marketed vigorously by a few companies in the UK. Most claimed anti-vibration gloves marketed before the adoption of EN ISO 10819 have been withdrawn but the performance of the few remaining that claim conformance with 10819 are the subject of controversy - different laboratories have found different gloves to meet the standard but no gloves have been shown to be highly effective at reducing risk.

The Health and Safety Laboratory (HSL) have found one glove that meets the criteria of the international standard and have shown that although the impact of the glove on risk is small, it may reduce risk in particularly favourable conditions - the vibration magnitude during grinding evaluated to ISO 5349 is likely to be reduced from 5.1 to 4.1 ms^{-2}.

HSE and HSL are organising round robin testing of EN ISO 10819 on behalf of CEN TC 23 l WG3 and the PPE committee. Previous round robin testing has indicated areas in EN ISO l0819 where the standard is ambiguous and significant differences can occur. HSE is proposing to evaluate the reduction in inter laboratory differences by suggested common interpretation of ambiguous passages by participating laboratories.

A major failing of the current glove test standard is that it does not require data to be provided to purchasers of gloves to enable them to perform their assessment of glove performance required by European law, although the standard does suggest (in notes) that this data is reported.

Correlation of manufacturers' declarations of vibration emission with risk of vibration injury

Great strides have been made in producing standards for reporting vibration emission of equipment. However, the standards do not always represent risk. It is probably true that those with the lowest evaluated vibration emission are amongst those presenting the lowest risk, but this is of limited use to a potential purchaser who wants to know which tools present similar and low risk in workplace situations. Manufacturers are obliged to warn of risk when this is not otherwise evident and most producers of powered hand tools do provide separate warnings of risk of vibration injury - not always sufficient to indicate the limit of safe use of the equipment - but usually enough to suggest that some thought should be given to the control of vibration exposures. Manufacturers' data may help produce a shortlist of tools for site trials.

HSE sponsored research has shown many limitations in the current vibration emission reporting regime and provided a number of indications as to how the revision of machinery vibration emission standards (11,12) can be improved. The adoption of laboratory test standards does not appear to offer improvements in accuracy of data for equipment comparison sufficient to justify the widespread abandonment of field testing.

The emission declaration threshold of 2.5 ms^{-2} is often mistaken as an indicator of risk - the methods used to determine this figure are not necessarily related to risk. The predominance in the use of a single axis vibration level - indeed not always the dominant axis - provides a poor basis for comparison of equipment vibration emission and even worse indication of likely risk. The implied accuracy of the methods is hopelessly misleading - a single value, sometimes to two places of decimals, is rarely appropriate to represent the wide range, sometimes several meters per second squared, in vibration emissions that are likely to occur in practice.

Review of the number and distribution of workers exposed

HSE's studies during the 1980's (7, 8, 9) of who was at risk concentrated on occupations giving rise to reportable disease (in the UK - at that time VWF). The studies identified nearly 500,000 people making use of hazardous equipment including 160,000 making high utilisation of such equipment.

A review of the number and distribution of workers exposed to hand-transmitted vibration (10), due to be completed during 1998, has found that around 4 million people have self reported use of vibration hazardous equipment in the previous week - though not necessarily for sufficient duration to present risk to health. The design of the new study has enabled inclusion of people ommitted from the earlier studies. Analysis of the data available to date has shown that use of vibration hazardous equipment extends far wider than the industrial activities studied previously. More surprisingly, preliminary results indicate that over 1 million people claim exposure in excess of HSE's criterion level for action (2.8 ms^{-2} A(8)) - a six fold increase on previous expectations. The most popular tools - hammer drills, angle grinders, and jig saws - are the tools most linked to high prevalence of Raynaud's phenomenon.

Responses to questions about specific symptoms of vascular injury associated with exposure to hand-transmitted vibration suggest that there may be 170,000 people presenting recognised symptoms. HSE's survey of work related ill-health (SWI) suggests there are around 36,000 cases of advanced disability.

Jobs that are known to cause vibration injury, e.g. in foundries or heavy fabrication, do not feature prominently in the survey analysis - the analysis shows that it is usually a minority of people in a particular industry or occupation that are exposed to high levels of vibration - perhaps 1 in 8 to 1 in 20 - and that these small numbers of people are present across many types of production and service industry - including many activities that do not appear to have been studied previously.

Verification of these preliminary findings is currently underway.

Conclusions

The HSE GHGB campaign is designed to raise employers' awareness of the good commercial sense in identifying and managing health risks. There are three main messages: there is risk of crippling injury; the risk can be controlled; and action to reduce risk is cost effective. The campaign recommends a four point action plan: find out if you have a problem; decide what action to take; take action; and check what you have done. Failure to meet the minimum standards of harmonised European legislation is likely to lead to enforcement action.

Work is ongoing to improve knowledge in several areas including the number and distribution of workers exposed to hand-arm vibration in Britain and to improve the value of standards mandated by the EC Machinery Directive.

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Investigation in the accuracy of vibration measurements for the declaration of emission values for hand-held machines

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Introduction

Characteristic values for mechanical vibration at the handle of hand-held tools are important information for the choice of low vibration emission tools, for the comparison of machines and for defining the state of technology. The assessment of the vibration emission values of hand-held tools was carried out in accordance with the EC Machinery Directive with harmonised European standards (e.g. EN 28662 and EN 50144).

The measurement of vibrations usually includes large deviations (7). Therefore, the only meaningful way to use the vibration emission values is in connection with information about the possible measurement uncertainty. In the past some investigations based on round-robin tests involving different laboratories were carried out in order to determine the measurement uncertainty (1, 2, 3, 4, 6). Depending on the type of machines, the measurement uncertainty between the laboratories involved amounted to between 30% and 100%. Up to now this information was only at the disposal of experts in hand-arm vibration. The evaluation of the uncertainty of the determination of the vibration emission values is mostly based on this information in addition to the researcher’s own experience.

To enable and support a wide field of application, a recently issued European standard (EN 12096) regulates the procedure for the declaration and verification of the vibration emission values. According to this standard the uncertainty K should be declared in addition to the emission value a. The most important basic quantity for the uncertainty K is the standard deviation of reproducibility σ_R. The standard deviation of reproducibility σ_R includes the deviation of vibration emission values obtained under reproducible conditions, i.e. the repeated application of the same vibration measurement method on the same machines at different time and under different conditions. This includes different laboratories, different operators and different measurement equipment. Other important quantities are the standard deviation of repeatability σ_r and the standard deviation of production σ_p. The EN 12096 demands that the standard deviation of reproducibility σ_R should be contained within the measurement standard for the respective machines in the future.

Since the currently available test codes make no statements about the standard deviation of reproducibility σ_R and the existing quantitative measurements of the uncertainties are already a few years old, the standard deviation of reproducibility σ_R was determined in a round-robin test for the most important machine types.

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Method

The investigation was carried out for 3 breakers, 3 rotary hammers, 2 chipping hammers, 1 electric impact drill and 3 chain saws. Eleven measuring laboratories were involved in the investigations. The laboratories however, did not investigate all machines in every case. In addition, some of the machines were measured by the laboratories of 7 manufacturers of hand-held tools. Table 1 shows an overview of the measurement program. Every machine was measured in at least 5 laboratories, usually in 7 or 8.

Table 1. Measurement programme (o: certified laboratory).

		Laboratory (L)																	
	Symbol	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Machine				o						o	o	o							
Breaker, little	AHK		■	■			■		■	■	■					■			
Breaker, medium	AHM	■	■	■			■		■	■	■					■			
Breaker, large	AHG		■	■			■	■	■	■	■								
Rotary hammer, little	BHK	■	■		■		■	■	■				■	■					
Rotary hammer, medium	BHM	■	■		■		■	■	■				■	■					
Rotary hammer, large	BHG	■	■		■		■	■	■				■	■					
Electric chipping hammer	MHE	■	■	■			■		■	■	■				■	■			
Pneumatic chipping hammer	MHP		■	■			■		■	■	■					■			
Electric impact drill	SBM	■	■	■	■		■	■	■								■		
Electric chain saw	KSE				■	■	■		■			■							
Chain saw, long sword	KSL				■	■	■		■			■							■
Chain saw, short sword	KSK				■	■	■		■			■						■	■
Reference generator	RG	■	■	■	■		■	■	■	■	■		■	■		■			

The measurements on the machines were carried out in accordance with the respective test codes in EN 28662, EN 50144 or ISO 7505. No information about the magnitude of the expected vibration emission was given to the laboratories. The results were documented in uniform test reports together with photos of the measurement situation, the posture of the operators and the accelerometer coupling.

Furthermore a separate mechanical signal generator for reference measurements was built. This reference generator produces a quasi-stochastical acceleration signal, based on a mechanical working principle, with weighted acceleration values comparable to those of breakers or rotary hammers. The comparison of the reference generator measurements allowed conclusions concerning the measurement equipment and the weighting filters.

Results

In almost every laboratory measuring and/or analysing, errors occurred for one or more of the machines. These errors were in some cases noticed by the laboratory itself and corrected by measuring again. In other cases the errors were noticed only after comparison with the results of the other laboratories. In these cases the laboratories were given the possibility of repeating the measurement in order to correct the results. The corrected results were used in the following calculations. There were also cases in which the measurement results of single laboratories deviated significantly from those of the other laboratories, and the repetition measurements again produced the same vibration emission value or the corresponding laboratory was of the opinion that the measurement result was correct. In these cases the results were not integrated into the final evaluations.

In the following presentation of the results the evaluations were based on the corrected data. In the figures the mean values of the results are shown as a point, the single standard deviations as a box and the 1.96 standard deviations as a whisker. For a normal distribution (gauss-distribution) 95% of the values are expected in the range of ±1.96 standard deviations.

The standard deviation of repeatability σ_r (same operator) usually amounts to between 0.1 and 0.5 m/s^2, it may however lie beyond 1 m/s^2 for certain machines (Figure 1). The demand in some test codes (parts of EN 28662) for a variation coefficient less than 0.15 was always fulfilled in these measurements. The values of the standard deviation of the operating persons σ_{op} (same laboratory, 3 operators) usually exceeds the standard deviation of repeatability σ_r only a little. Only in some cases values about 3 m/s^2 were measured. As Figure 1 shows, the mean values of the single operators have differences which are statistically significant in a lot of the cases.

There are also significant differences between the mean values of the different laboratories (mean of 3 operators). Figure 2 shows the mean values of the laboratories and the corresponding standard deviation for three selected machines and the reference generator.

One can see that the measurement differences from laboratory to laboratory and also within each laboratory are distinctly lower for the reference generator than for the real machines. Nevertheless, between the laboratories there are also significant differences in the measured mean values of the reference generator. In a lot of cases the differences of the measurement results of the machines are statistically significant too.

The mean values of the measurement results of all the laboratories and the corresponding standard deviations (and standard deviation of reproducibility σ_R) are presented in Figures 3 and 4.

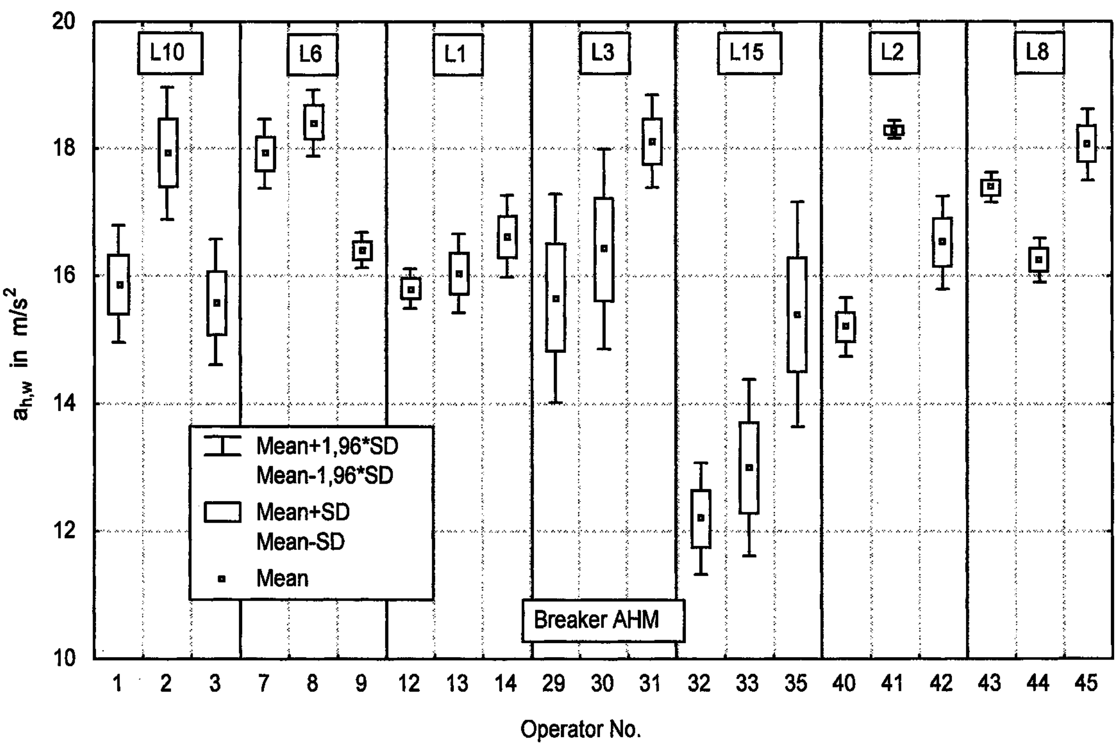

Figure 1. Means and standard deviation of repeatability σ_r for single operators exemplarily for a breaker.

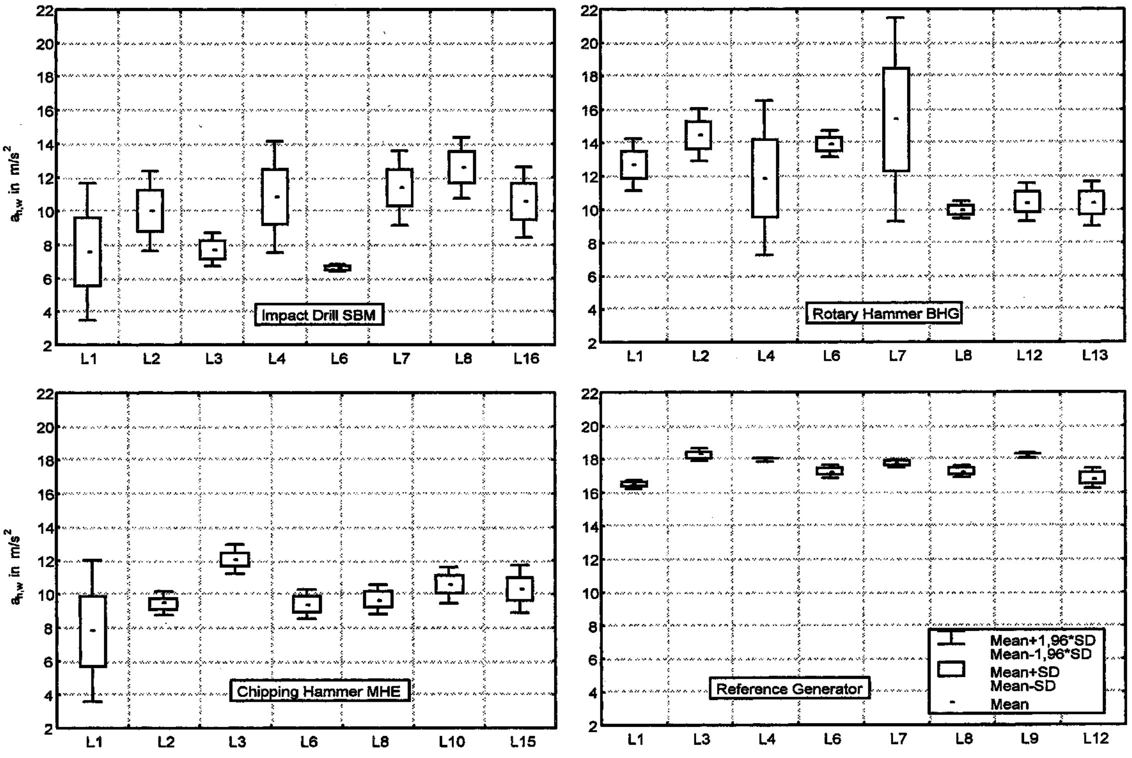

Figure 2. Means and standard deviation of the laboratories for three machines and the reference generator.

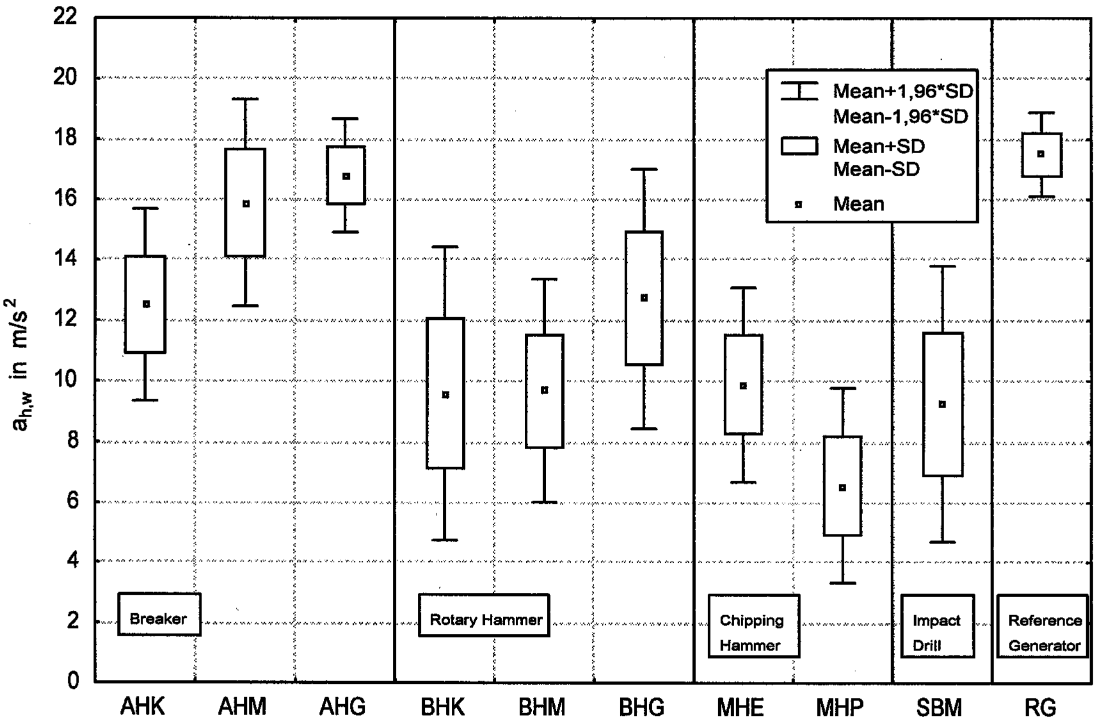

Figure 3. Means and standard deviation of reproducibility σ_R for hammers and drills.

The standard deviation of reproducibility σ_R (different laboratories) is in most cases between 0.6 m/s^2 and 3.0 m/s^2 (table 2). Furthermore, table 2 contains the measurement uncertainty K for the case of a verification measurement of a single tool (K = 1,65 σ_R).

Under favourable circumstances the standard deviation of reproducibility σ_R for measurements on real machines can obviously be on a low level comparable to the one achieved for the reference generator. This points to the fact that the influence of the operator and the employed measurement equipment can theoretically be minimised. In most of the cases the standard deviation of reproducibility σ_R is however, distinctly higher. Hereby, there is no clear connection between the level of the mean value of a single laboratory and the corresponding standard deviation. The correlation coefficient between the mean values and the standard deviation of reproducibility σ_R with r = 0.11 is not significant.

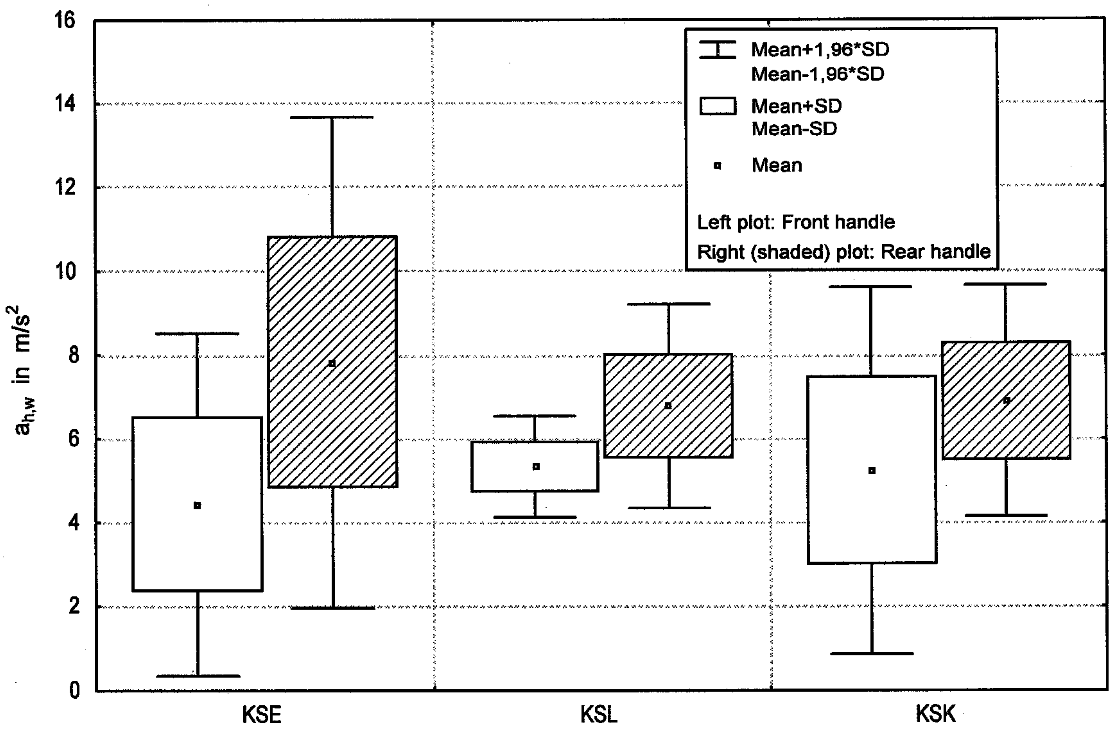

Figure 4. Means and standard deviation of reproducibility σ_R for chain saws.

Table 2. Mean, standard deviation of reproducibility σ_R and measurement uncertainty *K*.

	Mean (m/s^2)		Standard deviation of reproducibility σ_R (m/s^2)		Measurement uncertainty K (m/s^2)	
Machine	Rear Handle	Front Handle	Rear Handle	Front Handle	Rear Handle	Front Handle
AHK	12.53		1.6205		2.67	
AHM	15.89		1.7518		2.89	
AHG	16.80		0.9569		1.58	
BHK	9.59		2.4745		4.08	
BHM	9.69		1.8753		3.09	
BHG	12.73		2.1859		3.61	
MHE	9.88		1.6308		2.69	
MHP	6.56		1.6452		2.71	
SBM	9.25		2.3242		3.83	
KSE	7.82	4.44	2.9894	2.0881	4.93	3.45
KSL	6.78	5.34	1.2439	0.6150	2.05	1.01
KSK	6.91	5.24	1.4113	2.2336	2.33	3.69
RG	17.50		0.7080		1.17	

Discussion

With respect to repeatability and reproducibility, vibration measurements on hand-held tools still are problematic tasks.

Nowadays the influence of the measurement equipment (including the weighting filter) does not seem such a great problem. The results of the reference generator showed that the uncertainty is only 6.7%. In this case the differences mainly result from the measurement equipment and the accelerometer coupling. The significant differences of the measurement results obtained by the different laboratories suggest that there is still a possibility to minimise the measurement uncertainty resulting from the measurement equipment (5).

Machines with very short and powerful impacts set high demands for the measurement equipment. The investigation showed, that pneumatically driven hammers caused a lot of measurement errors and large deviations.

Another great problem is the method of fixation and the mounting position of the accelerometer which did not always comply with the standards. Some of the measurement errors in the laboratories clearly resulted from these mistakes.

The operators, with their individual methods of working and individual coupling forces, have a great influence. Moreover, higher standard deviations of reproducibility are probably caused by the operators postures, which were in some cases contrary to the standard test codes or not comfortable for the working task.

Due to the standardisation work of the last years, the influence on the measurement deviation of a lot of technical and technological parameters (e.g. absorber, materials, inserted tools) was reduced. Nevertheless, there are considerable measurement variations and deviations. Based on this study, the declared weighted acceleration for the rotary hammer BHK is a = 9.6 m/s^2 and K = 4.1 m/s^2. This means, that the uncertainty is 40% of the measured value for this machine.

The uncertainty and the deviation increase enormously if a measurement error is not discovered immediately. The investigation showed that certified laboratories also had large deviations and measurement errors.

Conclusions

The presented study gives information on the standard deviation of reproducibility for rotary hammers, breakers, chisel hammers, impact drills and chain saws. Similar investigations should be carried out for other hand-held or hand-guided tools (e.g. grinders, nibblers). In addition further investigations are necessary to determine the reasons for the deviations, especially for machines with very short and powerful impacts. With the employment of these results within the standard test codes, we have additional possibilities to reduce the measurement uncertainty.

Further investigations are especially necessary in the following problem areas:

- Development of specialised measurement equipment and measurement accessories for certain machines (e.g. pneumatic hammers).
- Further standardisation of the mounting position and the coupling of the accelerometer, especially on resilient material covered handles and grips offering little mounting space.
- More information in the standard test codes and more precise instructions with regard to the requirements and parameters necessary to avoid measurement errors.

Some simplifications of requirements and some comments regarding requirements which have to be strictly fulfilled are also necessary.
- Development of criteria to estimate the qualification and the practice of the skilled operator and the measurement staff.

Moreover, more efforts should be made to substitute the human operator in emission measurements in order to reduce the measurement uncertainty and deviations.

Acknowledgement

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Usefulness of vibration emission declarations in the management of hand-arm vibration risk at the workplace: grinding machines

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Introduction

The Directive of the Council of the European Communities (EC) on the approximation of the laws of the Member States relating to machinery (89/392/EEC, 91/368/EEC) requires that manufacturers and suppliers of hand-held tools supply, amongst other information, the vibration emission of their tools if the frequency-weighted root mean square acceleration value exceeds 2.5 m/s^2. When the acceleration does not exceed 2.5 m/s^2, this must be mentioned. The main purpose of such declaration should be to make purchasers aware of potential risks of vibrating tools on the market with the aim of the reduction of the risk from hand transmitted vibration, as stated by the EEC Directives on safety and health at the workplace. In this context, test codes used by manufacturers in declaring emission values should be able to provide "a*ccurate and reproducible results as well as results which are as far as possible in agreement with results measured under real working conditions*", as the ISO 8662-1 standard (2) states in the foreword of general part.

This paper reports the findings of an investigation on grinding and polishing machines to assess whether vibration emission declarations are adequate to compare vibration exposure from different machines in order to allow purchasers to single out the most effective tools with respect to the risk reduction expectation in actual work conditions.

Methods

Tools and working procedures

Ten grinders, six die grinders, and three polishers were investigated. Field measurements took place at five different companies. The main activities of the companies were stone manufacturing, stone carving and carriage refurbishment. Measurements were made on new, properly serviced machines, purchased by the companies for use in normal work cycles. The vibration emission declared by the manufacturers according to ISO 8662 (3, 4, 5) or EN 28862 was available for each tool. The characteristics of the tools are reported in table 1. Vibration measurements were carried out during simulated work procedure, designed to avoid interruptions between operations, due to picking up, putting down or replacing the work-piece operations, which usually occur during normal working. Two or three skilled operators performed 30-s series of five grinding, cutting or polishing operations of marble, granite, or steel plates, artificially created to represent actual vibration exposure conditions during normal tool operation.

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Measurement methods

Tri-axial acceleration measurements were performed according to the recommendations of the International Standards ISO 5349 (1) and ISO 8041(6). Three piezoelectric miniature accelerometers (B&K type 4374) were fixed to the handle of the tool by means of the handle adaptor (B&K type 4392). The axes were labelled as follow: Z axis: parallel to the rotation axis of the wheel; Y axis: parallel to the tool handle or the tool body; X axis perpendicular to both Y axis and Z axis.

Vibration signals were amplified by three charge amplifiers (B&K 4325) and then recorded using a 4 channel digital data recorder (Teach RD-101 T). Frequency analysis was performed using the spectrum analyser Larson - Davis mod. 2800. The measurement chain was calibrated using the calibration exciter B&K type 4294.

Table 1. Characteristics of the tools.

Tool	Type	Power source	Power (kW)	Declared vibration emission (m/s^2)
1	die grinder	pneumatic	0.2	<2.5
2	die grinder	pneumatic	0.2	<2.5
3	die grinder	pneumatic	0.14	<2.5
4	die grinder	pneumatic	0.14	<2.5
5	die grinder	pneumatic	0.14	2.8
6	die grinder	pneumatic	0.14	2.8
7	angle grinder	electric	0.9	<2.5
8	angle grinder	electric	0.9	<2.5
9	angle grinder	electric	0.9	<2.5
10	angle grinder	electric	1.8	2.3
11	angle grinder	electric	0.9	<2.5
12	angle grinder	electric	2.0	2.6
13	angle grinder	electric	1.8	5.5
14	angle grinder	electric	0.7	4.5
15	angle grinder	electric	0.7	4.5
16	angle grinder	electric	1.0	4.5
17	rotary polisher	electric	0.9	<2.5
18	rotary polisher	electric	0.9	<2.5
19	straight polisher	electric	1.8	<2.5

Results

For purpose of comparison between declared vibration values (3, 4, 5) and the frequency-weighted acceleration measured in the field, the vibrating tools were divided into two categories: those with declared values <2.5 m/s^2, and those with declared values >2.5 m/s^2.

Tables 2 and 3 report a summary of the frequency-weighted accelerations declared by the manufacturers and the average frequency-weighted acceleration sum (a_{hws}), measured during actual operating conditions.

Although a_{hwz} is used for vibration emission declaration in ISO 8662 test codes (3, 4, 5), the present work uses the vector sum as the primary quantity for expressing vibration measurement results. This is because the single axis acceleration component underestimates the exposure in the majority of field measurements, as shown in Figure 1.

However, a significant correlation between a_{hws} and a_{hwz} was found (see Figure 1), although Z axis was the dominant axis only in 63% of the field measurements.

Table 2 shows that about 65% of the tools with declared values <2.5 m/s^2 provided field values >2.5 m/s^2. In particular, the range of vibration field measurements of the grinders with declaration values <2.5 m/s^2 extends up to 6 m/s^2

The coefficient of variation for the vibration measurements on each tool was in the range 5%-12% (mean value 7%).

Table 2. Frequency-weighted acceleration for tools with declared values <2.5 m/s^2.

Tools	No. of tools with A_{wsum} <2.5 m/s^2	No. of tools with A_{wsum} >2.5 m/s^2	Field measurements (A_{wsum} in m/s^2, range)
Die grinders	2	2	1.0-3.7
Grinders	1	3	1.0-6.0
Polishers	1	2	1.0-3.5

Table 3. Frequency-weighted acceleration for tools with declared values >2.5 m/s^2.

Tool	Declared value (m/s^2)	Support handle (m/s^2)		Throttle handle (m/s^2)	
		A_{wz}	A_{wsum}	A_{wz}	A_{wsum}
Angle grinder	5.5	4.8	5.6	3.3	4.5
Angle grinder	4.5	4.1	5.1	2.5	3.1
Angle grinder	4.5	2.0	2.6	1.0	2.0
Angle grinder	4.5	5.0	5.8	4.0	4.3
Angle grinder	4.5	4.4	5.1	2.5	3.0
Angle grinder	2.6	3.3	4.5	3.0	3.5
Die grinder	2.8	1.0	1.0		
Die grinder	2.8	2.0	3.7		

The frequency distribution and cumulative distribution of field measurements from the two different classes of tools, those with vibration declarations <2.5 m/s^2 and those with vibration declarations >2.5 m/s^2, are illustrated in figures 2 and 3. There is the evidence for a strong overlapping of vibration measurement results from such different categories of tools.

The plot of field vibration results vs. declaration values (see Figure 4) shows that there is a poor correlation between the measured a_{hws} and the declared vibration values. This is mainly due to the wide spread of field results from tools with declaration values <2.5 m/s^2. On the contrary, a significant concordance correlation coefficient (7) was found for the vibration measurements on the tools with declared values >2.5 m/s^2 (rho = 0.59, p=0.035). For these tools, regression analysis showed the following relation between field vibration measurements and declared values: $a_{ws\ (measured)} = -0.25 + 1.04\ a_{(declared)}$ (p=0.06).

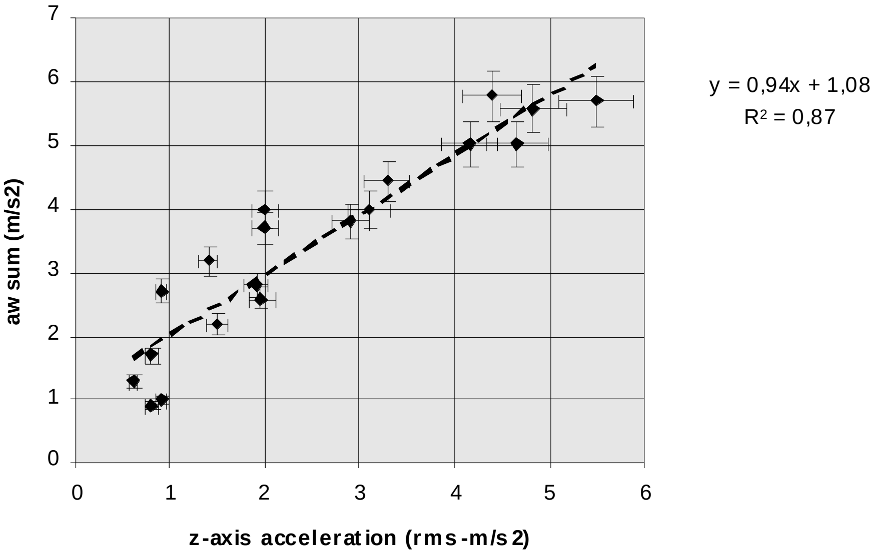

Figure 1. Frequency-weighted acceleration vector sum (a_{hws}) vs. Z-axis acceleration (rms-m/s^2): data from the handle with the highest acceleration magnitude.

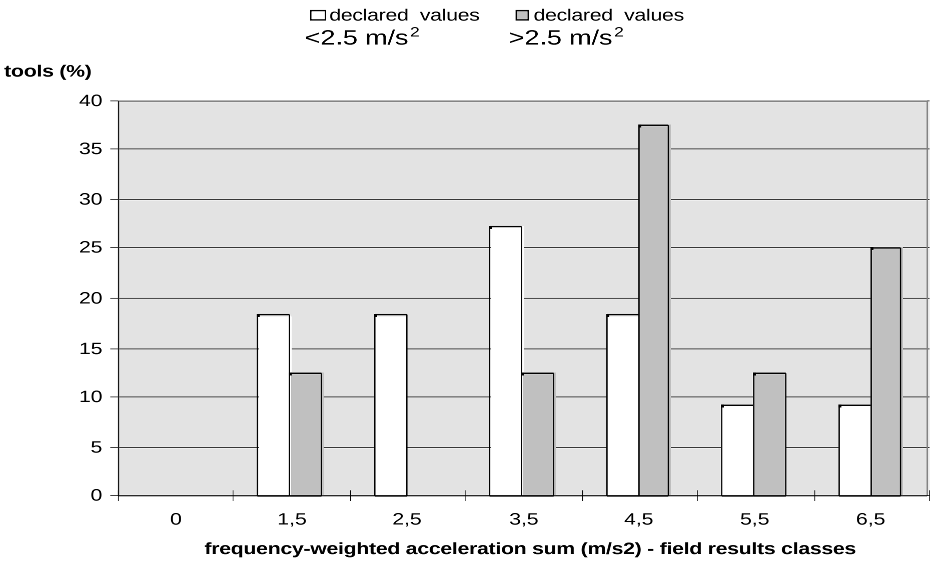

Figure 2. Comparison of frequency distributions of measurement results from tools with declared vibration emission <2.5 m/s^2 and tools with declared vibration emission >2.5 m/s^2.

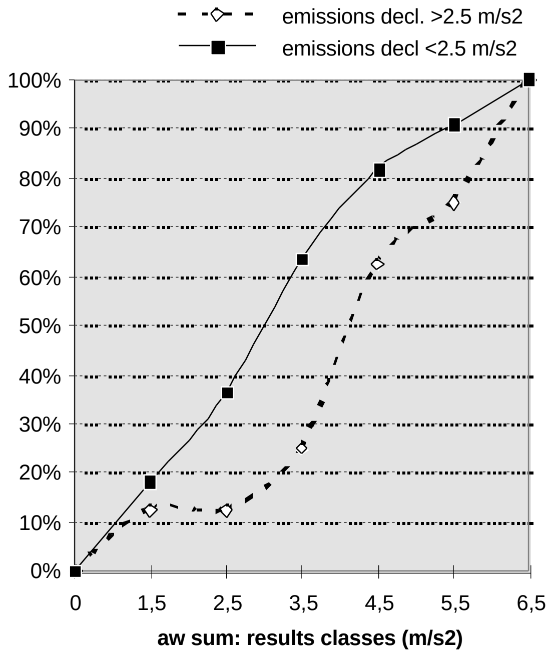

Figure 3. Comparison of cumulative distributions of measurements results from two tools categories: declaration vibration values <2.5 m/s^2 and declaration vibration values >2.5 m/s^2.

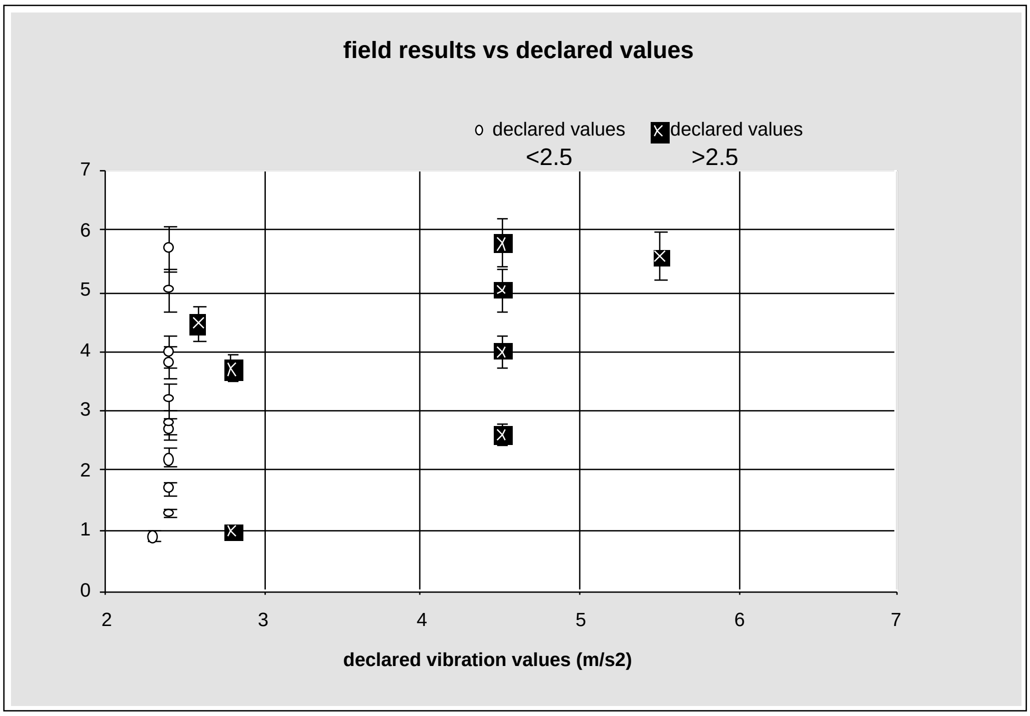

Figure 4. Plot of frequency-weighted acceleration vector sum (m/s^2) as measured in the field vs. declared vibration values.

Discussion

Comparison between emission vibration data and field measurements shows that declaration values are not adequate to compare vibration exposure from different machines in order to allow effective choices of low-risk tools.

More than 65% of tools with declared values <2.5 m/s^2 provided field values >2.5 m/s^2. In particular the range of vibration field measurements of grinders with declaration values <2.5 m/ s^2 extends up to 6 m/s^2. As a result of these findings, emission declaration values " *<2.5 m/s^2* " do not seem to be reliable to rate the vibrations of different machines, with respect to their relative magnitudes in normal working conditions.

The vibrating tools with declared values >2.5 m/s^2 seem to show more concordance with the rating of tool vibration in real operating situations. However, the survey pointed out that the uncertainty of vibration field measurements, associated with the variability of work conditions, makes it difficult to assess differences in vibration measurement results from tools with declared values in the range 4.5-5.5 m/s^2.

In particular, on the basis of the field vibration measurement results obtained in this study, the following classification of grinding machines could be proposed (see table 4).

Table 4. Grinding machines classification according to vibration magnitudes in working conditions.

Class 1	a_{hws} (normal work)<2.5 m/s^2	36% of tools with vibration emission declaration "<2.5 m/s^2 "
Class 2	2.5 m/s^2 <a_{hws} (normal work) <4.5 m/s^2	100% of tools with vibration emission values in the range 2.5-3.5 m/s^2
Class 3	4.5 m/s^2 <a_{hws} (normal work) <6.5 m/s^2	100% of tools with vibration emission values in the range 4.5-5.5 m/s^2

On the basis of these criteria, each grinding machine could be assigned unambiguously to a single class, with respect to the vibration magnitude in normal working conditions.

Conclusions

In agreement with the findings of other authors (8, 9), the present study on grinding machines indicates that declared vibration values are not adequate to compare vibration exposure from different machines in order to allow effective choices of low-risk tools. Particularly the vibration declaration "*<2.5 m/s^2* " can be misleading, due to the wide spread of the vibration measurement results found in this study.

Even though declared values in the range of 2.5-5.5 m/s^2 showed significant concordance with the vibration measurements obtained in real operating conditions, the result of the present survey suggest that it should be more appropriate, with respect to the vibration rating in normal work, to declare vibration emission on the basis of discrete ranges of vibration values, or in terms of discrete vibration risk classes. Further research seems to be needed to implement standard test codes adequate to allow comparative evaluation of vibration exposure from tools, and which can provide results in agreement with the actual vibration exposure at the workplace.

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Vibration emission of road breakers: Comparison of emission test data with vibration in real use

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Introduction

It is a requirement of the Machinery Directive (3) that manufacturers and suppliers must provide information relating to the vibration emission of their machinery. Declaration of such information allows purchasers and users of machinery to make informed choices regarding safety and occupational health. The declared vibration emission is also used in verifying that equipment has been designed and constructed so as to reduce to the lowest level the risks arising from vibration.

The standard relating to declaration of vibration emission values, EN 12096 : 1997 (1), states that manufacturer's declared emission should include both a vibration emission value, a, and an uncertainty K, an indication of spread of vibration emission in production. In practice many manufacturers declare the a value only. The term $a(K)$ is defined as a plus K.

The method of declaring vibration emission is to apply a standard test to a machine or tool (for example, the ISO 8662 series of standards define vibration test codes for specific types of machinery). The purpose of the standard test is to provide a repeatable and reproducible method of estimating vibration emission. However, test designers have reported difficulty in developing standard tests which are based on realistic operations and are repeatable and reproducible, so standard tests are often based on artificial operations. For this reason, there is concern that the vibration emission data produced from the standard test may not reflect the vibration produced by the tool when in normal use.

The purpose of this study was to examine the ISO 8662 Part 5 (2) test for road breakers for reproducibility, and to investigate the relationship between ISO 8662-5 emission values, and vibration emission under real working conditions for the same tools.

Method

Eleven road breakers were obtained from manufacturers and from INRS, France. All tools were supplied with vibration emission data; either declared emission values from manufacturers, or emission test data from INRS. The tools are listed in Table 1.

To gain some indication of the reproducibility of the ISO 8662-5 emission test, the vibration emission of the eleven tools was measured using a test rig for road breakers constructed following the requirements of that standard. These measured vibration emissions could then be compared with the manufacturers' declared vibration. The test rig consists of an artificial loading device, known as a steel ball energy absorber (SBEA). The SBEA consists of a steel tube filled with balls of hardened steel. The power tool works against a test bit resting on top of the balls. The principle of the SBEA is that the steel balls provide "appropriate absorption of the shock wave", and reflect a consistent 15 to 20% of the impact energy back to the tool. The SBEA is positioned so that the operator has an upright posture and works the tool vertically downwards. During testing the tool

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operator maintains a stable operation by applying a defined feed force which, expressed in Newtons, is equivalent to 15 times the mass of the tool in kilogrammes, limited to 200 N (e.g. a 10 kg tool would require a 150 N feed force to be applied by the tool operator).

Table 1. Road breakers used in this study.

Tool	Declared emission (m/s^2)		Chuck size (inches)	Weight (kg)	Speed (impacts/min)	Power source	Vibration isolation system
	a	K					
F	13	6.5[1]	1¼	23.5	1 320	Pneumatic	No
G	3.5	2.5[1]	1¼	26.5	1 320	Pneumatic	Yes
H	10	4	1⅛	29	1 030	Electric	Yes
I	15	2[1]	1¼	32		Pneumatic	No
J	3.5	1.8	1⅛	28	1 320	Pneumatic	Yes
K	8.5	3.4	1⅛	29		Pneumatic	Yes
L	9.5	3.8	1⅛	20	1 100	Pneumatic	Yes
M	4.9	2.5	1¼	35	1 300	Pneumatic	Yes
N	7.8	3.1	1⅛	22.4	1 320	Electric	Yes
O	37.2[2]	14.9	1¼	25	1 150	Pneumatic	No
P	5.5	2.2	1¼	28	1 300	Pneumatic	Yes

[1] K declared; all other K assumed to be 0.4 or 0.5 of a.

[2] Manufacturer acknowledges incorrect declared value.

The measurements of vibration emission consisted of three operators carrying out five test runs on a single tool. The mean of the resulting 15 values represents the vibration emission, a. The associated uncertainty, K, is calculated from both the spread of the values for individual operators and the spread of the average value for each operator.

The eleven road breakers were then taken into a range of typical work situations, where their vibration emission was measured under real working conditions. Four work situations were used, allowing a combination of tool bit, operator, ground type and operation to be studied. The operations ranged from cutting asphalt for resurfacing to trench digging through asphalt into clay and concrete. The type of tool bits used were point, chisel and cutter.

Results

The results of the vibration emission tests on road breakers are shown in Table 2. Measured emission refers to the emission tests carried out for this study. Declared emission refers to the manufacturer’s supplied data, or the test result from INRS.

The field measurements are summarised in Figure 1. Each vertical line in Figure 1 represents the range of observed in-use vibration magnitudes for a single breaker, with individual measurements indicated by a solid circle. These are plotted against measured vibration emission of the tool on the x-axis. A large variability in in-use vibration magnitude is observed on the same tool used by different operators under different conditions. Increases in vibration magnitude from variations in feed force, pulling on the tool, and ‘bottoming’ of suspended handles were noted; these are aspects of typical use of road breakers which are not reproduced in the emission test. An apparent lowest practical limit for breaker vibration under real use, of about 7 m/s^2, was observed.

Table 2. Results of emission tests.

Tool	Vibration emission			
	Measured		Declared	
	a	a(K)	a	a(K)
F	13.5	15.3	13	19.5
G	3.3	4.9	3.5	6
H	18.4	25.3	10	14
I	17.9	19.9	15	17
J	3.2	4.5	3.5	5.3
K	6.6	8.7	8.5	11.9
L	12.2	15.3	9.5	13.3
M	5.5	8.0	4.9	7.4
N	12.9	15.9	7.8	10.9
O	16.9	18.3	37.2	52.1
P	9.8	12.4	5.5	7.7

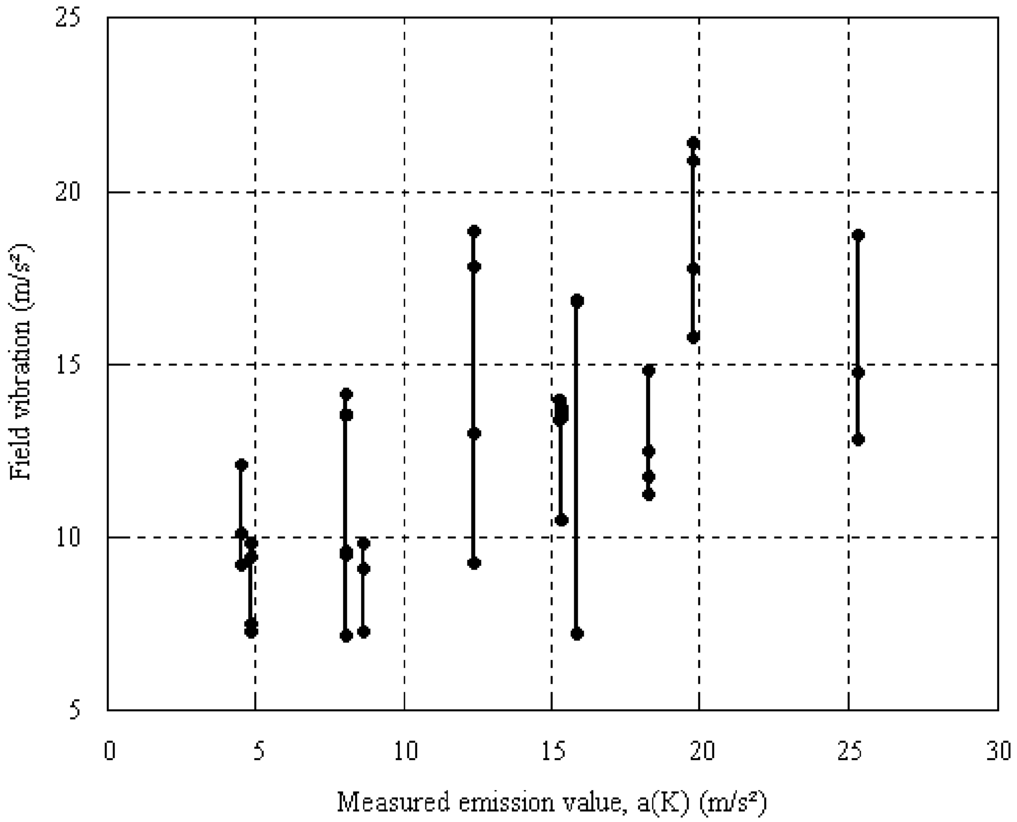

Figure 1. Field vibration vs. vibration emission.

Discussion

The measured and declared vibration emissions in Table 2 can be compared as a means of assessing the reproducibility of the ISO 8662-5 test. The method of comparison used here is the criterion in EN 12096 for verification of declared emission of a single machine. This states that a declared vibration emission value is verified if the measured *a* emission of a single machine is less than the declared *a(K)* emission. According to this criterion, the declared emission *a(K)* is verified by the measured *a* emission in 6 of the 10 cases, excluding the outlying tool O. Statistical analysis of the relationship, using the paired Students t-test with a null hypothesis that the measured *a* emission is greater than the declared *a(K)* emission, gives a probability of 0.38. Hence the null hypothesis is not rejected, and declared vibration emission has not in general been verified by the vibration emission measured here.

The data in Figure 1 show that a single road breaker will give large variations in vibration magnitude when used under different conditions by different operators. There is no evidence of a general relationship between vibration emission and in-use vibration, due to this variation. In addition, the vibration emission values are not useful in comparing tools, since it cannot be shown that in general a breaker with a lower vibration emission will produce less vibration in real use than a breaker with a higher vibration emission. Finally, there is evidence that there may be a lowest achievable limit for road breaker vibration in real use, of about 7 m/s^2. The ISO 8662-5 test code for road breakers therefore can produce vibration emission values below that which is achievable in real use; such emission values cannot reflect the true vibration characteristics of the tool.

Conclusions

The application of the ISO 8662-5 vibration emission test code on 11 road breakers produced measures of vibration emission which did not, in general, validate the declared emission according to EN 12096. The reproducibility of this test code is therefore questioned. It is noted that the test measures vibration under one defined condition of feed force and material/tool interaction, and does not take into account factors such as variations in feed force, off-load running of the tool, different types of tool bit or the material being worked, many of which can influence vibration during use.

The emission values produced by application of the test code do not in general relate to the vibration of the same tools under real operating conditions. The large variation in vibration magnitudes from individual tools under different work conditions, probably due to factors of real tool use not accounted for in the test code, makes it difficult to justify the use of a single emission value to characterise a tool.

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Health surveillance of forestry workers exposed to hand-arm vibration in Wakayama from 1974 to 1996

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Introduction

Vibration syndrome was first reported in Japan in the latter half of the 1930's (1). In the 1960's the national forestry workers suffered from "white finger attack" (Raynaud's phenomenon of occupational origin) as a result of operating chain saws in Japanese forests (1). The occurrence of vibration syndrome had been increasing as the various types of vibrating tools, including chain saws, spread to a wide range of industrial fields in a short time since the latter half of the 1960's (1). The occupational medical examinations for vibration syndrome in Japan were documented in 1970, and revised in 1975 by the Ministry of Labour (2).

In Wakayama there have been many private forestry workers. The first case suffering from vibration syndrome was reported in 1970's (1). Under these circumstances, the counterplan against vibration syndrome was practiced earlier in Wakayama than all over the country. The occupational medical examinations were first carried out in 1974. The regional occupational health care system on vibration syndrome has been established in Wakayama since 1975 (3). Now that more than 20 years have passed, the vibrating tools have been improved to reduce the level of vibration. In this report, the health conditions of private forestry workers have been surveyed to clarify the trends in the number and the severity of vibration syndrome in Wakayama for the past 23 years.

Methods

The subjects examined were 4652 (a total of 9920) workers in the private forestry industry who received occupational medical examinations for vibration syndrome under the regional occupational health care system in Wakayama from 1974 to 1996.

Here, we briefly summarise the regional occupational health care system for private forestry workers exposed to hand-arm vibration in Wakayama (Figure 1). The local office of the Industrial Health Association and the public health division of the local government arrange annual medical examinations for vibration syndrome among private forestry workers. Medical staff conduct the medical examinations at a workshop. The results of the medical examinations are forwarded to the Industrial Health Service Center. A diagnosis is made by the Advisory Committee for vibration syndrome which includes a medical attendant and specialists of vibration syndrome. The health condition and the advice concerning health of the forestry workers are then conveyed personally to the forestry worker by either the local office of the Industrial Health Association or the public health division of the local government.

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The medical examinations for vibration syndrome consist of analysis of working career, working conditions, and physical examinations of the subjects concerned. “Working career” means not only the number of years spent working in the forest, but also the number of years spent operating vibrating tools and the various kinds of tools used. “Working conditions” refers to working environmental conditions, how to attend workshops and the payment system. “Physical examinations” involves a primary examination and a secondary examination to determine peripheral circulatory disturbances, peripheral nerve disturbances and motor disturbances.

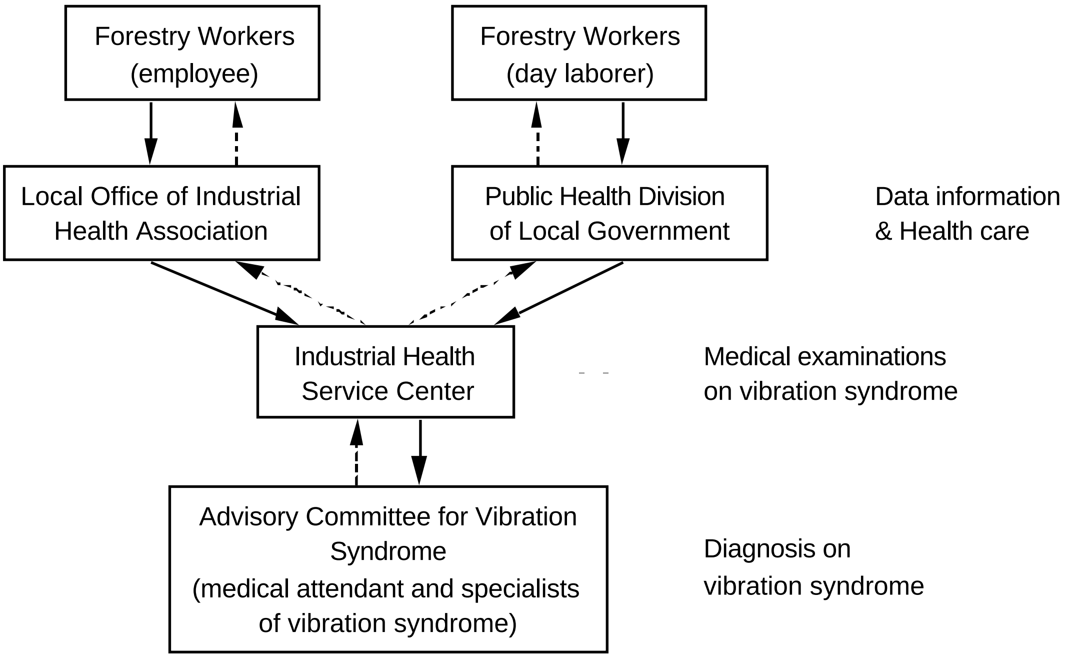

Figure 1. Diagram of the regional occupational health care system.

A diagnosis on vibration syndrome is made by the Advisory Committee for vibration syndrome. Considering the results of the medical examinations, the diagnoses are classified into three health conditions for vibration syndrome; Class A (no abnormality in medical examinations), Class B (periodical clinical observation required), Class C (medical treatment required) (Table 1). All records of the medical examinations for vibration syndrome are kept in the Industrial Health Service Center.

In this report, the records of the medical examinations for vibration syndrome of all subjects were analysed to clarify the trends in the number of the subjects and the severity of vibration syndrome experienced by the subjects examined.

Table 1. Classification of health conditions for vibration syndrome.

Class A:	No abnormality in medical examinations
Class B:	Periodical clinical observation required positive symptoms and signs, positive findings in some examinations
Class C:	Medical treatment required abnormal symptoms and signs, abnormal findings in some examinations

Results

The number of the subjects who took medical examinations for vibration syndrome is shown in Figure 2. In 1978, the number of the subjects was a maximum of 1242. After that, the number decreased, but it was still over 500 until 1983. From 1988, it remained at about 300 or less. The rates of workers undergoing medical examinations to forestry workers in Wakayama were between 12.3% (1990) to 18.7% (1980) since 1980.

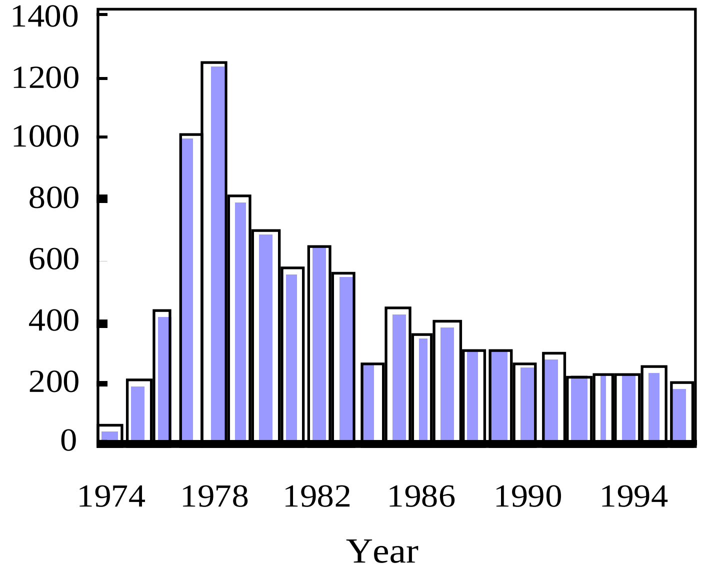

Figure 2. The number of the subjects who took the medical examinations for vibration syndrome.

The age composition was calculated among 1242 subjects in 1978, 304 subjects in 1988 and 186 subjects in 1996 (Figure 3). In 1978, the majority of subjects were in their forties (39%). Next were those in their fifties (36%). In 1988, the subjects in their fifties were a majority (46%) and next, those in their sixties (34%). In 1996, the majority of subjects were in their sixties (38%) and next, those in their fifties (26%). This shows a steady increase in the age level of the subjects examined.

Figure 4 shows the distribution of total operating career of vibrating tools in 1978 and 1996. In 1978, the number of operating years between 10 and 14 years were at a majority (35%) and then, those less than 5 years (24%). In 1996, the number of operating years increased. Subjects who had been operating the vibrating tools for 30 years or more stood at 34%.

The major vibrating tools used were counted in 1978 and 1996 (Table 2). In both years, many subjects used chain saws. 80% of the subjects used the chain saws in 1978 and 91% in 1996. Those who used both a chain saw and a bush cleaner significantly increased from 40% in 1978 to 65% in 1996.

A real number of 4652 (a total of 9920) subjects received medical examinations for vibration syndrome from 1974 to 1996. 59% of the subjects had received medical examinations only once. 82% of the subjects were examined 3 times or less. The mean average was 2.5 times during 23 years. When the subjects were limited to those who had medical examinations in 1996, the average was 7.0 times.

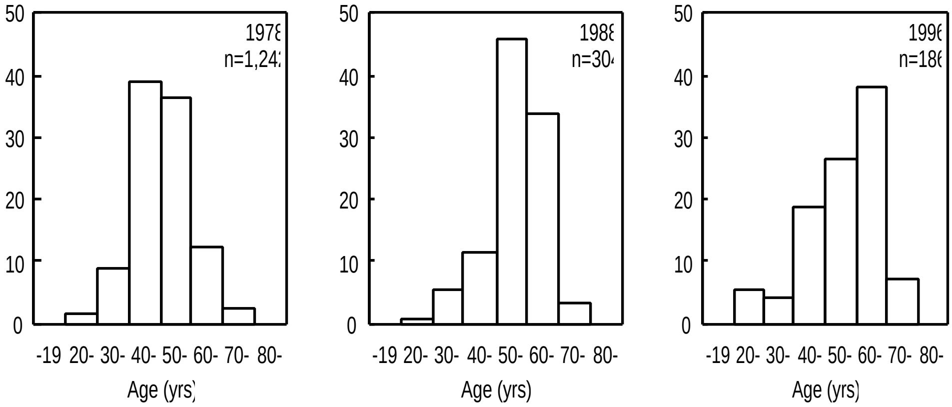

Figure 3. Age composition of the subjects in 1978, 1988 and 1996.

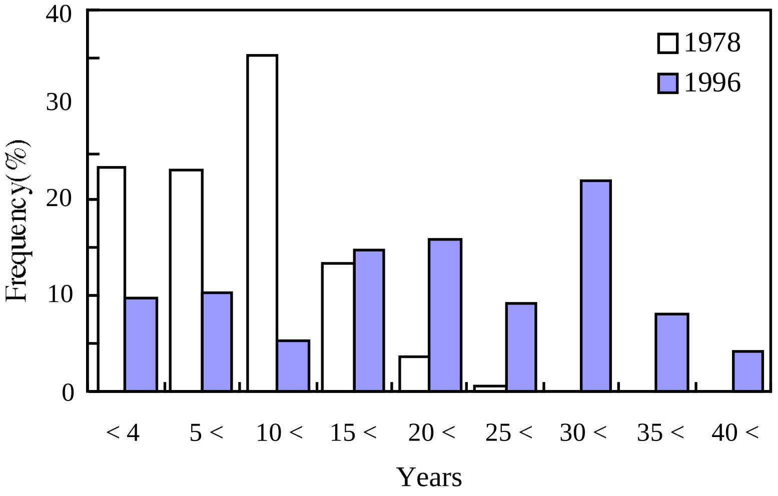

Figure 4. Distribution of total operating career of vibrating tools.

Table 2. Vibrating tools and the frequencies (%) of the usage.

	Year	
	1978 Subjects (1242)	1996 Subjects (161)
Chain saw	30.0	22.4
Bush cleaner	10.4	6.8
Rock drill	3.0	1.9
Chain saw & Bush cleaner	39.5	64.6
Chain saw & Rock drill	0.8	0
Chain saw, Bush cleaner & Rock drill	1.4	3.7
Others	15.0	0.6
Total	100.1	100.0

Trends in the health conditions for vibration syndrome are shown in Figure 5. Class C workers were more than 30% of subjects examined before 1977. In 1978 and 1979, they drastically decreased and then made up less than 10%. In the last 5 years, the proportion of Class C workers was 2%. On the contrary, Class A workers totalled less than 10% of subjects before 1983. Since then, they have been increasing year by year. In the last 5 years, the proportion of Class A workers was 42%. In relation to this trend, the rates of workers complaining symptoms were also analysed in 1978, 1988 and 1996. The rates of workers complaining a vibration induced white finger were 25.9% in 1978, 25.7% in 1988 and 15.1% in 1996, respectively. The rates of workers complaining numbness of the finger were 74.7% in 1978, 70.4% in 1988 and 50.5% in 1996, respectively. The rates were decreasing and answering to the trend.

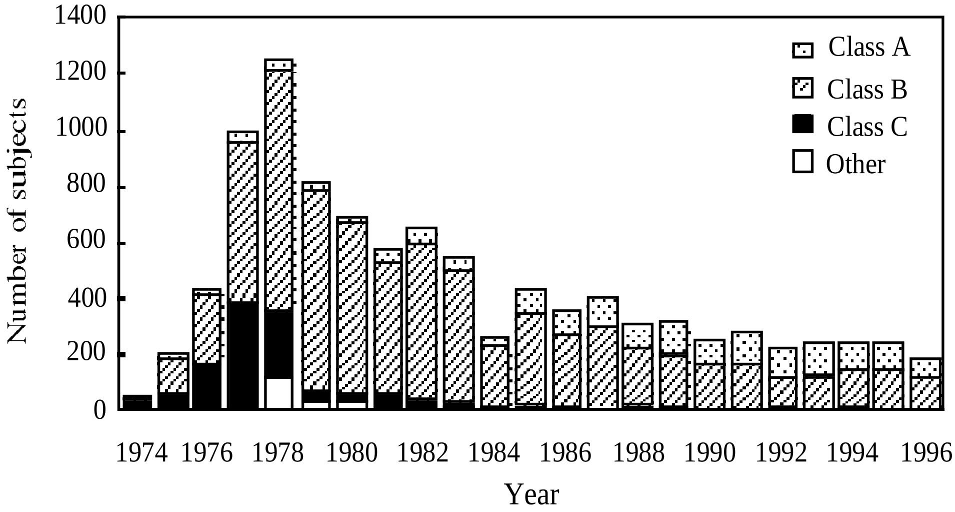

Figure 5. Trends in the health condition of the subjects by medical examinations for vibration syndrome.

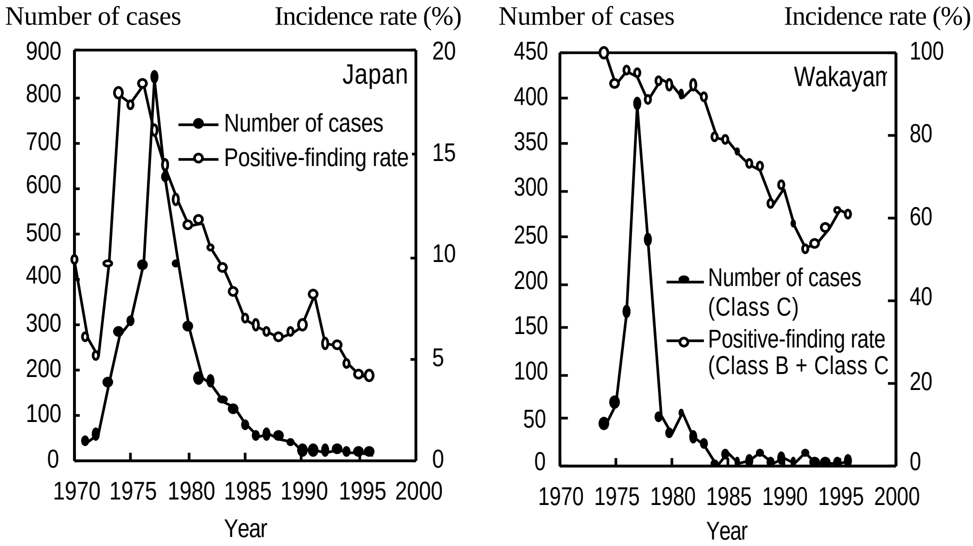

Figure 6. Trends in the number of compensated cases for vibration syndrome and the positive finding rate of medical examinations in Japan and in Wakayama

Figure 6 shows the trends in the number of compensated cases for vibration syndrome and the positive finding rate from medical examinations carried out in Japan and in Wakayama. The Worker’s Accident Compensation Law Statistics shows that the number of cases of people suffering from vibration syndrome in Japan peaked at 841 in 1978, then it gradually decreased year by year. In the last 10 years, less than 60 cases have been discovered. The number of the cases with Class C in Wakayama showed a similar trend to that of compensated cases in Japan. It reached a maximum number of 393 cases in 1977, and then decreased year by year. In the last 10 years, there were 13 or fewer cases. The total number of the cases with Class C was 1181. The positive finding rate of medical examinations, Class B and Class C, in Wakayama was much higher than the overall national figure. It has, however, been steadily decreasing year by year.

Discussion

The Ministry of Labour gave administrative orders for preventive measures against vibration syndrome caused by chain saws in 1970. Then, various administrative orders for preventive measures were enforced to summarise the General Countermeasures against vibration syndrome (2). They are outlined under five main headings: (a) vibration reduction of vibrating tools, (b) work control, (c) medical examination and treatment, (d) education for safety and health, (e) investigation and research. The first general countermeasures have been practiced since 1987.

In Wakayama, according to the orders of the Ministry of Labour, improvements of forestry working conditions, the travelling guidance for the proper use of vibrating tools and the campaign for taking medical examinations for vibration syndrome have been introduced since 1976 (4). However, vibration syndrome commonly occurred at that time. The number of cases suffering from vibration syndrome peaked in Wakayama in 1977.

Concerning the background on the frequent occurrence of vibration syndrome in Wakayama, we can point out the following:

- There were so many private forestry workers because forestry is one of the main industries in Wakayama.
- These forestry workers have been working in small scale industries, so they have been excluded from the occupational health care system.
- Wages have been calculated according to work output, so that getting high wages required longer working hours.
- Working environments were uncomfortable; the cold environment of the forests and poor working posture on the slope of mountains.

The regional occupational health care system for vibration syndrome has been active in Wakayama since 1975 (4). It is a result of combining the occupational health care system with the regional health care system. It matched the occupational health of small scale industries in the local area. Under this system, health care and work control have been practiced strictly according to the diagnosis. Class B workers are permitted to operate vibrating tools for only short periods, or are relocated to a workshop free of exposure to hand-arm vibration. Class C workers are prohibited from operating vibrating tools and receive necessary medical treatment for their disturbances or disabilities. The number of Class C workers drastically decreased in 1979, and then totalled less than 10% among the subjects. This indicates that comprehensive countermeasures, including health care and control of operating hours were effective against vibration syndrome.

As another improvement of the regional occupational health care system for private forestry workers, the health surveillance card has been introduced since 1975. It enables us to observe longitudinal changes of circulatory function, nerve function, motor function and symptoms of hands. Forestry workers can utilise these serial findings to keep an eye on health and work conditions. Health management can conduct continuous follow-up for the health conditions of forestry workers or effects of vibration on health. The regional occupational health care system including the surveillance card has probably contributed to the decrease of, or prevention of, the occurrence of vibration syndrome in Wakayama.

Not only an establishment of the health care system, especially the medical examinations widespread in various workshops requiring vibrating tools, but also an improvement of vibrating tools has played an important role in decreasing vibration syndrome. Vibration acceleration levels of chain saw handles decreased from 3-7G in 1974 to 1-1.5G in 1980 (5). Almost all vibration tools have been improved to the level below the allowance level. However, even if the vibration level of tools is below the allowance level, the health effects of long-term exposure to vibration should be considered.

Although the occurrence of severe cases is rare, vibration syndrome is still one of the most serious occupational diseases in Wakayama. The private forestry workers get older. They are easily affected by the hand-arm vibration of the tools and by the static muscular loads of the work, showing neck-shoulder-arm syndrome. Thus, a further advanced health care system is needed for private forestry workers operating vibrating tools.

Conclusion

To clarify the trends in the number and the severity of vibration syndrome in Wakayama for these 23 years, the records of the medical examinations for vibration syndrome were analysed with 4652 (a total of 9920) private forestry workers exposed to hand-arm vibration. The number of the subjects who took the medical examinations reached a maximum of 1242 in 1978. After that, it decreased year by year, but remained at about 300 or less from 1988. There was a corresponding increase in age and the number of years of operating chain saws among the subjects examined. The compensated cases reached a maximum number of 393 cases in 1977, and then a drastic decrease was noted. Year by year there was an increase in the number of cases whose medical examinations revealed no abnormality. The regional occupational health care system including the surveillance card, which has been active since 1975, has probably contributed to the decrease or prevention of occurrence of vibration syndrome in Wakayama.

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Evaluation of the test procedures for the testing of antivibration gloves per ISO Standard 10819

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Introduction

In the field of personal protective equipment, gloves were being manufactured and marketed that claimed to significantly reduce the magnitude of vibration transmitted from vibrating tools to the hand. Most of these claims proved to be false. As a result, the International Organization for Standardization adopted ISO Standard 10819 to define test procedures that must be used to measure the vibration attenuation characteristics of gloves that were designed to reduce vibration into the hand (1). This standard also specified the vibration attenuation values that must be achieved for a glove to be labelled as an ”antivibration glove”.

A project was undertaken at the Center for Mechanical & Environmental Systems Technology (CMEST) at the University of Nevada, Las Vegas in the USA to develop a test system that can be used to conduct glove vibration transmissibility tests per the test procedures specified in ISO Standard 10819. The test system that was developed during this project is described in a companion paper by the authors of this paper (3). The test protocol for measuring the vibration transmissibility of gloves per the test procedures specified in ISO Standard 10819 were examined and evaluated as part of this project. The results of this analysis are discussed in this paper.

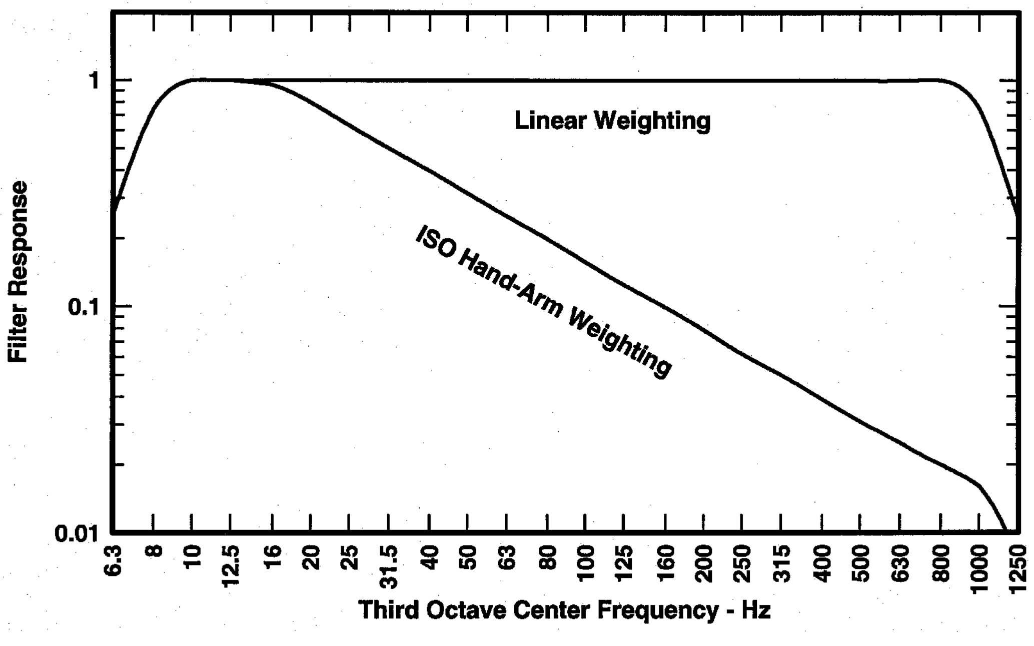

Figure 1. ISO weighting filter per ISO Standard 5349 and a linear weighting filter.

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ISO standard 10819 test procedure

ISO Standard 10819 specifies the test procedures that must be used to measure the vibration transmissibility of gloves (1). The vibration transmissibility of a glove per ISO Standard 10819 is the ratio of the vibration amplitude directed into the palm of the hand inside of a glove divided by the vibration amplitude directed into the palm on the outside surface of the glove. The vibration signals that are measured at the handle and into the palm are the overall acceleration signals that are passed through an ISO weighting filter that is specified by ISO Standard 5349 (2). Figure 1 shows the ISO weighting filter. The vibration transmissibility of a glove is a measure of the attenuation of vibration into the hand and arm by means of a resilient or vibration-damping material placed in the glove. The lower the vibration transmissibility, the more effective a glove is in reducing vibration energy into the hand and arm.

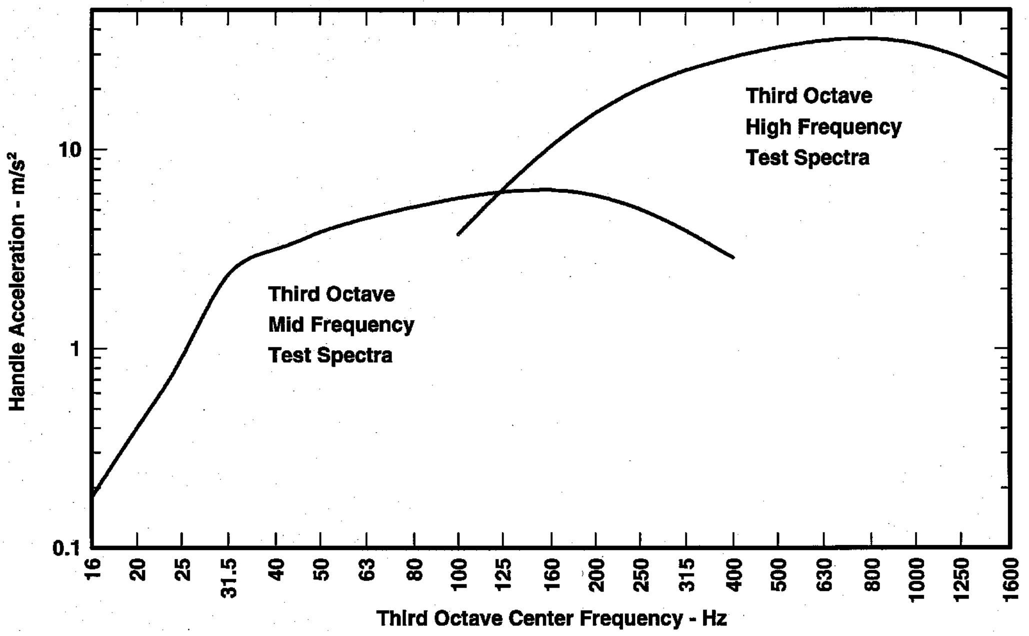


Figure 2. ISO Standard 10819 mid and high frequency test spectra.

ISO Standard 10819 specifies the amplitude of vibration transmissibility that must be achieved for a glove to be classified as an antivibration glove. The standard requires the overall vibration transmissibility of a glove to be measured for mid frequencies (16-400 Hz) and for high frequencies (100-1600 Hz). Figure 2 shows the third octave amplitudes of the vibration spectra for the mid and high frequency test signals, respectively. Tables 1 and 2 shows the third octave band amplitudes and required band tolerance values for the mid and high frequency test signals, respectively. Vibration first corresponding to the mid frequency test spectrum and then to the high frequency test spectrum are directed into the hand by means of a 40 mm diameter handle attached to a vibration shaker. Sets of two measurements on each of three test subjects for a total of six measurements are made for each frequency range. Three different gloves, one for each test subject, are used for each test series. The six individual transmissibility values for each of the mid and high frequency test signals are averaged to obtain the respective average ISO Standard 10819 vibration transmissibility values. The average mid-frequency transmissibility is designated $\underline{TR}_M$, and the average high-frequency transmissibility is designated $\underline{TR}_H$. For a glove to be classified as an antivibration glove:

- $\underline{TR}_M$ must be less then 1.0, and $\underline{TR}_H$ must be less than 0.6.
- The resilient or vibration-damping material must be placed in the palm and the full finger and thumb stalls of the glove.

Table 1. ISO Standard 10819 mid frequency acceleration and tolerance values.

Frequency Hz	a_{ms} - m/s^2	a_{ms} - dB	Tolerence - dB
16	0.18	85.1	± 2
20	0.40	92.0	± 2
25	0.90	99.1	+ 2
31.5	2.36	107.5	± 1
40	3.18	110.0	± 1
50	3.88	111.8	± 1
63	4.54	113.1	+ 1
80	5.16	114.3	± 1
100	5.71	115.1	± 1
125	6.14	115.8	± 1
160	6.28	116.0	± 1
200	5.89	115.4	± 1
250	5.04	114.0	± 2
315	3.94	111.9	± 2
400	2.89	109.2	± 2

Table 2. ISO Standard 10819 high frequency acceleration and tolerance values.

Frequency Hz	a_{ms} - m/s^2	a_{ms} - dB	Tolerence - dB
100	3.77	111.5	± 2
125	6.29	116.0	± 2
160	10.47	120.4	± 2
200	15.24	123.7	± 1
250	20.20	126.1	± 1
315	24.86	127.9	± 1
400	29.07	129.3	± 1
500	32.48	130.2	± 1
630	35.15	130.9	± 1
800	35.95	131.1	± 1
1000	33.79	130.6	± 1
1250	28.91	129.2	± 2
1600	22.40	127.0	± 2

Table 3. Legend for gloves that were tested.

Glove No.	Vibration-damping material	Glove/outer shell material
1	Air Bladder	Leather
2	Air Bladder	Leather
3	Air Bladder	Leather
4	Air Bladder	Leather
5	Air Bladder	Leather
6	Air Bladder	Leather
7	Air Bladder	Leather
8	Viscolas	Leather
9	Gelfom	Leather
10	Gelfom	Kevlar
11	Gelfom	Leather
12	Akton	Leather
13	Sorbothane	Lycra/Leather

Glove vibration transmissibility tests

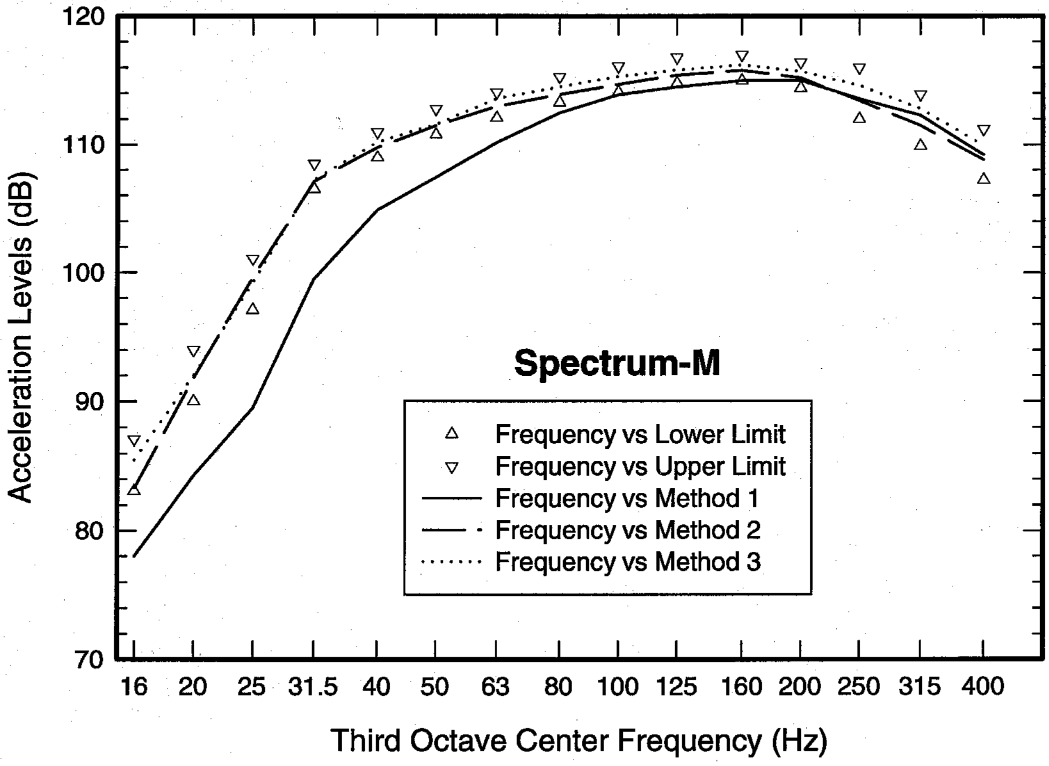
Thirteen different gloves were tested. The type of vibration-damping material that was placed in each glove is listed in Table 3.

Manual method of controlling shaker handle acceleration values

The ISO Standard 10819 mid and high frequency test spectra for this project were manually adjusted for the glove vibration transmissibility tests. Three methods for adjusting the shaker handle acceleration spectra were examined:

Method 1: The third octave mid and high frequency acceleration values of the shaker handle were adjusted with no one clasping the handle. When the handle was clasped for a test, the acceleration amplitudes in the third octave frequency bands below 160 Hz decreased as is shown in Figure 3. ISO Standard 10819 tests were conducted where no adjustments were made to compensate for these decreased acceleration values.

Method 2: The acceleration values of the shaker handle were adjusted per the procedures used in Method 1. The decreases in third octave acceleration values were measured for each of the three test subjects that were used for a specific test series. The corresponding average values were calculated for each affected third octave frequency band. The third octave graphic equalizer that was used to control the input spectrum to the shaker handle was then adjusted to compensate for the ”averaged” changes in acceleration values. Figure 3 shows the effectiveness of this method in controlling the ISO Standard 10819 mid and high frequency acceleration values of the shaker handle. ISO Standard 10819 tests were conducted with no further adjustments being made to the shaker handle vibration amplitudes.



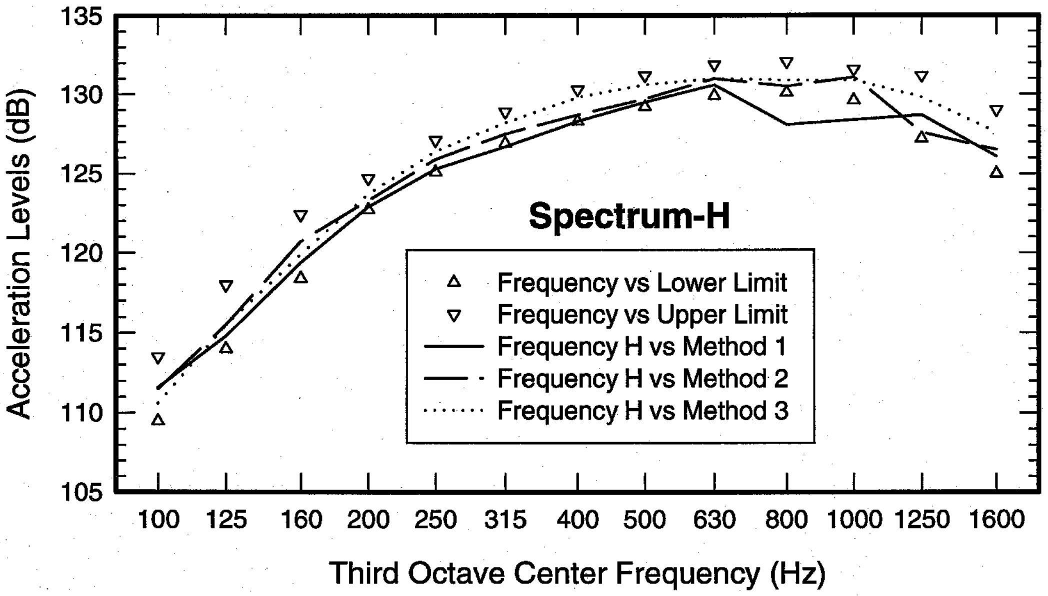


Figure 3. Typical handle mid frequency acceleration spectra (Spectrum-M) and high frequency spectra (Spectrum-H) for methods 1, 2, and 3 (The triangular symbols represent the lower and upper acceleration limits specified by ISO Standard 10819).

Method 3: The acceleration values of the shaker handle were adjusted per the procedures used in Method 1. As each test subject clasped the shaker handle for a test, the third octave graphic equalizer was manually adjusted until the handle acceleration values for the test were within the third octave amplitude limits specified by ISO Standard 10819. Method 3 was used for all of the ”official” ISO Standard 10819 vibration transmissibility tests that were conducted at CMEST.

Table 4. Test results (Value (±SD)) for gloves 1, 9, and 12 using methods 1, 2, and 3 .

Glove No.	Weighting Filter	Frequency Range	Method 1	Method 2	Method 3
1	ISO	$\underline{TR}_M$	0.77 (0.06)	0.79 (0.04)	0.78 (0.08)
		$\underline{TR}_H$	0.72 (0.03)	0.70 (0.04)	0.70 (0.08)
	Linear	$\underline{TR}_M$	0.76 (0.04)	0.76 (0.01)	0.72 (0.05)
		$\underline{TR}_H$	0.48 (0.04)	0.46 (0.03)	0.47 (0.03)
9	ISO	$\underline{TR}_M$	0.82 (0.04)	0.81 (0.05)	0.84 (0.03)
		$\underline{TR}_H$	0.79 (0.03)	0.77 (0.01)	0.75 (0.01)
	Linear	$\underline{TR}_M$	0.82 (0.02)	0.82 (0.01)	0.82 (0.01)
		$\underline{TR}_H$	0.60 (0.06)	0.57 (0.02)	0.54 (0.03)
12	ISO	$\underline{TR}_M$	0.95 (0.06)	0.90 (0.04)	0.94 (0.02)
		$\underline{TR}_H$	1.00 (0.05)	0.93 (0.01)	1.01 (0.03)
	Linear	$\underline{TR}_M$	0.95 (0.03)	0.95 (0.01)	0.94 (0.02)
		$\underline{TR}_H$	0.96 (0.05)	0.91 (0.02)	0.97 (0.04)

ISO Standard 10819 vibration transmissibility tests were conducted using the ISO weighting filter as specified by the standard and a linear weighting filter (Figure 1). Table 4 shows a comparison of the test results for Methods 1, 2, and 3. Table 4 indicates that the method of adjusting the shaker handle acceleration values had little effect on the ISO and linear glove transmissibility values.

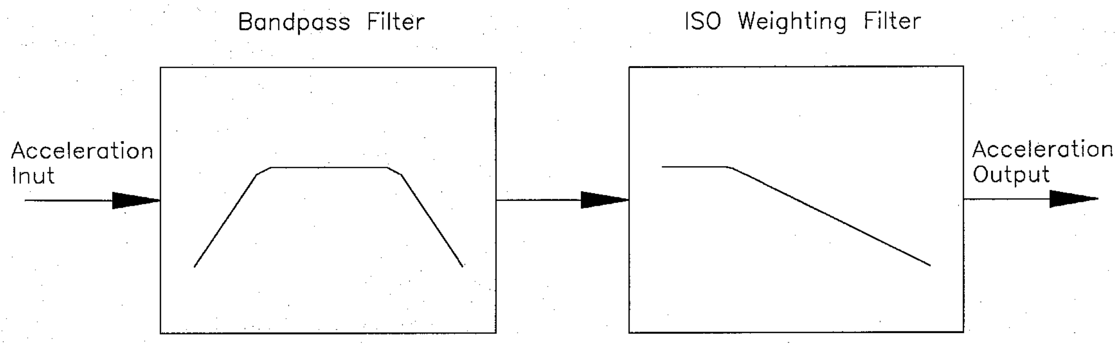


Figure 4. Filter setup for measuring the ISO weighted acceleration value.

Weighting filter bandwidths

ISO Standard 10819 requires that the rms acceleration values at the shaker handle and at the palm of the hand be measured using the ISO weighting filter that is specified in ISO Standard 5349. Figure 4 shows a schematic of the filter setup for measuring the ISO weighted acceleration amplitudes. Figure 1 shows the overall results of the filter setup when the corner frequencies of the bandpass filter are 6.3 Hz and 1250 Hz.

Table 5. Bandpass filter corner frequencies.

Spectrum	CMEST	DELTA	BIA
Mid frequency	16-400	31.5-200	6.3-1250
High frequency	100-1600	200-1250	6.3-1250

Different laboratories have interpreted the above requirements differently. Table 5 shows how the requirements of ISO Standard 10819 have been interpreted by the Berufagenossenschaftliches Institut für Arbeitssicherheit (BIA), Delta Acoustic & Vibration (DELTA), and the Center for Mechanical & Environmental Systems Technology (CMEST). Each of these laboratories have selected different corner frequencies for the bandpass filter for the mid and high frequency measurements. Table 6 shows a comparison of the vibration transmissibility test results that were obtained at CMEST and the corresponding results that were obtained at DELTA and BIA

Table 6 indicates that the ISO Standard vibration transmissibility results that were obtained at the above three laboratories agreed well with each other. This good agreement occurred because the ISO mid and high frequency spectra to the shaker handle was properly controlled at the three laboratories. Vibration energy outside of the frequency bandpasses for the mid frequency spectrum (16-400 Hz) and for the high frequency spectrum (100-1600) were properly attenuated (at least -12 dB/octave at the low and high corner frequencies). When this is the case, any of the corner frequencies given in Table 5 can be used for a bandpass filter that is placed before an ISO weighting filter and yield similar results.

Table 6. Comparison of ISO Standard 10819 glove vibration transmissibility test results (Value (±SD)).

GLOVE		CMEST	DELTA	BIA
Glove 3	$\underline{\mathrm{TR}}_M$	0.85 (0.03)	0.89 (0.09)	
	$\underline{\mathrm{TR}}_H$	0.71 (0.01)	0.69 (0.09)	
Glove 4	$\underline{\mathrm{TR}}_M$	0.68 (0.04)	0.73 (0.12)	
	$\underline{\mathrm{TR}}_H$	0.52 (0.03)	0.52 (0.09)	
Glove 5	$\underline{\mathrm{TR}}_M$	0.65 (0.06)	0.72 (0.07)	
	$\underline{\mathrm{TR}}_H$	0.51 (0.04)	0.51 (0.07)	
Glove 7	$\underline{\mathrm{TR}}_M$	0.79 (0.02)		0.87 (0.06)
	$\underline{\mathrm{TR}}_H$	0.56 (0.02)		0.58 (0.03)
Glove 9	$\underline{\mathrm{TR}}_M$	0.82 (0.04)	0.87 (0.09)	
	$\underline{\mathrm{TR}}_H$	0.80 (0.02)	0.79 (0.11)	
Glove 11	$\underline{\mathrm{TR}}_M$	0.79 (0.02)	0.85 (0.09)	
	$\underline{\mathrm{TR}}_H$	0.76 (0.04)	0.76 (0.13)	
Glove 10	$\underline{\mathrm{TR}}_M$	0.86 (0.04)		0.93 (0.01)
	$\underline{\mathrm{TR}}_H$	0.83 (0.04)		0.72 (0.02)

ISO weighted versus linear vibration transmissibility values

ISO Standard 10819 requires that glove vibration transmissibility values be obtained using the ISO weighted acceleration values at the shaker handle and palm of the hand. One of the problems with this is that the ISO weighted vibration transmissibility values tend to underestimate the vibration attenuation characteristics of antivibration gloves. Figure 5 shows the effects of the ISO weighting filter on the mid and high frequency input spectra for ISO Standard 10819. This figure indicates that the ISO weighting biases the ISO weighted values of acceleration to the third octave acceleration values that are closest to the lower frequency limits of the respective input spectra. Thus, the attenuation effectiveness of a glove at the third octave frequencies near the upper frequency limits of the respective input spectra is significantly underestimated.

This problem can be addressed by measuring the glove vibration transmissibility values, using a linear weighting filter (Figure 1). Table 7 shows the ISO and linear weighted vibration transmissibility values of the gloves that were tested during this project. There was not a significant difference between the ISO and linear transmissibility values for the mid frequency vibration input. However, the linear transmissibility values were substantially less than their corresponding ISO weighted values for the high frequency input.

Figure 6 shows the relations that exist between the ISO and linear weighted vibration transmissibility values for the ISO 10819 mid and high frequency input spectra. The equation for the mid frequency input spectrum is:

$$TR_{(Lin)} = 0.2176 + 0.8265\ TR_{M(ISO)}$$

The correlation coefficient for this equation is 0.98 and the standard error of fit is 0.028. The equation for the high frequency input spectrum is:

$$TR_{H(Lin)} = -716.7 + 639.3\ TR_{H(ISO)} - 406.2\ TR^{2.5}_{H(ISO)} + 216.4\ TR^{3}_{H(ISO)} + 728.9\ e^{-TR_{H(ISO)}}$$

The correlation coefficient for this equation is 0.99 and the standard error of fit is 0.042. These two equations can be used to convert from ISO weighted vibration transmissibility criteria values to their corresponding linear criteria values. This yields the following:

$\underline{TR}_{M(Lin)} < 1$ and $\underline{TR}_{H(Lin)} < 0.37$.

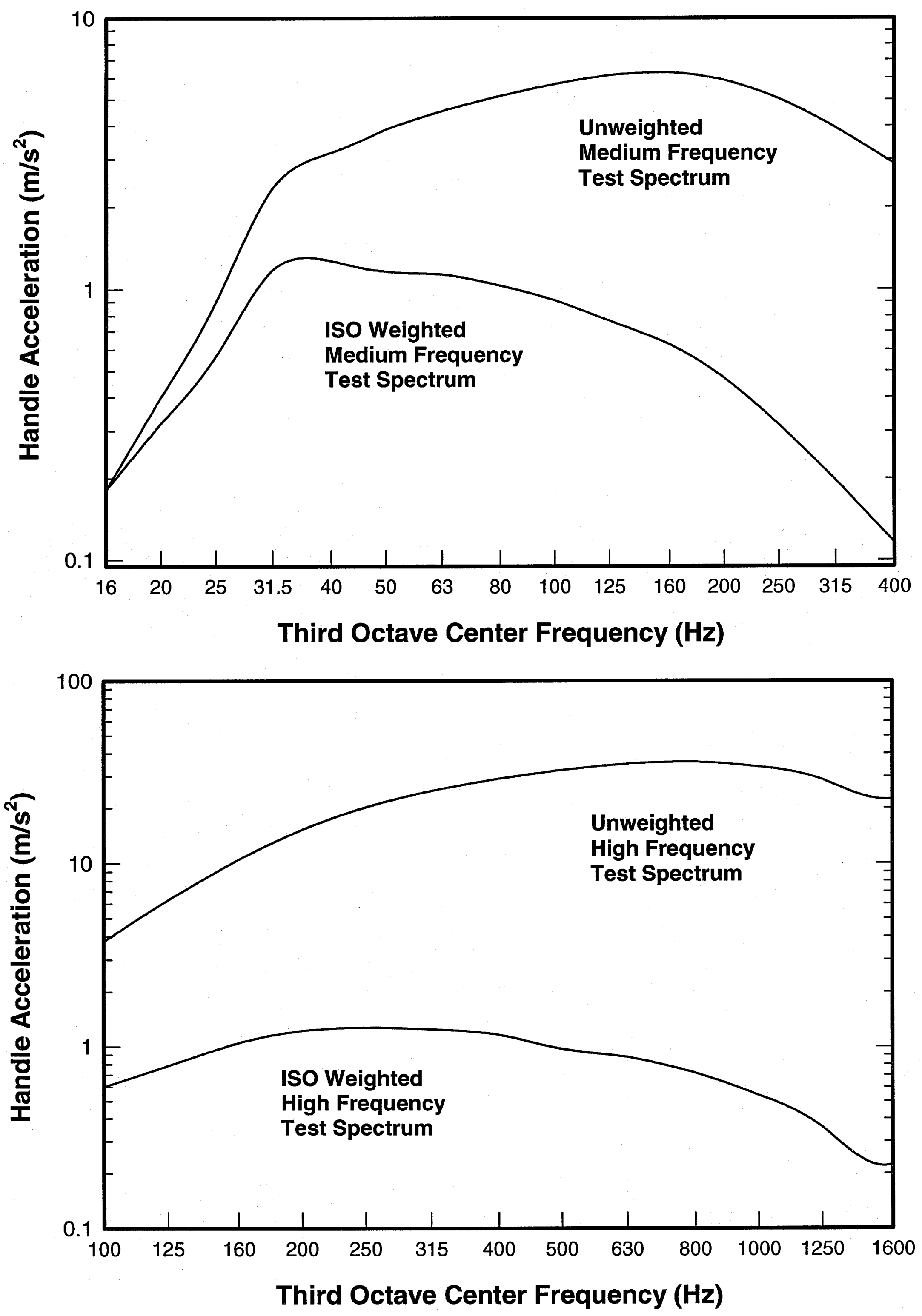


Figure 5. Effects of the ISO weighting filter on the mid and high frequency vibration input spectra.

Table 7**.** Summary of ISO 10819 vibration transmissibility test results (Value (±SD)).

Glove	Frequency Range	ISO weighting	Linear weighting
Glove 1	$\underline{TR}_M$	0.78 (0.08)	0.72 (0.05)
	$\underline{TR}_H$	0.70 (0.08)	0.47 (0.03)
Glove 2	$\underline{TR}_M$	0.87 (0.04)	0.79 (0.03)
	$\underline{TR}_H$	0.72 (0.03)	0.48 (0.02)
Glove 3	$\underline{TR}_M$	0.85 (0.03)	0.80 (0.02)
	$\underline{TR}_H$	0.71 (0.01)	0.49 (0.03)
Glove 4	$\underline{TR}_M$	0.68 (0.04)	0.60 (0.04)
	$\underline{TR}_H$	0.52 (0.03)	0.27 (0.02)
Glove 5	$\underline{TR}_M$	0.65 (0.06)	0.57 (0.08)
	$\underline{TR}_H$	0.51 (0.04)	0.30 (0.03)
Glove 6	$\underline{TR}_M$	0.77 (0.02)	0.68 (0.02)
	$\underline{TR}_H$	0.55 (0.04)	0.31 (0.02)
Glove 7	$\underline{TR}_M$	0.79 (0.02)	0.71 (0.04)
	$\underline{TR}_H$	0.56 (0.02)	0.31 (0.03)
Glove 8	$\underline{TR}_M$	0.92 (0.01)	0.93 (0.01)
	$\underline{TR}_H$	1.00 (0.00)	0.97 (0.05)
Glove 9	$\underline{TR}_M$	0.82 (0.04)	0.82 (0.03)
	$\underline{TR}_H$	0.80 (0.02)	0.52 (0.04)
Glove 10	$\underline{TR}_M$	0.86 (0.04)	0.86 (0.04)
	$\underline{TR}_H$	0.83 (0.04)	0.54 (0.04)
Glove 11	$\underline{TR}_M$	0.79 (0.02)	0.76 (0.02)
	$\underline{TR}_H$	0.76 (0.04)	0.50 (0.05)
Glove 12	$\underline{TR}_M$	0.92 (0.02)	0.92 (0.02)
	$\underline{TR}_H$	1.00 (0.00)	0.89 (0.03)
Glove 13	$\underline{TR}_M$	0.95 (0.02)	0.96 (0.00)
	$\underline{TR}_H$	0.99 (0.00)	1.00 (0.08)

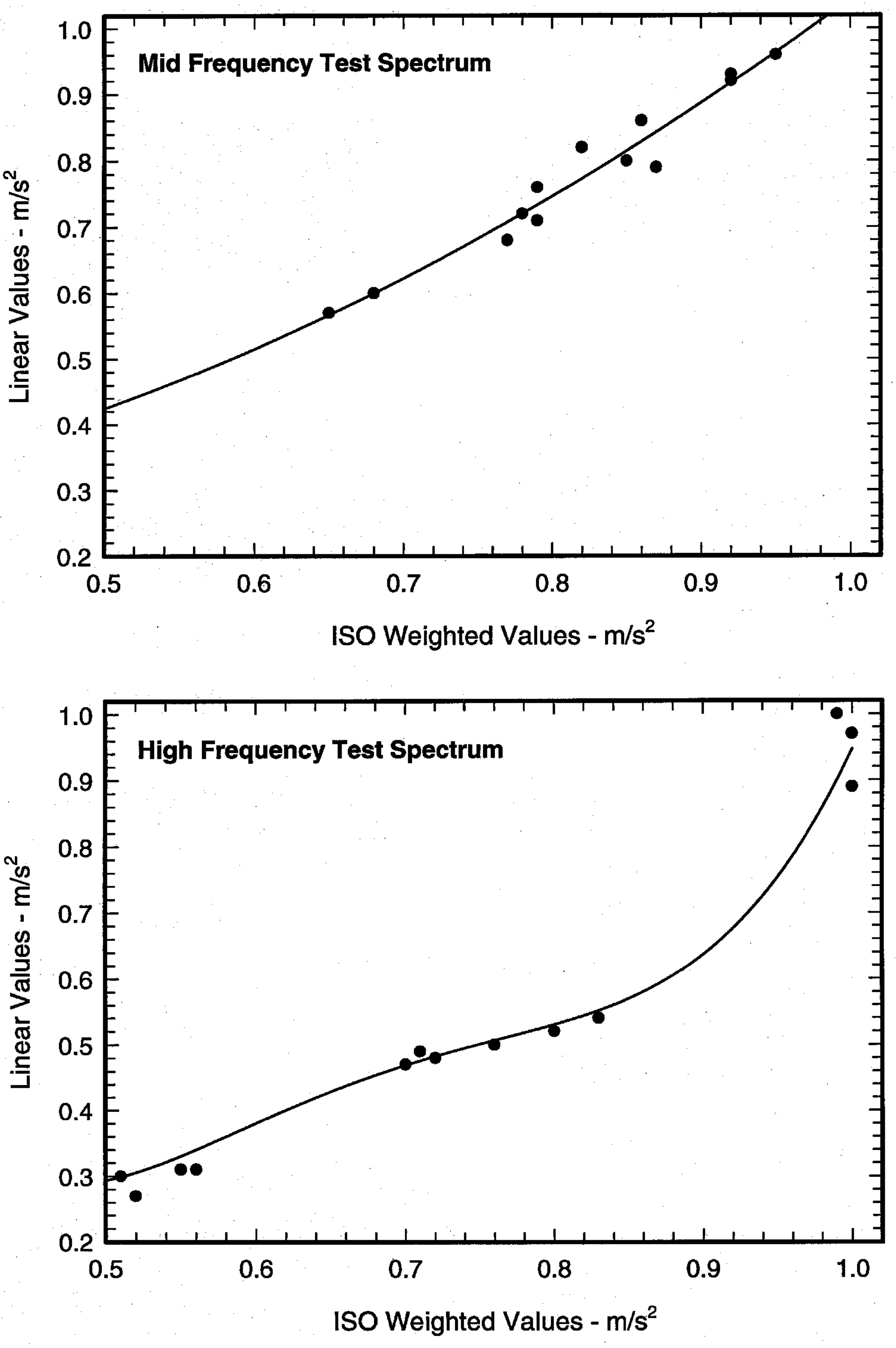


Figure 6. Relationship between ISO and linear weighted vibration transmissibility values.

Observations associated with ISO standard 10819 tests

Observations associated with test subjects

- The test subjects had a significant effect on the vibration transmissibility test results. Proper posture during a test was very important, There were a few test subjects who had consistently high transmissibility values, while there were a few who had consistently low transmissibility values. Proper training of the test subjects was necessary to obtain reliable and repeatable test results.
- Those test subjects who consistently had unusually high transmissibility values could result in a glove not meeting the requirements of ISO Standard 10819 to be classified as an antivibration glove.
- It took training and great care to ensure that the palm accelerometer adapter was properly placed between the palm of the hand and the glove during a test.
- When only three test subjects are used for the ISO Standard 10819 tests, a test subject who consistently has unusually high vibration transmissibility tests results can negatively bias the transmissibility tests for a glove. Increasing the number of test subjects to four or five can minimize this problem.

Observations associated with the test procedures

- It was very difficult to generate the mid and high frequency vibration input spectra within the amplitude band limits that are specified by ISO Standard 10819 without the use of a vibration feedback controller.
- Allowing the mid and high frequency input spectra to deviate from the amplitude band limits specified by ISO Standard 10819 did not have a significant effect on the measurement of the mid and high frequency vibration transmissibility values.
- Vibration energy outside of the lower and upper frequency band limits of the mid and high frequency test spectra must be sufficiently attenuated to prevent this energy from negatively biasing the mid and high frequency test results. This is particularly important for the high frequency test spectra.
- If a feedback vibration controller is used to generate the vibration test signals, the controller output must be checked to ensure that the controller significantly attenuates the controller output signal outside of the lower and upper frequency limits of the test signal.
- When a vibration feedback controller is not used to generate the vibration test signals, a bandbass filter must be placed after the signal generator to attenuate the vibration signal outside of the test frequency bandpass. This filter must have a minimum attenuation of -12 dB/octave at the lower and upper frequency limits of the test signal.
- When the ISO Standard 10819 test signals are properly processed before the signals enter the power amplifier for the electromechanical shaker, it does not make any difference whether or not the output signals from the accelerometers on the shaker handle and on the palm accelerometer adapter are directed through bandpass filters before they are directed through ISO weighting filters. If the test signals are not properly processed before they enter the shaker power amplifier, the use of bandpass filters before the ISO weighting filters and the selection of the corner frequencies for these filters can have a significant effect on the ISO Standard 10819 vibration transmissibility test results.

- ISO weighting of the acceleration signals for the ISO Standard 10819 tests biases the measured glove vibration transmissibility values to the lower frequency limits of the mid and high frequency test signals. This often causes the ISO weighted vibration transmissibility values to underestimate the effectiveness of a glove in attenuating vibration to the hand. This is particularly true for the high frequency vibration transmissibility tests. This problem can be resolved by using linear weighting filters instead of ISO weighting filters (Figure 1).
- Shaker handle resonance frequencies within the test frequency band limits of the mid and high frequency test signals can negatively bias the ISO Standard 10819 test results. This is particularly true for the high frequency vibration transmissibility tests. A shaker handle should be tested for resonance frequencies before it is used for ISO Standard 10819 tests. If resonance frequencies are found to exist within the test signal frequency limits, the handle must be redesigned to eliminate the resonance frequencies.
- Sharp edges on the vibration-damping material side of the palm accelerometer adapter can cause the adapter to ”dig” into the vibration-damping material. This can negatively effect the ISO Standard 10819 vibration transmissibility test results. This problem can be resolved by rounding the edges of the accelerometer adapter.

Conclusions

- Use only trained test subjects for ISO Standard 10819 vibration transmissibility tests.
- Test subjects who consistently yield unusually low or high vibration transmissibility values should not be used as test subjects.
- Consideration should be given to increasing the number of test subjects to four or five.
- The allowable amplitude band limits for the mid and high frequency test spectra should be increase to ±2 for all third octave band frequencies.
- Care must be taken to ensure that the vibration energy into the shaker power amplifier outside of the of mid and high frequency test spectra lower and upper frequency limits is significantly attenuated.
- The ISO weighting of the acceleration signals for the ISO Standard 10819 vibration transmissibility tests causes the ISO Standard 10819 vibration transmissibility values to understate the effectiveness of a glove in attenuating vibration to the hand.
- Linear filters should be used instead of the ISO weighting filters should be used on the acceleration signals before they are processed to obtained the ISO Standard 10819 vibration transmissibility values.
- When linear filters are used on the acceleration signals to obtain the ISO 10819 vibration transmissibility values, the criteria levels should be changed to $\underline{TR}_{M(Lin)} < 1.0$ and $\underline{TR_{H(Lin)}} < 0.37$.
- The shaker handle must not have any resonance frequencies in the frequency bandpass of the mid and high frequency test signals.
- The sharp edges on the bottom side of the palm acceleration adapter must be rounded to prevent the adapter from ”digging” into the glove vibration-damping material during an ISO 10819 test.

References

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Measurement and evaluation of attenuation effectiveness of anti-vibration gloves

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Introduction

The prolonged and habitual use of hand-held power tools or other machines which transmit vibration to the hand and arm may cause an important occupational disease known as vibration syndrome. Some preventive measures for reduction of such vibration hazards have been developed. One of the approaches to reduce the vibration transmitted to the hand is personal protection for the operator, namely, anti-vibration gloves.

Various types of anti-vibration gloves are commercially available, but most of those gloves have no vibration attenuation characteristics attached. Some investigators have conducted experiment studies on vibration attenuation efficiency of anti-vibration gloves (1, 2, 3, 4, 5). There were only limited reports regarding screening tests. The objective of the present study was to investigate the attenuation effectiveness of anti-vibration gloves available and prepare for drafting a national standard on measurement and evaluation of attenuation efficiency of anti-vibration gloves.

Methods

Twelve samples of new anti-vibration gloves purchasable in the market, which were made by ten companies, from four countries (U.S., Japan, Canada and China), were tested. The experiment was performed in the laboratory under conditions analogous to typical use of hand-held power tools at actual workplaces.

A special handle of 33 mm diameter, designed for measuring the grip force was attached to a feed force measurement device, which was mounted on an electrodynamic shaker (D-100B). The signals of grip force and feed force were amplified by a strain gauge amplifer (7V13) and then transferred to a computer, with which both the grip and the feed forces were displayed and alarmed simultaneously for operators to monitor and control both forces within the required limits. Two types of vibration signals, spectra M and H according to ISO/DIS 10819, were simulated in the electrodynamic shaker, which was driven by a power amplifier (SA-30) and a signal processor (UD320). A miniature accelerometer (Endevco 22) was fixed on the inside of the handle for measuring the accelerations at the reference point, the other one was mounted on an adaptor to measure the accelerations at the palm of the hand. The signals from the two accelerometers were amplified with charge amplifiers (DHF-10) and then fed to a tape recorder (R81) and a frequency analyser (CF 880). The latter was connected with a computer for calculating the mean corrected transmissibility. Figure 1 illustrates the experiment system utilized for measuring the attenuation efficiency of the gloves.

Three healthy male subjects, with hand sizes 8 and 9, as described in EN 420, were instructed to apply and maintain the grip and feed forces within the specified ranges, 30N±5N for grip force and 50N±8N for feed force throughout the test. Three sets of measurements for each operator were performed for the spectra M (31.5-200 Hz) and H

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(200-1250 Hz) respectively, one without gloves (bare) and two with gloves. The operator stood on an adjustable platform. The forearm of the operator was directed in the axis of vibration excitation with the elbow bent approximately 90° and wrist angle kept from 0° to 40°. Figure 2 illustrates the posture of the operator and test apparatus. The values of the mean corrected transmissibility were determined in accordance with ISO/DIS 10819 (6).

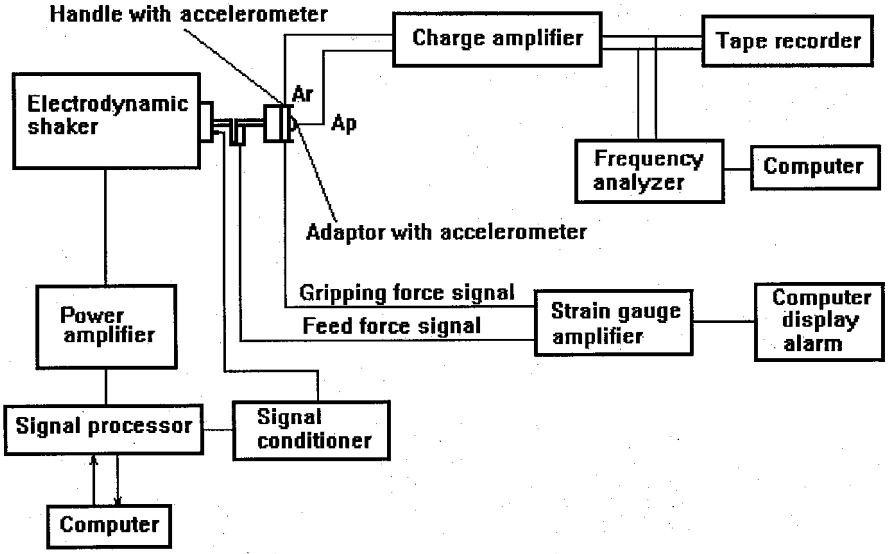

Figure 1. Block diagram of the test system.

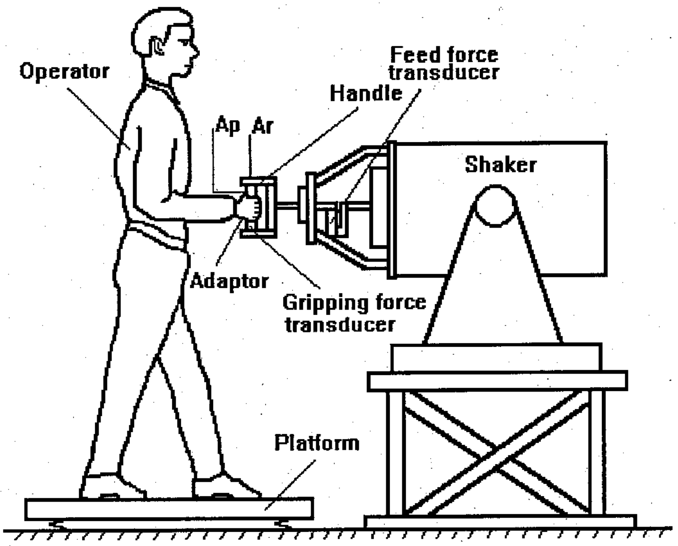

Figure 2. Posture of the operator and the test apparatus.

Eight liner resilient materials from the twelve gloves above were tested in order to compare the results of the transmissibility measurement of the gloves to those of the glove liners and to investigate the correlation of both tests. The experiment was performed in the frequency range of 20-500 Hz. The test and the determination of the transmissibility of the liner material were conducted according to ISO/DIS 13753 (7).

Results and discussion

Table 1 presents the mean corrected transmissibilities of twelve samples of anti-vibration gloves for spectra M and H . For comparison, the transmissibility curves for spectra M and H are illustrated in Figures 3 and 4. As can be seen, the distribution of transmissibility curves is more concentrated at the lower frequencies below 125 Hz, where all values of the transmissibility are greater than 0.7. At frequencies above 125 Hz, however, the results are relatively dispersed. Some gloves, for instance, samples 9 and 12, exhibit considerable reduction of the vibration transmitted to the hand. The values of the transmissibility in the 125–1250 Hz frequency range are from 0.7 to 0.15 and others still present the same properties as at lower frequencies. The outcome shows that the values of mean corrected transmissibility of the gloves in this study are from 0.81 to 1.03 for spectrum M and from 0.39 to 1.03 for spectrum H. According to the criteria of ISO/DIS 10819, nearly half of the samples should not be considered anti-vibration gloves.

Table 1. Mean corrected transmissibility for spectra M and H.

Glove	1	2	3	4	5	6	7	8	9	10	11	12
TRMm	0.965	1.021	0.998	1.034	0.982	1.002	0.903	0.902	0.875	0.839	0.811	0.838
TRHm	0.964	0.906	0.964	0.958	0.605	1.032	0.497	0.651	0.523	0.503	0.420	0.393

The comparison between transmissibility curves from the gloves test and those from the test of resilient liners which gloves are made of, are illustrated in Figures 3-12. At frequencies below 160 Hz, or when the vibration attenuation is smaller in the entire frequency range tested, there is no obvious difference between the two curves. At higher frequencies above 160 Hz, where some samples have pronounced vibration attenuation, the significant disparities between the two transmissibility curves can be observed. When the results of transmissibility of resilient materials are used to predict the transmissibility of the gloves, the outcomes may not conform to those from practical experiments.

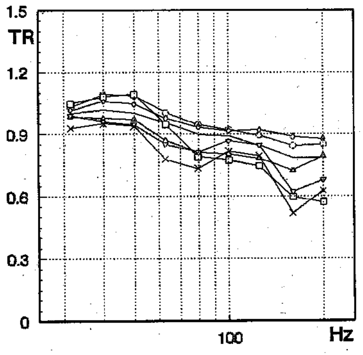

Fig . 3 Transmissibility curves of glove
1, 2, 3, 5, 7, 9, 12 for spectrum M
— -1, o-2, ◇-3, □-5, △-7, ▽-9, ×-12

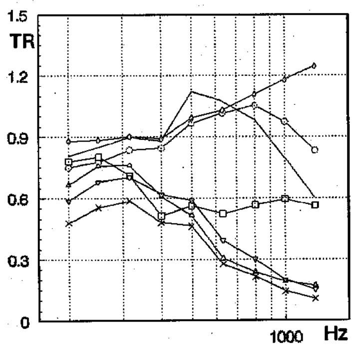

Fig . 4 Transmissibility curves of glove
1, 2, 3, 5, 7, 9, 12 for spectrum H
— -1, o-2, ◇-3, □-5, △-7, ▽-9, ×-12

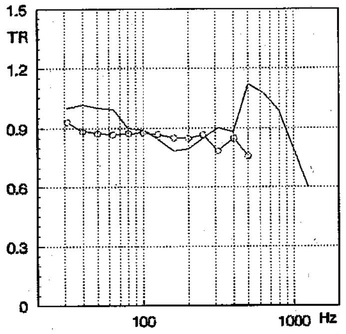

Fig. 5 Comparison of transmissiblity
curve for glove 1 with that of
liner resilient material of it

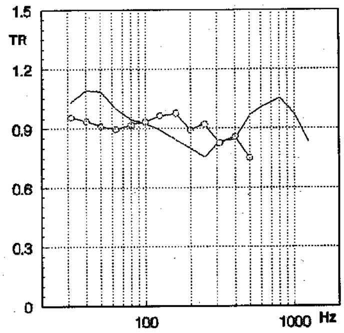

Fig. 6 Comparison of transmissiblity
curve for glove 2 with that of
liner resilient material of it

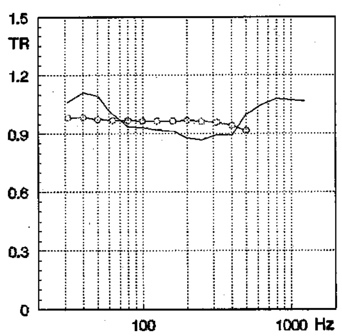

Fig. 7 Comparison of transmissiblity
curve for glove 4 with that of
liner resilient material of it

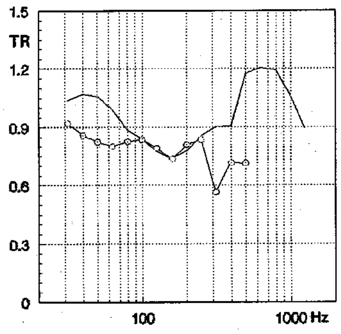

Fig. 8 Comparison of transmissiblity
curve for glove 6 with that of
liner resilient material of it

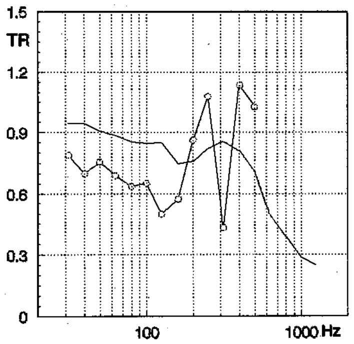

Fig. 9 Comparison of transmissiblity curve for glove 8 with that of liner resilient material of it

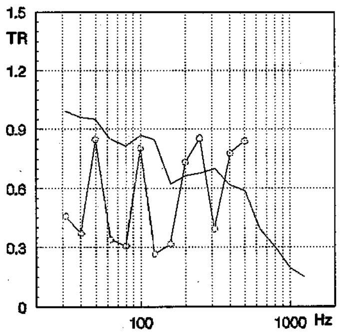

Fig. 10 Comparison of transmissiblity curve for glove 9 with that of liner resilient material of it

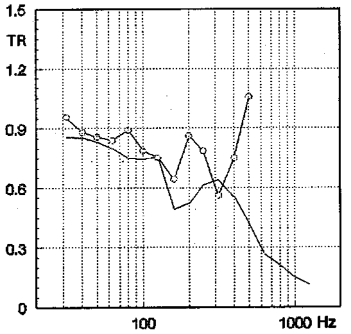

Fig. 11 Comparison of transmissiblity curve for glove 11 with that of liner resilient material of it

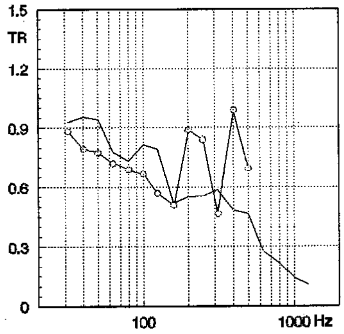

Fig. 12 Comparison of transmissiblity curve for glove 12 with that of liner resilient material of it

Acknowledgements

The financial support provided by the Ministry of Labour of P.R. China and experiment apparatus assistance by 606 Institute of China are greatfully acknowledged.

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An attempt to construct anti-vibration gloves on the basis of information on the vibration transmissibility of materials

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Introduction

Because occupational exposure to hand-transmitted vibration causes various kinds of injury in the human body, it is necessary to look for different measures to minimise this physical agent. Effective protection against vibration usually requires a combination of measures. It is supposed that some reduction of the risk of vibration damage could be achieved by using anti-vibration gloves. Minimum criteria, which must be met in order to claim anti-vibration properties for a glove, are specified in ISO 10819 (3). Some results of testing gloves offered on the markets as AV gloves show that most of them do not fulfil the established requirements (1, 4, 5)

This paper presents and discusses the experimental results of investigating the vibration transmissibility of materials and gloves intended for protection against vibration. The main focus of the investigation was to establish the qualitative and quantitative relations between the vibration transmissibilities of resilient materials and the vibration transmissibilities of gloves made of these materials and subsequently to construct gloves which could minimise the risk of developing Vibration White Finger (VWF) for workers exposed to hand-arm vibration.

Methods

The material and glove tests were performed under the very strict conditions described in two international standards ISO/DIS 13753 and ISO 10819 (2,3), specially elaborated for these purposes and with the use of measurement stands fulfilling the requirements of these standards. The vibration transmissibility of materials was determined at the one-third octave band centre frequencies between 10 and 500 Hz (considering the stated values of hand-arm system impedance). In the case of the glove tests, two values for each glove were determined: the mean corrected vibration transmissibility $\overline{TR}_M$ for the medium frequency range 31.5 - 200 Hz (test signal M) and the mean corrected vibration transmissibility $\overline{TR}_H$ for the high frequency range 200 - 1250 Hz (test signal H). The test signals M and H specified in the glove standard (3) were generated by computer. Apart from the mean corrected vibration transmissibilities for M and H signals, the transmissibility of gloves was also measured as a function of frequency. During the measurements, the values of the gripping force and the feed force were monitored continuously so as to keep them at the required levels.

The evaluation of the anti-vibration properties of the materials and gloves was made on the basis of criteria provided in the above mentioned standards in order to make a comparison of the results with other laboratories possible.

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Results

In order to gather information on the vibration transmissibilities of various resilient materials which seemed to be useful for making anti-vibration gloves, about 80 types of one-layer and multi-layer compositions were tested according to the material standard (2). The tested combinations of materials were composed of various polymeric materials in the form of foams (neoprene, polyisobutylene, polychloroprene, polyurethane), natural porous rubber, knitted fabrics, nonwoven fabrics, wool fabrics, laminated fabrics, wool sheepskin, leathers, and so forth. Thicknesses of the samples were comprised in the range from 3 to 12 mm.

On the basis of the obtained results it was found that among all material compositions that had been tested, only 10 types performed well in the material test. Their vibration transmissibility was less than 0.6 at most frequencies from the range 50 to 500 Hz, which is a condition to suppose that the material can probably provide attenuation in a practical situation. So, from all compositions tested, 10 types were classified as possibly useful for making anti-vibration gloves. Vibration transmissibilities of the five material compositions that turned out to be the best are shown in Figure 1. Figure 2 shows the values of the vibration transmissibility for the next five compositions selected for further investigations.

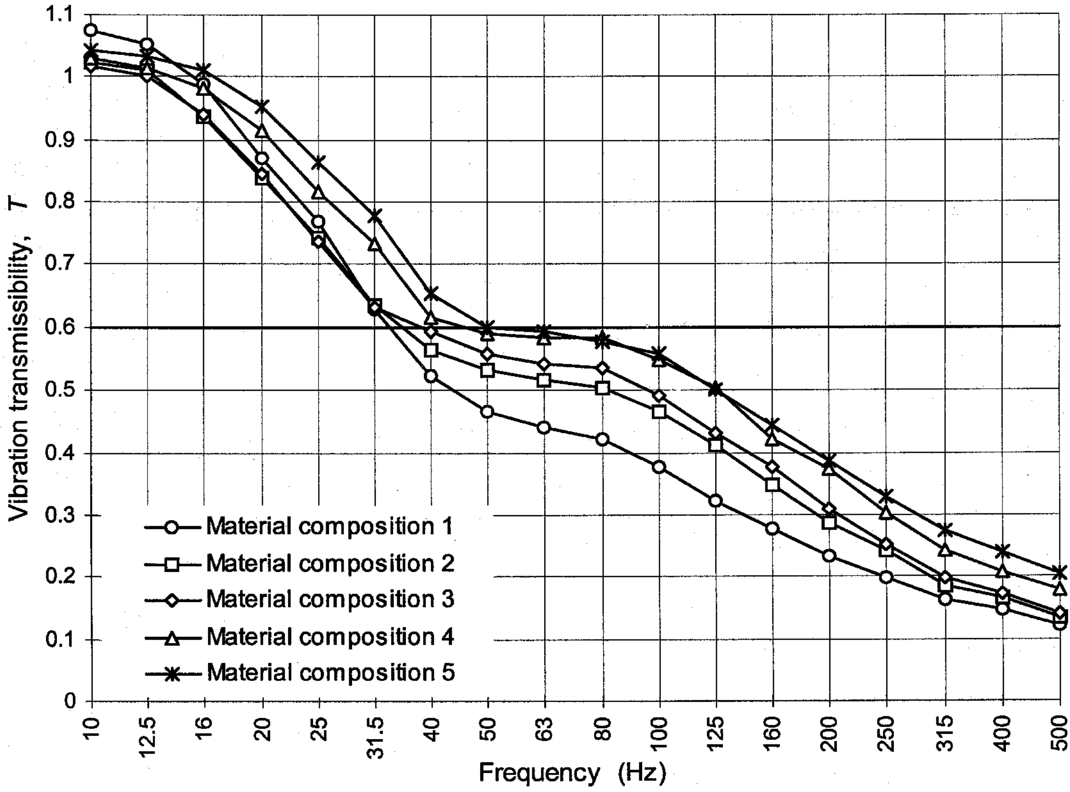

Figure 1. Vibration transmissibility of the best material compositions selected for making gloves.

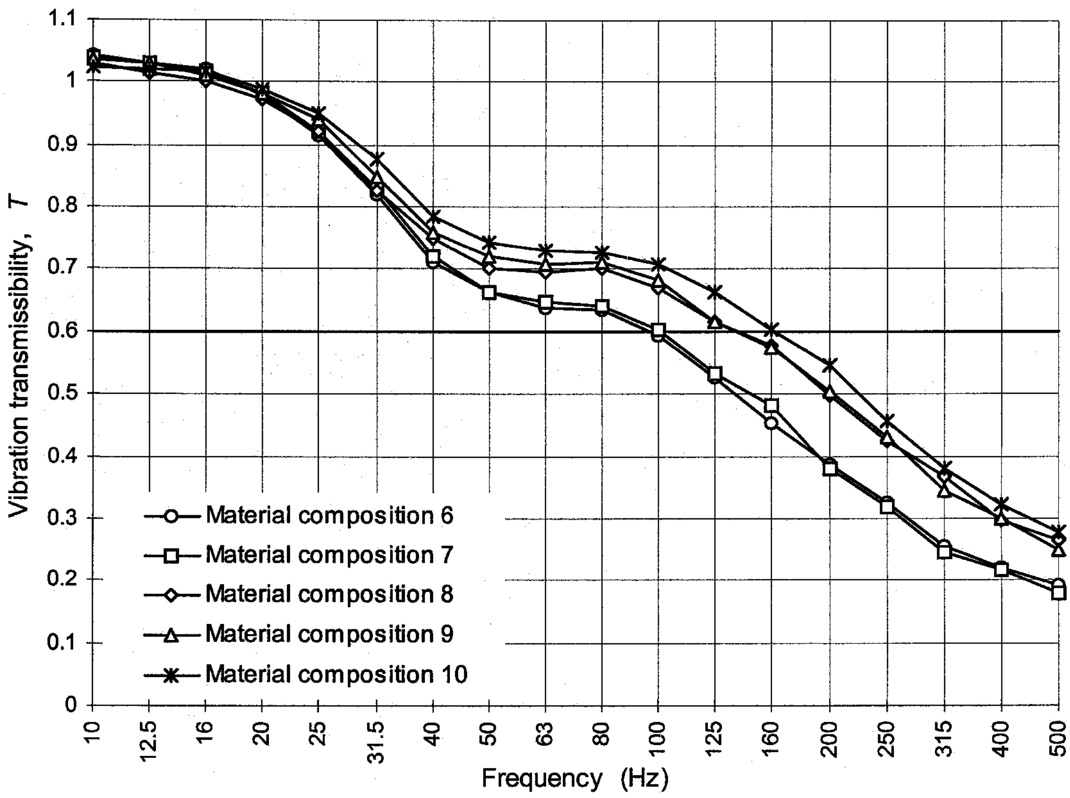

Figure 2. Vibration transmissibility of the next material compositions selected for making gloves.

The 10 selected material compositions were used for making 10 types of prototype gloves. Material composition numbered as 1 was used for constructing a glove of type 1, composition numbered as 2 for constructing a glove of type 2 and so on. It is necessary to emphasise that the 10 material compositions chosen were numbered taking into consideration their damping properties - number 1 is the best, number 10 is the worst, in the light of the material test results (see Figures 1 and 2).

Each pattern of the prototype gloves was produced as a full three-finger glove. For each pattern, the fingers (including thumb) were made of the same material with the same thickness as the part of the glove covering the palm of the hand. The part of the glove that covers the back of the hand was made of elastic fabric and leather. For each pattern, three gloves were made and tested according to the procedure stated in the glove standard (3). The test results in terms of mean corrected vibration transmissibilities ($\overline{TR}_M$ and $\overline{TR}_H$), standard deviation (STD) and coefficient of variation (ε_r) are shown in Table 1.

Additionally, for each type of glove, the vibration transmissibility as a function of frequency was determined to gather information on the attenuation of gloves at the particular frequencies. Such information is very important for both buyers and users. Figure 3 shows the values of the vibration transmissibility at the frequency range from 32 to 1250 Hz for two types of the prototype gloves tested (type 8 the worst and type 5 the best).

Table 1. Results of measurements of vibration transmissibility of gloves made according to own designs

Glove	M spectrum			H spectrum		
	$\overline{TR}_M$	STD	ε_T	$\overline{TR}_H$	STD	ε_T
1	0.908	0.034	3.74 %	0.883	0.022	2.49 %
2	0.875	0.034	3.89 %	0.805	0.075	9.32 %
3	0.849	0.028	3.30 %	0.657	0.073	11.11 %
4	0.870	0.045	5.17 %	0.798	0.071	8.90 %
5	0.805	0.057	7.08 %	0.607	0.076	12.52 %
6	0.819	0.036	4.40 %	0.664	0.057	8.58 %
7	0.835	0.052	6.23 %	0.715	0.018	2.52 %
8	0.967	0.003	0.31 %	1.030	0.014	1.36 %
9	0.801	0.033	4.12 %	0.641	0.057	8.89 %
10	0.833	0.010	1.20 %	0.651	0.068	10.45 %

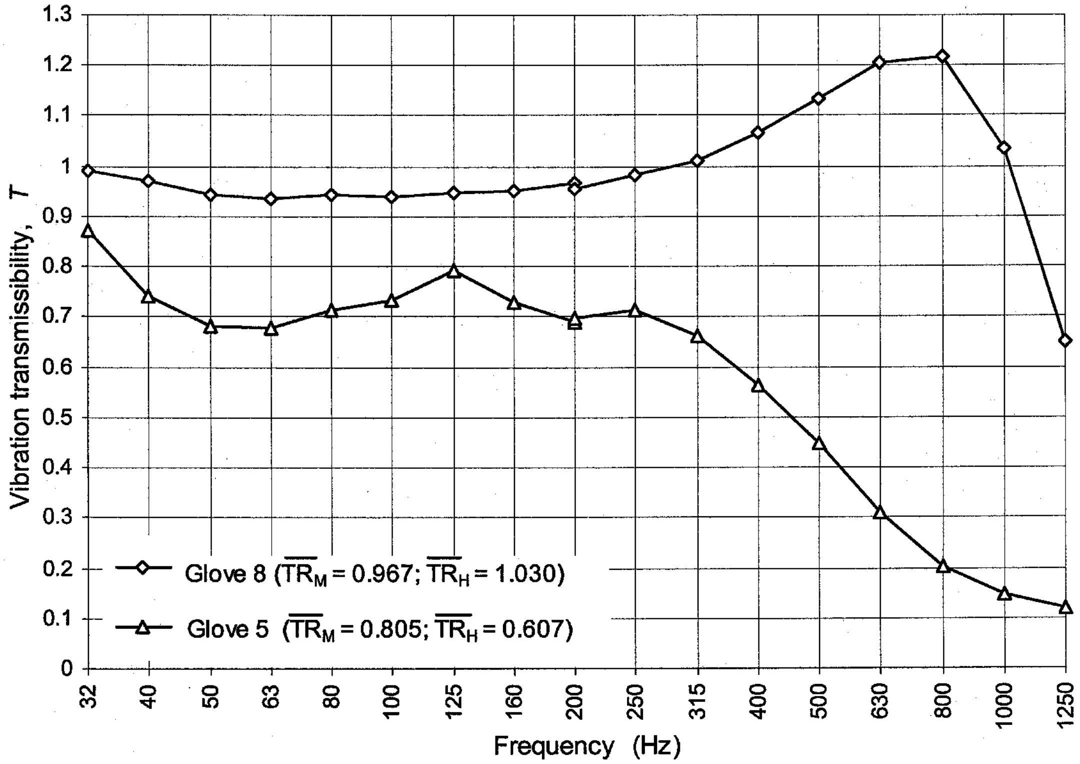

Figure 3. Vibration transmissibility of two prototype gloves made according to own designs.

Discussion

On the basis of the glove test results it is necessary to say that none of the prototype gloves fulfils the condition $\overline{TR}_H < 0.6$ stated for anti-vibration gloves in the glove standard (3) for the test signal H covering the frequency range from 200 to 1250 Hz. On the other hand, all prototype gloves fulfil the condition $\overline{TR}_M < 1$ stated in the same standard for the test signal M covering the frequency range from 32 to 200 Hz. However, according to the standard, gloves can be classified as anti-vibration gloves if they fulfil both of the above mentioned criteria. So, it is necessary to say that none of the patterns of the prototype gloves can be considered anti-vibration gloves although all of them were made of the material compositions classified as perhaps useful for constructing anti-vibration gloves.

With this fact in mind, it was decided to check the performance of the material composition used for making gloves type Kompress, which met the minimum criteria for AV gloves (as the only type among all types tested so far in the laboratory of the Central Institute for Labour Protection in Warsaw). The results of the measurements of this composition showed that it’s transmissibilities are greater than 0.6 at almost all frequencies up to 500 Hz (see Figure 4a). Thus, in view of the material standard (2), this composition should be classified as useless for making AV gloves. However, in view of the glove standard (3), the Kompress glove made from it is an AV glove as previously mentioned. Vibration transmissibilities of glove type Kompress (in terms of the mean corrected transmissibilities and a frequency transfer function) are shown in Figure 4b.

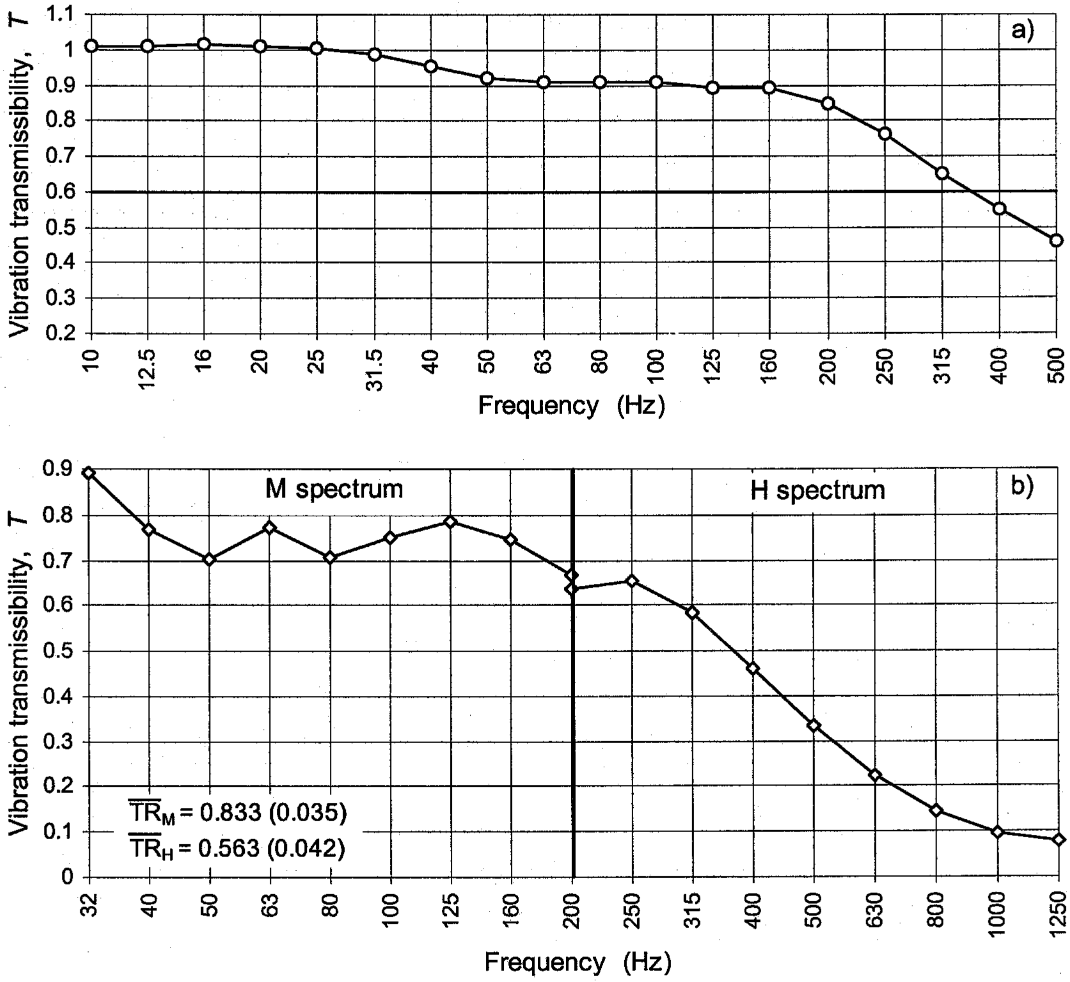

Figure 4. a) Vibration transmissibilities determined according to the material standard (2) for material composition used for making glove type Kompress.
b) Vibration transmissibilities determined according to glove standard (3) for glove type Kompress.

Taking into consideration the values of the mean corrected transmissibilities determined for the H spectrum for all prototype gloves, it was found that in the case of the 5 prototypes (types 3, 5, 6, 9 and 10) their $\overline{TR}_H$ values are comprised in the range from 0.607 to 0.664, so they are close to the minimum required value. However, the best of the prototype gloves tested (type 5, $\overline{TR}_H$ = 0.607) was made of a material composition which was not the best among the materials selected according to the material standard (2). The next two gloves with the lowest values of the mean corrected vibration transmissibility $\overline{TR}_H$ (type 9, $\overline{TR}_H$ = 0.641 and type 10, $\overline{TR}_H$ = 0.651) were made of the two worst material compositions among the 10 selected. Instead, the type 1 glove, made of the best material composition, turned out to be nearly the worst ($\overline{TR}_H$ = 0.883).

On the basis of the results obtained so far it was not possible to find any relations between the material vibration transmissibilities determined according to the material standard (2) and the vibration transmissibilities of gloves made of these materials and tested according to the glove standard (3).

Comparing the test results for 5 prototype gloves made according to our own designs (types 3, 5, 6, 9, 10) with the results obtained for gloves produced by various firms in Poland and in other countries and sold as anti-vibration gloves on the Polish market, it can be found that our own patterns of gloves are better on account of their anti-vibration properties than the others which have been tested so far in our Institute. For those gloves, the determined values of the mean corrected vibration transmissibility $\overline{TR}_H$ were comprised in the range from 0.759 to 1.008 (4). It is much easier to fulfil the condition $\overline{TR}_M$ <1. Almost all gloves tested meet this minimum requirement. Work to improve our own patterns of gloves intended for protection against vibration is still continuing.

Conclusions

1. It is not easy to find materials or their compositions that have good anti-vibration properties and that are at the same time elasticity and thin enough to make of them gloves that ensure dexterity.
2. It is very difficult to construct an anti-vibration glove, that is, a glove that meets the minimum criteria stated in the glove standard (3) although vibration damping materials for making gloves were selected according to the material standard (2).
3. It seems that maybe the material standard (2) is not sufficiently correlated with the glove standard (3). On the basis of investigations carried out according to these two standards it is very difficult to find relations between the transmissibility of a material and the transmissibility of a glove made of this material. Taking into account the obtained results, it could be said that the material standard (2) does not enable rank ordering of materials for gloves. Explaining this problem requires further studies.
4. The anti-vibration properties of the glove are not entirely dependent on the damping properties of the material used for making it. There are a number of factors other than the material (e.g. fitting, sewing pattern, kind of thread) which influence the performance of the glove. This fact adds to the difficulty of making anti-vibration gloves according to the requirements specified in the glove standard (3). But, in the light of the results obtained in our laboratory for the Kompress glove and taking into account the results obtained for the Chase Ergonomics glove (5) as well as the results

submitted in the Report (1), it can be said that the requirements which must be met so as to claim anti-vibration properties for a glove can be met.

5. Having in mind the narrow assortment of real anti-vibration gloves on the markets it is argued that it is necessary to seek new solutions of such gloves that will fulfil the stated criteria.
6. All new patterns of gloves intended for protection against vibration should be measured, evaluated and approved by authorized units before distributing among workers.

Acknowledgement

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Effect of push force on the transmission of shear vibration through gloves

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Introduction

International Standard 10819 (1) specifies a procedure for testing the vibration transmission properties of gloves and determining whether a glove can be considered to be an 'anti-vibration glove'. The test involves using a palm adapter to measure vibration at the glove-palm interface; three subjects are to be used in the test; the gloves are tested using two different vibration spectra ('M', a medium frequency spectrum from 16 Hz to 400 Hz; 'H', a high frequency spectrum from 100 Hz to 1600 Hz). Both the push force (50 N) and the grip force (30 N) to be applied on a handle are specified in the standard, and the duration of vibration exposure is defined as 30 seconds. If the vibration transmitted through a glove passes a set of criteria (i.e. the quotient transmissibilities for the two vibration spectra should be below 1.0 for the medium spectrum and below 0.6 for the high spectrum), the glove can be categorised as being an 'anti-vibration glove'. The direction of vibration considered within the standard is perpendicular to the palm of the glove and the hand. The vibration on tools generally occurs in all three translational axes and there are situations where the principal direction of vibration is in the shear direction relative to the surface of the hand and glove (i.e. the vibration is parallel to the palm of the hand). An example of such a tool includes a percussive chipping hammer when holding the chisel. International Standard 10819 does not consider this type of vibration.

Transmission of shear axis vibration through gloves has received little previous attention, even though many vibrating tools expose the hands of workers to high levels of shear vibration. The purpose of this study was primarily to determine the effect of push force on the transmission of vibration in the shear axis as a function of frequency through a selection of gloves. Also presented is the variability in the transmission of shear vibration between subjects (i.e. inter-subject variability), and between gloves.

Equipment and procedure

The experiment was conducted using an electrodynamic vibrator, Derritron type VP30, powered by a 1500 watt amplifier. A basic handle comprising a steel bar of diameter 32 mm and length 102 mm was attached to the vibrator such that the grip of the hand would be horizontal and in line with the axis of vibration. The first resonance of the handle occurred at approximately 1340 Hz.

Acceleration was measured at two locations: on the vibrating handle, and between the palm of the hand and the glove using a palm adapter of mass 9.21 grams (ISO 10819 states a maximum mass of 15 grams). The accelerometers were of piezoelectric type (Brüel and Kjær type 4374) each with a mass of 0.65 gram. The acceleration signals from the two locations were passed through charge amplifiers (Brüel and Kjær type 2635) and then acquired into a computer-based data acquisition and analysis system.

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The subjects stood on a horizontal surface and applied a downward force with the right hand on to the handle that vibrated in the horizontal direction and in the lateral axis of the subjects. The gloved hand was placed on the handle such that the metacarpal bones were horizontal and at right angles to the axis of vibration. The subjects held their forearms horizontal at an angle of 90° to the axis of vibration with the elbow having an angle of approximately 180° between the forearm and the upper arm. There was no contact between the elbow and the body during the measurements. Three downward push forces of approximately 20, 40 and 60 N were applied during the measurements; no grip force was applied. (The handle was not instrumented to measure force; the subjects were able to practise the push force required on a separate similar handle instrumented to measure both push and grip forces.) The order of presentation of the three forces was balanced across the subjects.

Ten gloves were tested (9 commercially available); Table 1 summarises the characteristics of the gloves. In accord with ISO 10819 (1), the gloves were worn by the subjects for at least 3 minutes prior to the vibration measurements. The room temperature during the tests fluctuated between 22 °C and 25 °C (the standard specifies a temperature range of 20±5 °C) and the relative humidity varied between 37% and 51% (the standard specifies that the relative humidity shall be below 70%).

Table 1. Description of the 10 gloves used in the experiment.

Glove number	Description
1	blue nylon lycra, yellow leather palm, hand pad, fingerless mitten, no wrist protection
2	yellow leather palm covering spikes of sorbothane, full finger, full wrist protection
3	anti-vibration working gloves, black leather palm and back, full finger, full wrist protection
4	anti-vibration working gloves, cotton covered with green rubber, full finger, some wrist protection
5	terri-ester knitted glove, normally used as an outer glove for a pair of gloves
6	pumpable air pad for palm, red plastic covering for palm and back, full finger, full wrist protection
7	knitted nylon covering palm and back, hand pad, fingerless mitten, no wrist protection
8	knitted nylon covering palm and back, hand pad, fingerless mitten, no wrist protection, similar to glove 7
9	beige leather on palm, cotton covering on back, full finger, some wrist protection
10	12 mm thick black open-cell rubber glued to leather palm, full finger, some wrist protection, experimental glove (see Griffin *et al.*, (2))

The experiment was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research. Eight right-handed male subjects participated in the study of inter-subject variability and the effect of push force (mean age 28.75 years; mean weight 71.25 kg; mean height 1.78 m). Each subject was exposed to the vibration 31 times: once with the ungloved bare hand and a push force of 40 N, and once with each of the three push forces for the ten gloves.

A commercial data acquisition and analysis system, *HVLab*, developed at the Institute of Sound and Vibration Research, was used to conduct the experiment and analyse the acquired data. A computer-generated Gaussian random waveform having a nominally flat acceleration spectrum was used with a frequency-weighted acceleration magnitude of 5.0 ms^{-2} r.m.s. at the handle. The frequency weighting used was W_h as defined in British Standard BS 6842 (3). The frequency range of the input vibration was 6 Hz to 1800 Hz. The waveform was sampled at 6097 samples per second and low-pass filtered at 1800 Hz before being fed to the vibrator. Acceleration signals from the handle and the palm adapter were passed through signal conditioning amplifiers and then low-pass filtered at 1800 Hz via anti-aliasing filters with an elliptic characteristic; the attenuation rate was 70 dB/octave in the first octave. The signals were digitised into a computer at a sample rate of 6097 samples per second. The duration of each vibration exposure was 5 seconds.

Analysis

Transfer functions were calculated between acceleration on the handle (i.e. the input) and acceleration measured at the palm-glove interface adapter (i.e. the output). The 'cross-spectral density function method' was used. The transfer function, $H_{io}(f)$, was determined as the ratio of the cross-spectral density of input and output accelerations, $G_{io}(f)$, to the power spectral density of the input acceleration, $G_{ii}(f)$: $H_{io}(f) = G_{io}(f)/G_{ii}(f)$. Frequency analysis was carried out with a resolution of 5.95 Hz and 124 degrees of freedom (Bendat and Piersol, (4)).

Results and discussion

Transmissibilities between acceleration on the handle and in the palm-glove adapter were calculated for the subjects pushing the handle while wearing the gloves. Figure 1 shows individual shear transmissibilities between the vibrating handle and the adapter for the 8 subjects and for the 10 gloves with a push force of 40 N. The transmissibilities show the different dynamic characteristics for the 10 gloves. Gloves 2 and 10 show attenuation of vibration at frequencies above about 400 Hz, while other gloves show the transmission of high frequencies to the palm adapter. Glove 5 showed no attenuation of vibration transmitted to the palm adapter, but amplification over the frequency range studied and for all subjects. Similar individual transmissibilities were also calculated for push forces of 20 N and 60 N. (Individual subject transmissibilities for a push force of 20 N are shown elsewhere, Paddan and Griffin, (5).)

A large variability between the 8 subjects is apparent in some of the shear transmissibilities. Examples of the variability include the transmissibilities for the subjects wearing glove 3 and applying a downward push force of 40 N on the handle. At 1200 Hz, one subject showed a transmissibility of 0.19 whereas another subject showed a transmissibility 3.38 times greater at 0.65. Transmissibilities for other gloves and at other frequencies may show greater variation between subjects.

Figure 2 shows the median and interquartile ranges of the transmissibilities between the handle and the palm adapter with the subjects applying a push force of 40 N on the handle. The interquartile range in transmissibility varies between gloves. For example, glove 3 shows a large interquartile range for some of the frequency range compared to the small interquartile range for glove 4.

To assist in the comparison of shear transmissibilities for the 10 gloves, Figure 3 shows only the median transmissibilities for the 10 gloves for a push force of 40 N. A very large variation in shear transmissibility between gloves is apparent. For example, at a frequency of 1036 Hz, glove 5 (highest curve) shows a median transmissibility that is over 16 times greater than the median transmissibility for glove 2 (lowest curve).

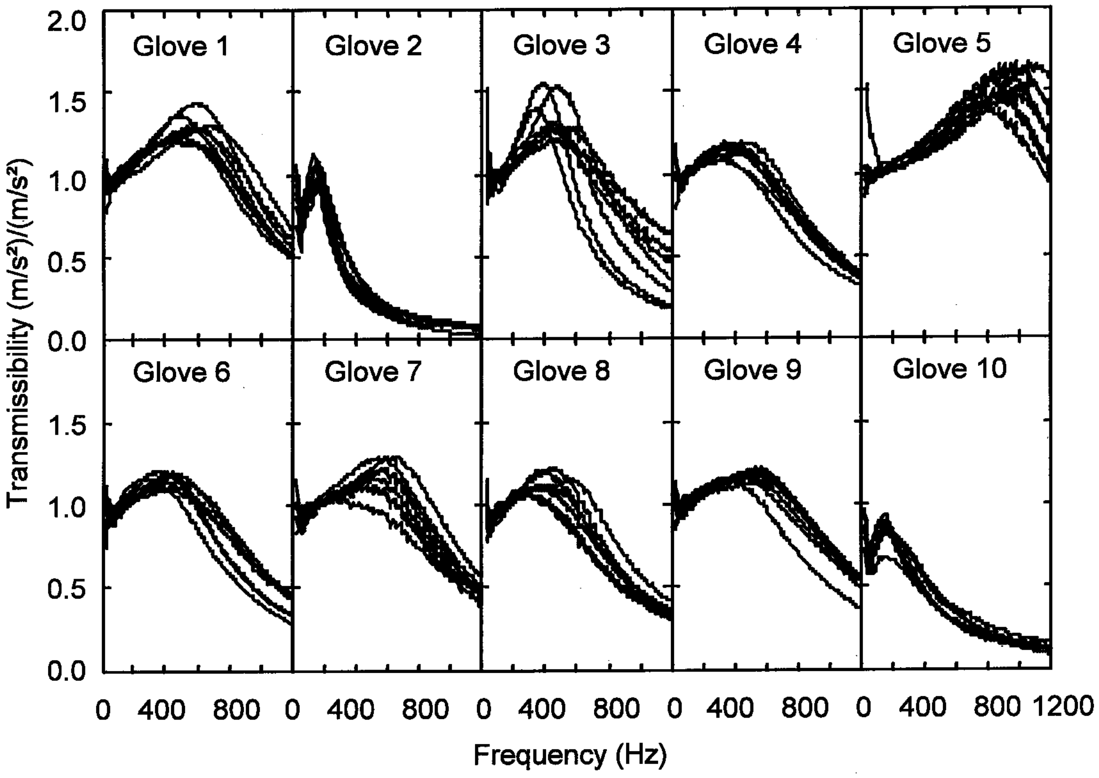

Figure 1. Glove shear transmissibilities between the handle and the adapter for a push force of 40 N (5.95 Hz frequency resolution, 124 degrees of freedom, 8 subjects).

The effect of 3 push forces on the transmission of shear axis vibration through the gloves is shown in Figure 4 for the median transmissibilities between the handle and the palm adapter for the 8 subjects. Increases in push force from 20 N to 40 N and from 40 N to 60 N increased vibration at the palm adapter, indicating that the increased force increased the vibration transmitted through the glove at medium and high frequencies. The effect of push force is more prominent for some gloves and at some frequencies than others. The increased transmission occurred predominantly at high frequencies which contribute least to the frequency-weighted acceleration on many powered hand tools.

The median transmissibilities presented in Figure 4 show a visual effect of push force on shear transmissibilities. Statistical analysis was conducted using the Wilcoxon matched-pairs signed ranks test (2 tailed) with a significance level of $p<0.01$ (see Table 2). Table 2 also shows the direction of the effect of push force on transmissibility.

Vibratory tools often require high grip forces. The force obtained by pushing in this experiment could also be applied by gripping. If grip and push forces are not sufficiently high, the control and operation of a vibratory tool may be difficult or inefficient, but increased force (grip or push) will increase the vibration transmitted to the hands through gloves, especially at high frequencies.

The transmission of shear axis vibration to the hands has received little previous attention. The results from this investigation suggest that the vibration transmitted through gloves to the hand in the shear direction can be as great or greater than that transmitted perpendicular to the palm. Even if a glove shows significant reduction in vibration as measured according to ISO 10819, it might not usefully reduce vibration when the transmission of shear vibration is taken into consideration. It therefore seems desirable that the revision of ISO 10819 (1) should consider the need for the additional measurement of the transmission of vibration in shear axes.

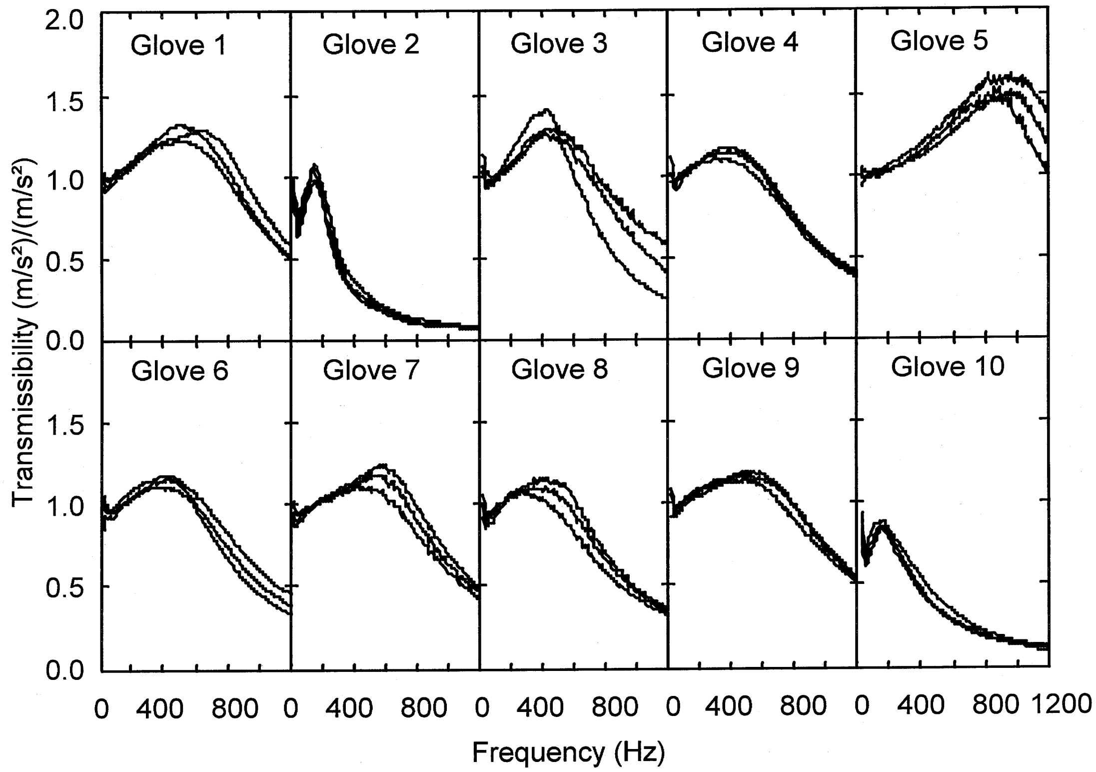

Figure 2. Medians and interquartile ranges of shear glove transmissibilities between the handle and the adapter for a push force of 40 N (5.95 Hz frequency resolution, 124 degrees of freedom, 8 subjects).

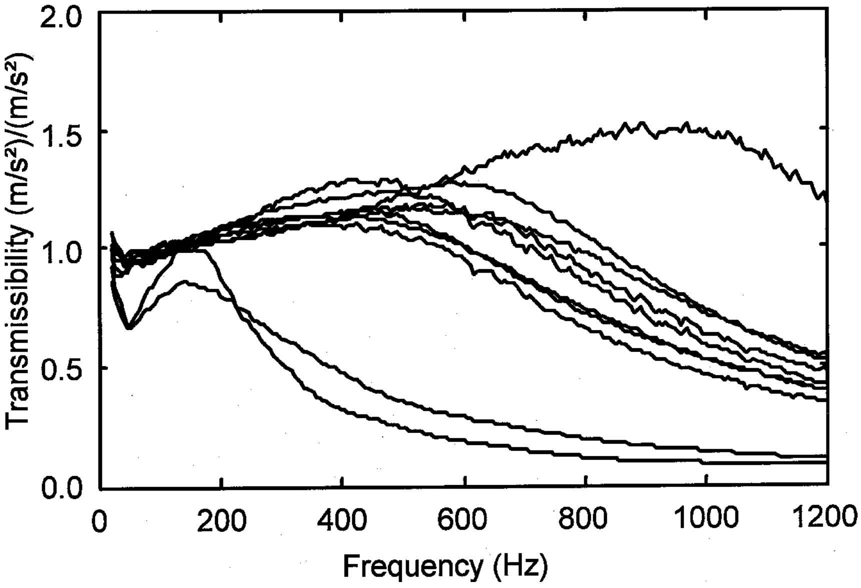

Figure 3. Median glove shear transmissibilities between the handle and the adapter for a push force of 40 N (5.95 Hz frequency resolution, 124 degrees of freedom, 8 subjects).

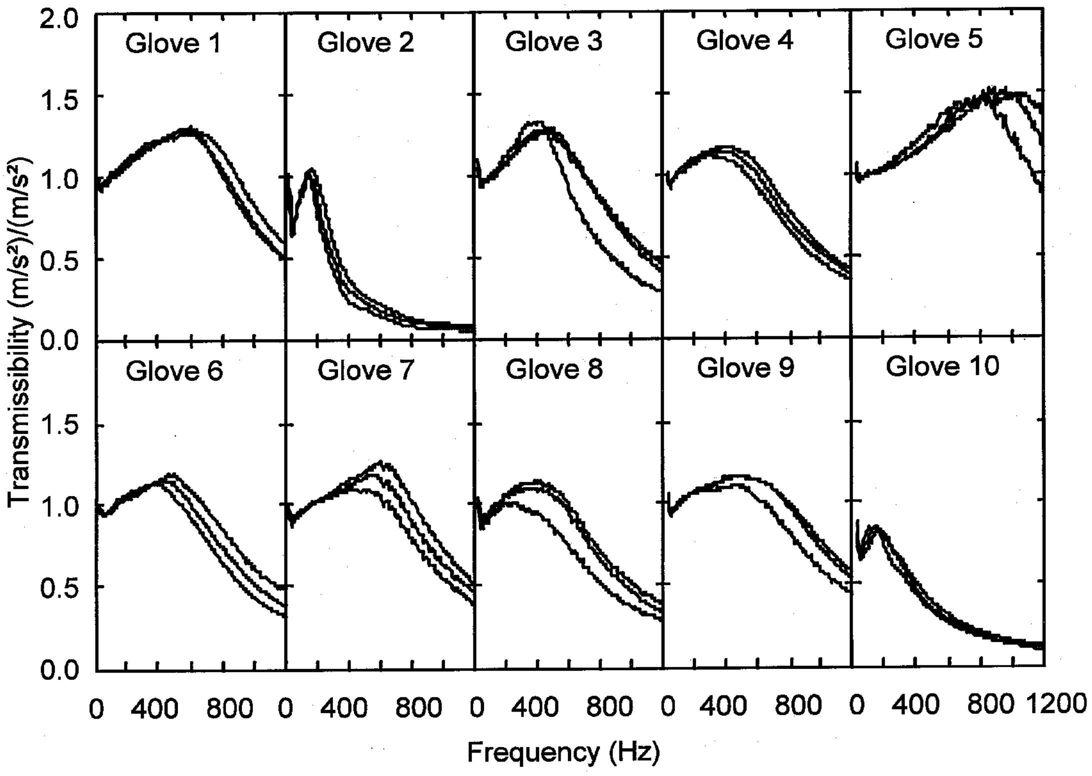

Figure 4. Median glove shear transmissibilities between the handle and the adapter for push forces of 20 N, 40 N and 60 N (5.95 Hz frequency resolution, 124 degrees of freedom, 8 subjects).

Table 2. Frequency ranges for significant changes in shear transmissibility with push force applied to the gloves (NS - not significant; * p< 0.01).

	Push forces (N)		
Glove number	20 N and 40 N	40 N and 60 N	20 N and 60 N
1	NS	NS	77-399 Hz (–)* 851-1200 Hz (+)*
2	536-1200 Hz (+)*	244-815 Hz (+)*	238-956 Hz (+)*
3	NS	NS	NS
4	NS	NS	NS
5	NS	NS	256-613 Hz (–)* 1065-1200 Hz (+)*
6	857-1200 Hz (+)*	NS	428-1200 Hz (+)*
7	NS	297-1143 Hz (+)*	NS
8	274-1200 Hz (+)*	NS	256-1200 Hz (+)*
9	1000-1200 Hz (+)*	NS	518-1200 Hz (+)*
10	NS	NS	NS

Conclusions

The transmission of shear axis vibration through 10 gloves showed a large variation among a group of 8 subjects. Two of the 10 gloves showed attenuation of vibration at frequencies above about 400 Hz. The other gloves offered no beneficial attenuation of shear axis vibration at any frequency below 1000 Hz, indeed they generally amplified vibration in the shear axis. With increasing push force there was an increase in the transmission of shear vibration through most of the gloves at high frequencies.

Acknowledgement

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Soft handle surfaces on powered drills

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Introduction

It is often recommended that the handle surface should be smooth and slightly compressible (3-5). Reasons for this are that a compressible handle material such as foam rubber is considered more comfortable and it distributes the surface pressure more evenly in the hand (1) compared to an incompressible handle material. Compressible handle materials are also considered to be vibration attenuating. However, compressible materials on the handle have not been shown to significantly reduce vibration (6). Furthermore, the surface should not be too soft because sharp objects may be embedded in the grip, which may cause injuries and make the tool difficult to use. Finally, a study (1) has shown that the grip force produced in order to hold the tool may increase with a soft grip. A minority of powered hand tools such as drills have handles with rubber backs made out of compact rubber, but only a few have handles which are completely covered with rubber. There are also a few rubber covers for power tool handles available on the market. For other types of tools (such as garden tools), however, rubber handles are more common.

The aim of the study was to further investigate the advantages of rubber covered handles.

Methods

Subjects

The investigation was performed as two separate studies. In the first study (handle preferences), twelve male (age (mean ± SD): 32 ± 4 years, weight: 86 ± 12 kg, stature: 183 ± 5 cm) and twelve female (age: 33 ± 11 years, weight: 68 ± 9 kg, stature: 170 ± 6 cm) unprofessional tool users participated. Before the tests the subjects had some minutes of drill training, both in steel and concrete.

In the second study (vibration measurements), six male (age (mean ± SD): 39 ± 11 years, weight: 81 ± 7 kg, posture: 181 ± 6 cm) unprofessional tool users participated.

Study design

The handles of four similar impact drills (Bosch PSB 450 R, maximal non-load rotation speed: 2600 rpm, non-load impact frequency: 693 Hz) were covered with 3 mm rubber (approximate hardness, shore A): 7-9° (foam rubber), 34-35°, 55-57° and 88-90° (almost incompressible). The rubber was covered with a thin layer of tape in order to make the surfaces similar. After the rubber was covered with tape the hardness was 27-30°, 46-52°, 61-64° and 90-91°. The drill used was a 200 x 6 mm concrete drill.

During drilling (duration 30 seconds, with >1 minute rest between each drilling session) the subjects were instructed to stand in an upright position with the lower arm horizontal (Figure 1). They were also instructed to hold the drill as relaxed and comfortably as possible with one hand only, drill with maximal speed and to keep a

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small distance between the arm and the torso. Before drilling each hole they drilled an initial hole (about 2-4 mm deep), afterwards they relaxed for a while.

In the preference assessments the drills were tested in a balanced order. After testing the four drills the subjects ranked them depending on comfort. In the vibration measurements the four drills and also a drill without rubber cover were tested in a standardised order.

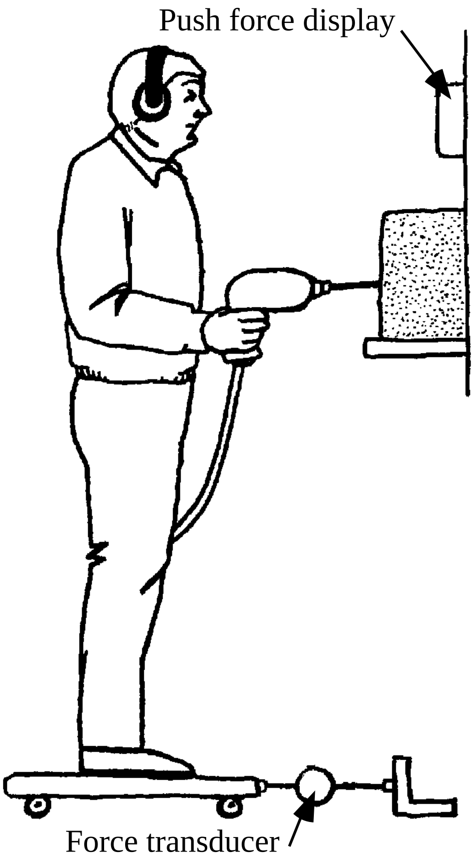

Figure 1. The design of the test. It resembled the standard for vibration testing of impact drills (ISO 8662-6). In contrary to the standard, the subjects drilled in a concrete block instead of the wall using a 6 mm bit instead of a 8 mm bit and the push force was displayed as deviation from the target value (80 N).

Vibration measurements

The vibration was measured using three accelerometers (Brüel & Kjaer 4374) fastened on an aluminium holder (Brüel & Kjaer UA 0894), which was placed between the handle and the hand. The signals were analysed on a digital frequency analyser (Brüel & Kjaer 2131, 1/3 octave band) and also with custom made software (Vib 2131) developed at our institute. The frequency weighted vibration level was calculated according to ISO 5349.

Separate from the other vibration measurements, the vibration level of one of the drills, the foam rubber covered drill, was measured with accelerometers glued on a small aluminium cube fastened on the back of the drill just above the normal hand grip. The vibration between the hand and the rubber cover was measured simultaneously using the aluminium holder. The acceleration transfer function of the foam handle grip was calculated with a digital frequency analyser (Brüel & Kjaer 2032).

The impact on the vibration level from different bits was evaluated by letting one subject drill one hole with each of five 200 x 6 mm concrete bits and also five holes with one bit of the same type, using the drill with the foam rubber handle.

In all of the vibration measurements the vibration level was measured in one direction at a time (X, Y, and Z directions).

Results

Six male and eleven female subjects ranked the foam rubber handle as the most comfortable (Table 1). Eight male and seven female subjects ranked the hardest rubber handle as the least comfortable. Statistical analyses (Friedman) showed that the differences in ranking were significant ($p < 0.0001$).

As seen in Table 2 the total vibration level was lowest for the foam rubber. Statistical analyses (ANOVA) based on the sum of vector of frequency weighted values in each direction showed that there were significant differences between the handles ($F_{5,4} = 12.5$, $p < 0.0001$). Additional two-tailed t-tests showed that there was a significantly ($F_5 > 3$, $p < 0.05$) lower vibration level for the foam rubber handle compared to the second softest, the hardest rubber and also compared to the handle without a rubber cover.

Vibration frequency spectra showed that there was a peak in the 1/3-octave band spectrum at 31.5 and 63 Hz and also in a higher frequency range between 500-800 Hz. These peaks determined to a large extent the frequency weighted vibration level.

The vibration transfer function calculation of the foam rubber handle showed that in the X direction there was an attenuation of the vibration between 25-210 Hz and above about 370 Hz, in the Y direction vibrations were attenuated between 25-210 Hz and above about 330 Hz, in the Z direction vibrations were attenuated between 25-250 Hz and above about 600 Hz.

The mean vibration level was about the same when drilling with five different bits as when drilling five times with the same bit (mean values ± SD, in X, Y and Z direction): 5.6 ± 1.0, 9.6 ± 1.0 and 8.0 ± 0.7 m/s^2 compared to: 5.6 ± 1.5, 10.4 ± 0.7 and 7.7 ± 0.8 m/s^2.

Table 1. Results from the ranking (number of rankings) of the rubber covered handles. The hardness values refers to the measured hardness on the tape covered rubber.

handle	Rank (most comfortable=1)							
hardness	Males				Females			
(shore A)	1	2	3	4	1	2	3	4
27-30°	6	4	2	0	11	0	1	0
46-52°	0	4	6	2	1	2	4	5
61-64°	5	4	1	2	0	7	5	0
90-91°	1	0	3	8	0	3	2	7

Table 2. Frequency weighted vibration level (X, Y, and Z directions, mean sum vector and SD) when using the rubber covered handles and also a handle without rubber cover.

Handle hardness (shore A)	Vibration (m/s^2 rms) X	Y	Z	Sum	SD
27-30°	8.6	7.5	6.1	13.3	2.9
46-52°	6.4	10.4	9.0	15.3	2.5
61-64°	6.4	9.5	8.8	14.5	2.5
90-91°	11.1	11.1	9.3	18.4	2.6
original handle	10.3	10.0	7.0	16.0	1.8

Discussion

Foam rubber on the handle was rated as more comfortable than harder rubber. Foam rubber also attenuated vibrations about 15% compared to the drill without rubber on the handle.

The transfer function of the vibration showed that there was a resonance of the foam rubber handle material at about 15-20 Hz, in good accordance with vibration theory. However, the vibration level in this frequency range was hard to evaluate due to too low vibration energy from the machine. The main vibration influence on the operator originated from vibration frequencies at 31.5 Hz and 63 Hz. The foam rubber handle attenuated these frequencies better than the other materials. However, not even the foam rubber handle decreased the vibrations to the levels in modern electro-pneumatic drills.

However, there were some factors in the experimental set-up which may have caused bias:

- the foam rubber handle was a little smaller (since foam rubber is compressible), this may have given it an advantage compared to the others in the ranking. The foam rubber was also more compressed under the holder for the accelerometers compared to the compression with the bare hand. This decreased the vibration attenuating effect of the foam rubber during the measurements.
- the hardest rubber was not as well shaped over the handles as the others (since it was stiffer). This might have given it a disadvantage compared to the others (in the ranking).
- the vibration caused artefacts of the EMG (which were cut away). This cutting may have influenced the results.
- the subjects were non-professional tool users. Professional tool users may have other preferences.

The comparison of the vibration level when shifting bits compared to when using the same bit with repeated measurements showed that the bits caused about the same vibration level.

In spite of these biasing factors, the results indicate that foam rubber is a more preferable covering material compared to harder rubber when ergonomic factors decide. The effects from rubber covers on the pressure distribution and produced grip force need to be investigated before recommendations can be determined. This is currently being done. A handle with exchangeable foam rubber grips in different sizes may be an attractive solution. The additional advantages of such a solution are that the handle shape could fit each individual user better and a worn or damaged grip could easily be replaced. In order to increase the durability of the handle prevent sharp objects from becoming embedded in the grip and to impede liquid from being soaked up, it might be advantageous if the foam rubber is covered with a thin harder layer, as in the present study.

Conclusion

Tape covered foam rubber on the handle is a more preferable covering material compared to harder rubber. Foam rubber on the handle may also to some extent attenuate vibration.

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Measurement of vibration isolation of gloves and resilient materials

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Introduction

Vibration exposure from power tools is known to involve a risk of the development of Vibration White Finger (VWF) for heavily exposed workers. ISO 5349 provides in an annex what is believed to be the best knowledge on the dose response relationship. The EU Machinery Safety Directive (89/392/EEC and 91/368/EEC) states that,

”The instructions must give the following information concerning vibration transmitted by hand-held and hand-guided machinery:
-the weighted root mean square acceleration value to which the arms are subjected, if it exceeds 2.5 m/s^2 as determined by the appropriate test code ....”

This statement leads to international standardisation efforts to determine what ”appropriate test codes” could be and, for a number of tool types, test codes have been defined, e.g. ISO EN 8662 series with 14 parts for different tools. However, even if manufacturers today succeed in decreasing vibration emission values, the situation remains that a number of work processes involve vibration exposure of a potentially dangerous nature. As for any other physical agent, the question of Personal Protective Equipment (PPE) is therefore relevant. With regard to vibration, the PPE could be gloves, and today a number of standards and standard proposals provide information on procedures of how to measure and evaluate Anti Vibration (AV) gloves. In addition, there exist EU rules and regulations for PPE, and these are given in Directive 89/686/EEC with the later amendment 93/68/EEC. This paper describes the situation for gloves and resilient materials. A number of problems with the test method for gloves are pointed out and suggestions for changes to the standard are given.

Methods

The two methods dealt with by this paper are:

Glove test:	EN ISO 10819 (1)
Materials test:	EN ISO 13753 (2)

Problems

A number of European laboratories have worked with the glove tests and a group of experts have been gathered in order to resolve a number of problems. The obvious main problem has been of interpretational nature. In one interpretation the glove standard presents a method that is able to identify gloves with no AV- properties, but not able to identify a glove with good AV-properties. In another interpretation this is not the case. The paper describes this matter together with a number of more technical matters.

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Recommendations

The paper suggests that the future standard for transmissibility of gloves should be altered from the present determination of transmissibility for two excitation spectra to determination of transmissibility per octave band. This will eliminate the interpretation problem and, furthermore, bring the glove standard in better agreement with the materials testing standard.

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Main parameters influencing damping performance of resilient materials

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Introduction

Resilient materials are used for handles on hand-held and hand-guided machinery and for anti-vibration gloves. The aim is to reduce vibration exposure. ISO 13753 (1) defines a measuring method for the laboratory to determine material characteristics which provide quantitative information about the expected reduction of vibration (2), (3). First round-robin tests (CIOP - BIA) showed that the obtained test results were largely heterogeneous.

The most important parameters and their effect on vibration reduction were investigated in order to make sure that laboratory test results can actually be transferred to practical applications and to enhance the reproducibility of the test results.

Method

The tests were carried out in accordance with the method referred to in ISO 13 753. This method is based on the determination of material impedance in the frequency range between 10 and 500 Hz; in addition account is taken of the hand-arm system by including a standardised hand-arm-impedance in the calculation.

Three different materials, viz. natural rubber (sample A), polyurethane (sample B) and cellular polyether urethane with a mixed cell structure (sample C), served to analyse the effect of temperature, moisture absorption and material ageing as follows:

Temperature

Temperature has a modifying effect on the material characteristics; in the case of low temperatures the elastic properties decrease while the damping performance is enhanced.

A special test facility was developed to investigate the temperature range between 5 and 35°C, which is particularly important for practical applications. The surface temperature of the vibrating table remains stable due to a tempered liquid flow; the temperature gradient is measured at both faces of the sample. This method has a twofold advantage: test conditions are very close to those in the field and expenditure is clearly reduced, as testing is possible without a climatic chamber.

Moisture absorption

Moisture absorption is determined in accordance with DIN 53472 (4). The samples are first tested without initial conditioning, then dried at 50°C for 24 hours, cooled at ambient temperature in a dry atmosphere and tested again. Another test was carried out after 15 minutes of storage in distilled water. The sample weight was measured every time moisture absorption had changed.

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Material ageing

Testing with regard to material ageing was conducted as described in DIN 50 016 (5). For each type of material one temperature-aged sample and one comparative sample were analysed after a few months. The samples were weighed to check how ageing affected the material properties.

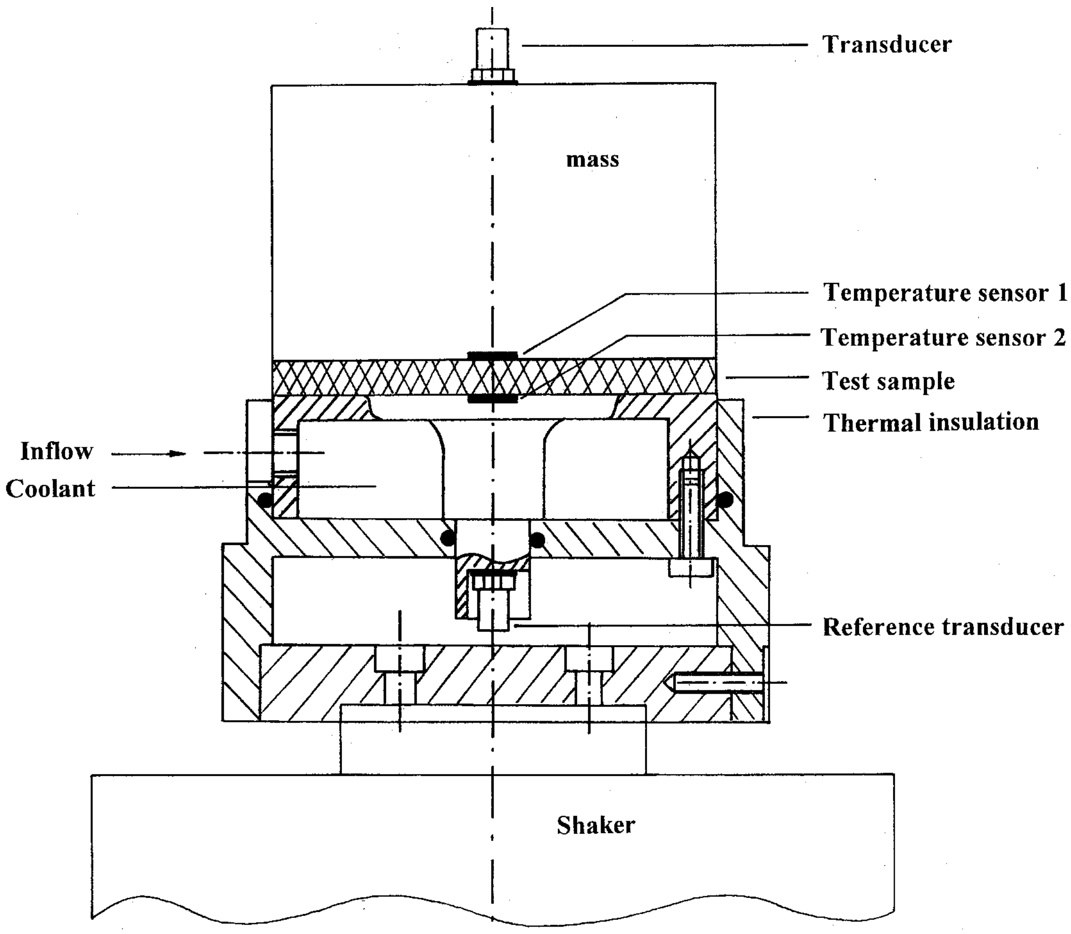

Figure 1. Sketch of the measuring facility.

Results

The results show that the effect of the three investigated parameters depends on the material.

Figure 2 illustrates how the transmissibility of sample C is affected by temperature changes. A temperature drop leads to a rise in oscillation and a slow-down in resonance increase. Phase-frequency characteristics draw an even clearer picture of the modified resonance (Figure 3).

On the whole, damping properties are reduced in the case of a temperature drop as far as the medium frequency range is concerned.

In the framework of humidity absorption testing, small differences in weight were found between the unconditioned samples and the dried materials; humidity absorption as a result of the water bath, however, was very different depending on the material (Table 1).

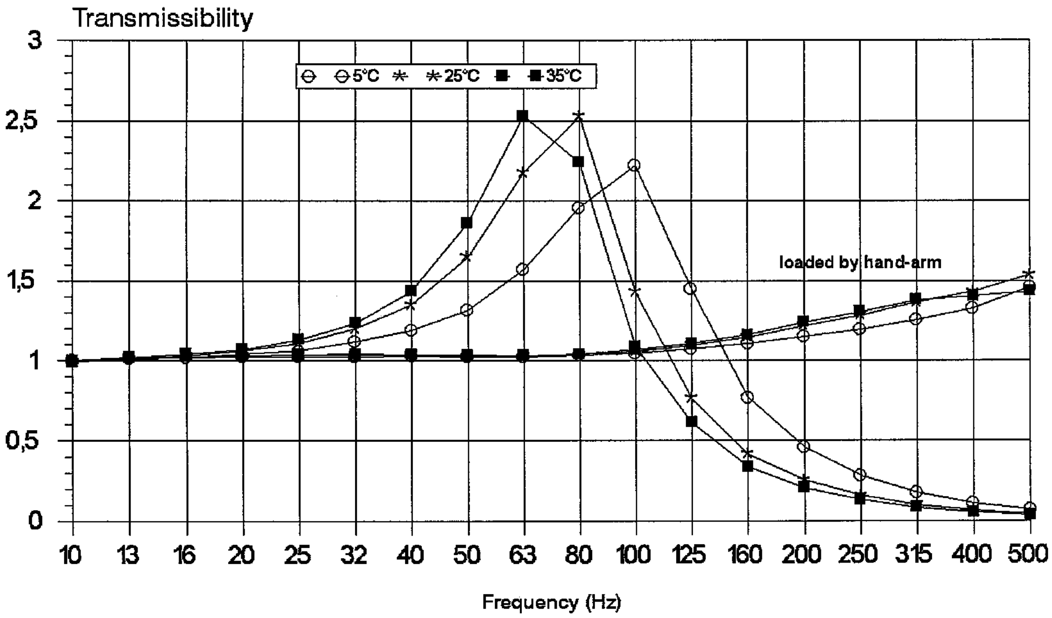

Figure 2. Vibration transmission at different temperatures, sample C.

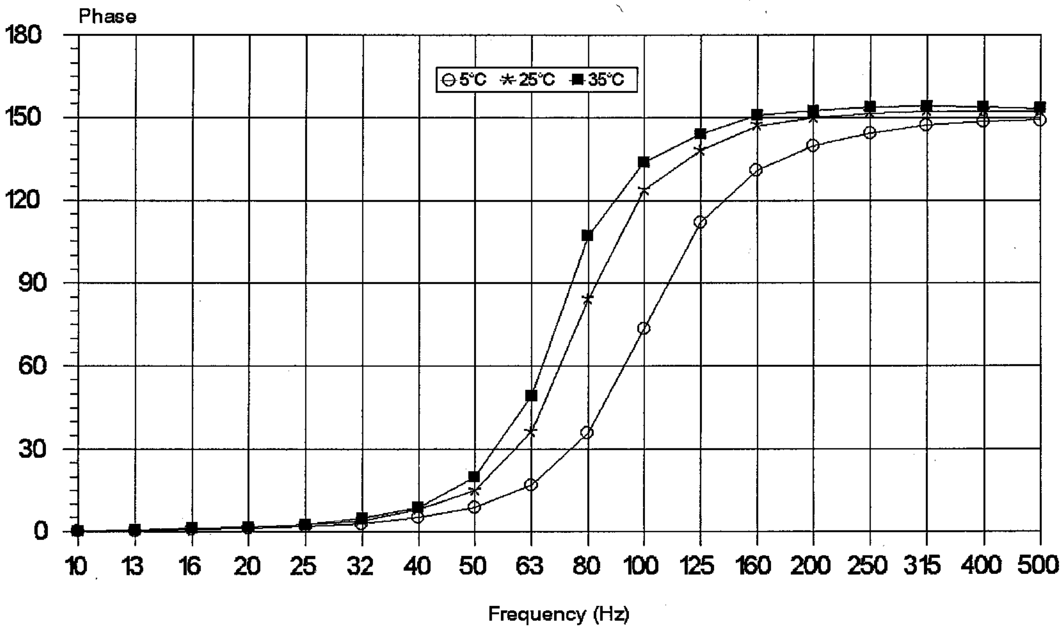

Figure 3. Phase-frequency characteristics at different temperatures.

Table 1.

	Weight			
Sample	Normal	Dry	After water	Bath increase
A	10.63 g	10.63 g	12.5 g	18 %
B	7.52 g	7.49 g	13.79 g	84 %
C	3.81 g	3.80 g	9.99 g	163 %

Figure 4 illustrates the transmissibility characteristics of sample C in dry state and after water absorption. As could be shown for all of the materials, humidity absorption results in a lower oscillation on the one hand and an increased resonance ratio on the other. Besides, vibration transmission on account of the hand-arm system is especially affected in the upper frequency range.

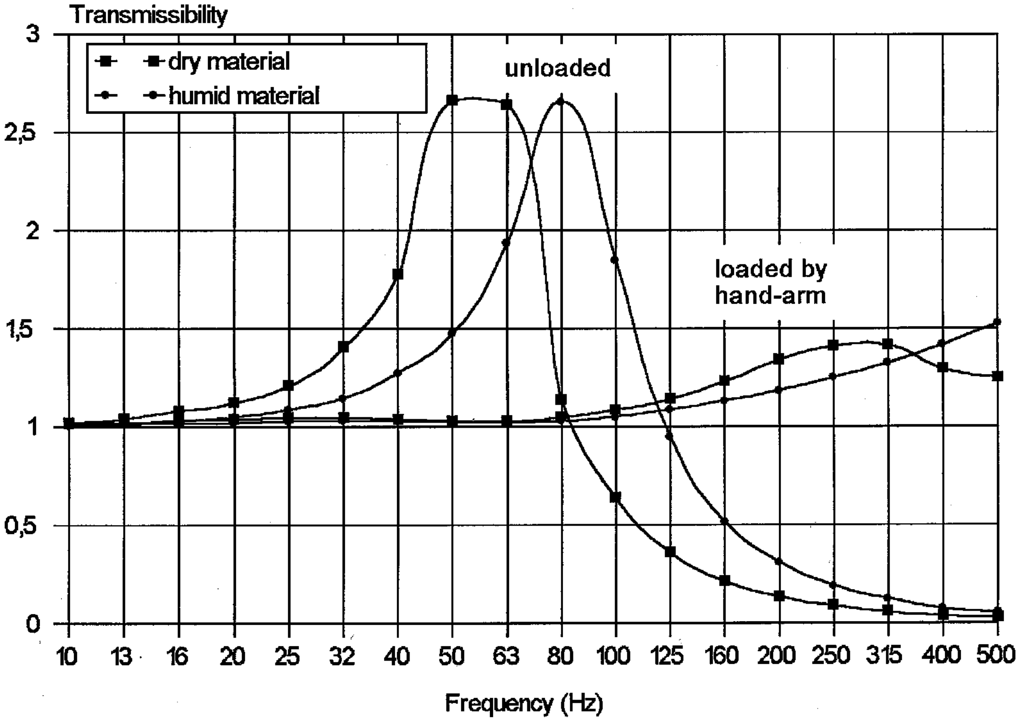

Figure 4. Comparison of transmissibility before and after humidity absorption.

The results after material ageing show an even clearer relationship between effect and material. Material samples B and C do not show any significant modification in terms of damping behaviour. Damping properties of material sample A (see Figure 5) were deteriorated by ageing.

Artificial ageing does not include all ageing parameters present under real-life conditions. From our viewpoint, the thermal ageing method allows an evaluation of ageing effects under storage conditions only.

Discussion

The investigated parameters, viz. temperature, moisture absorption and ageing, do have a distinct effect on the test results obtained for resilient materials on the basis of ISO 13 753.

Consequently, additional testing with respect to these parameters is necessary for the determination of handle and glove material characteristics as referred to in the relevant standard. In addition, test standards must be more precise to ensure a better reproducibility of test results. With certain reservations, the same applies to the test standard for anti-vibration gloves ISO 10819 (6).

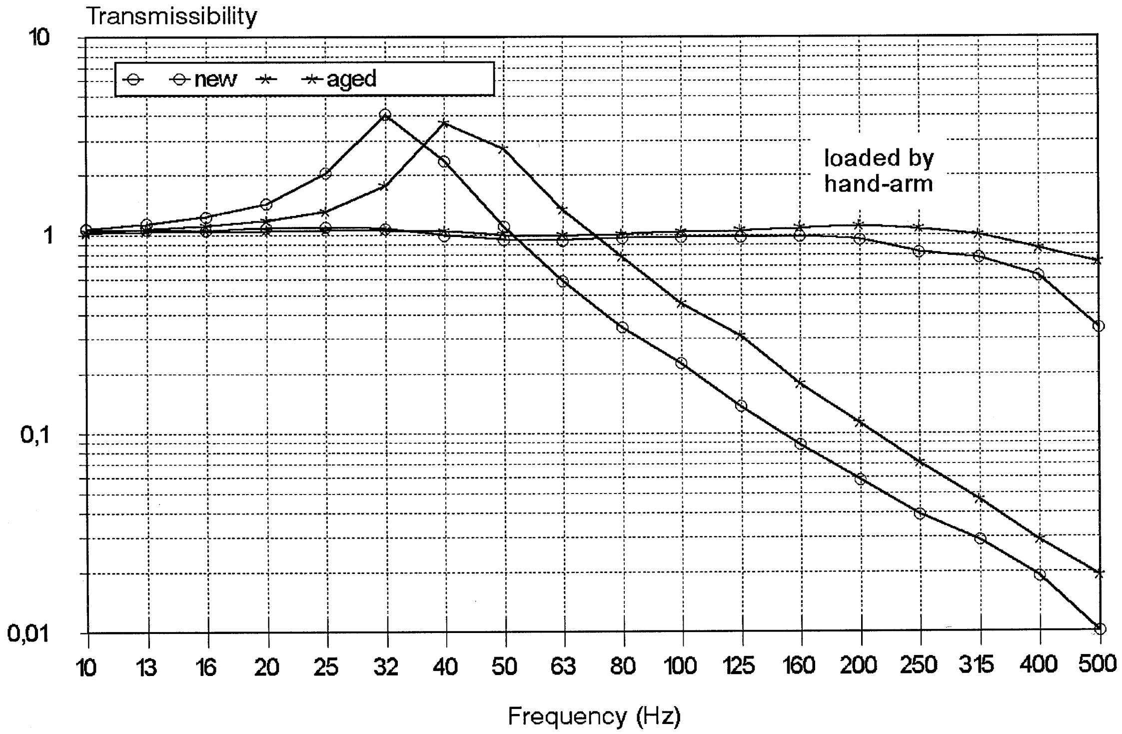

Figure 5. Comparison of transmissibility before and after ageing, sample A.

Conclusion

The effects of temperature, humidity absorption and ageing on the properties of resilient materials were analysed by choosing three material examples. It could be shown that more precise specifications in ISO 13 753 are indispensable, particularly if we want to make sure that laboratory results can actually be transferred to practical applications.

The described test facility to determine the transmissibility at different temperatures and the presented methods for humidity absorption testing and ageing could serve as a basis for the revision of the standard.

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Use of air bladder technology to solve hand tool vibration problems

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Introduction

Repetitive trauma associated with excessive vibration directed into the hands and arms is a significant health problem in U.S. industry. It is estimated that between two to four million workers are exposed to on-the-job hand-arm vibration in the U.S. and that around 50% of these workers either have or will develop symptoms associated with hand-arm vibration syndrome (HAVS). HAVS is associated with the destruction of the small blood vessels and with nerve damage in the fingers. HAVS is caused by excessive vibration directed into the hands from vibrating hand tools and vibration-intensive work processes. Symptoms associated with HAVS usually show up as a combination of finger blanching, particularly in response to cold, and progressive finger numbness (1). In advanced stages, HAVS can result in the loss of tactile discrimination and manipulative dexterity (1). When the level of vibration exposure to the hands is excessively high, symptoms associated with HAVS can appear within as little as one year's time (2).

While most emphasis in the area of hand-arm vibration has been placed on HAVS, NIOSH publication 97-141 indicates there is evidence of a relationship between the use of vibrating tools and carpal tunnel syndrome (3). The pathology of the mechanisms of the onset of carpal tunnel syndrome is still uncertain as to whether it is directly related to the ergonomics of hand position or gripping associated with the use vibrating hand tools. However, this relationship is becoming increasingly important in dealing with hand-related injuries associated with the use of vibrating tools.

One method of reducing vibration energy into the hand and arm is to use protective clothing, in particular antivibration gloves. NIOSH publication 89-106 states that strategies for reducing hand-arm vibration in the U.S. shall be supplemented by the "use of antivibration clothing, mittens, gloves, and equipment." (4). The NIOSH publication further states that the vibration-damping material in an antivibration glove must:

- "provide adequate damping with minimal thickness so that the dexterity required for safe and efficient tool operation will not be reduced, and
- have adequate damping characteristics over the vibration frequency spectrum associated with HAVS."

The International Organization for Standardization adopted ISO Standard 10819 to define the performance criteria and related test procedures that must be met and used to classify a glove as an antivibration glove (5). An antivibration glove must:

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- have an average ISO weighted transmissibility of less than 1, $\underline{\mathrm{TR}}_{\mathrm{M}} < 1$, in the mid frequency range from 16-400 Hz and of less than 0.6, $\underline{\mathrm{TR}}_{\mathrm{H}} < 0.6$, in the high frequency range from 100-1600 Hz.
- be a full-fingered glove that has the same vibration protection in the palm and fingers.

Many glove manufactures make and market gloves that are advertised to reduce vibration into the hand and arm. However, many of these gloves are ineffective in reducing vibration, and nearly all of them do not meet the requirements of ISO Standard 10819 to be classified as an antivibration glove. Thin flexible air bladders have been developed that can be used as vibration-damping elements in gloves. The air bladders are effective in reducing vibration energy into the hand and arm. Tests have shown that a glove that uses an air bladder as its vibration-damping element will meet the requirements of ISO Standard 10819 to be classified as an antivibration glove.

Ergonomic requirements for antivibration glove design

The ergonomic effects of a tool on the hand include hand posture, grip strength, push force, tactile feedback, and temperature. The design of an antivibration glove must address these issues. Five ergonomic factors must be considered in the design of an antivibration glove. Paying proper attention to these factors increases the effectiveness of the glove in reducing vibration while making the glove comfortable to wear.

- *The thickness of the vibration-damping material placed in a glove to reduce vibration must be relatively thin.* Placing vibration-damping material in the palm and the finger and thumb stalls of a glove increases the effective diameter of a tool handle when clasped while wearing the glove. Placing a material with too great a thickness in a glove can make the glove feel bulky and uncomfortable when clasping a hand tool or work piece. This can also make proper control of a tool difficult to maintain. A larger diameter handle requires a greater grip force to clasp the handle with the same grip effort, as compared to a smaller diameter handle. This increases muscle fatigue and the intracompartment pressure in the carpal tunnel in the wrist (6). Increased muscle fatigue and intracompartment pressure in the carpal tunnel raises the risk of developing carpal tunnel syndrome (7). Both HAVS and carpal tunnel syndrome must be considered when designing an antivibration glove. Increasing the thickness of the vibration-damping material in a glove usually increases the effectiveness of the glove in reducing vibration. However, thicker material can cause a glove to feel bulky and be uncomfortable. It can also increase the risk of developing carpal tunnel syndrome when using the glove over an extended time period. Material placed in the finger and thumb stalls of a glove should have a thickness less than 4.6 mm (0.18 in.) and in the palm area less than 6.4 mm (0.25 in.).
- *Vibration-damping materials placed in a glove should be flexible and pliable, and they should not interfere with tactile feedback.* These materials should easily conform to the natural flex-lines in the palm and fingers. This allows the worker to easily maintain control of his tool or work piece. Vibration-damping materials should minimize the reduction in tactile feedback associated with their use. To

properly perform work operations, an operator must be able to feel his tool and/or work piece.

- *The vibration-damping material must cover the full palm area and all of the digits of the fingers and thumb.* Vibration from a tool or work piece enters the hand at the palm, fingers and thumb. The primary damage associated with HAVS occurs in the fingers and thumb. Thus, to protect the fingers and thumb, all of the digits of the fingers and thumb must be isolated from the tool or work piece. Figure 1 shows a schematic drawing of an air bladder between a handle and the hand.

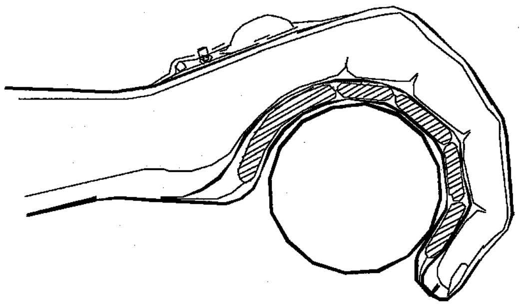

Figure 1. Air bladder between the handle and hand.

- *An antivibration glove must have an opposed thumb.* Figure 2 shows a glove with a wing thumb. A wing thumb is often used in a glove because it simplifies the manufacturing of the glove. When a glove that contains vibration-damping material and that has a wing thumb is used to clasp a tool handle, the material in the thumb stall rotates to the outside surface of the thumb. This places the thumb in direct contact with the tool handle, exposing it to vibration. Using an opposed thumb, as shown in Figure 3, will prevent this. When a glove with an opposed thumb is used to clasp a tool handle, the vibration-damping material always stays properly positioned between the thumb and handle.

Figure 2. Glove with a wing thumb.

Figure 3. Glove with an opposed thumb.

- *An antivibration glove should be loose fitting.* Vibration-damping material that is placed in an antivibration glove can make the glove feel tight and stiff, particularly in the finger and thumb stalls. This usually reduces manipulative dexterity. Over-sizing a glove to accommodate vibration-damping material will increase manipulative dexterity. It is particularly important to over-size the finger and thumb stalls.

Glove with an air bladder vibration-damping element

A thin layer of air placed between a vibrating handle or work piece and the hand is the most efficient means of attenuating vibration into the hand. A thin layer of air can be achieved with an air bladder that is made by welding two layers of thin-film thermoplastic material together with a quilted pattern of weld points and with weld lines that correspond to the natural flex-lines of the hand. An air bladder made by this process is thin, pliable, and flexible. This allows the bladder to naturally conform to the palm and fingers when clasping a handle or work piece. The air bladder for each hand has a bulb inflater. The inflater is connected to the air bladder by means of a flexible tube that allows the inflater to be placed on the backside of the glove. Figure 4 shows a picture of an air bladder placed on the outside of a glove. The air bladder is placed in a pocket in the glove between the palm of the hand, fingers and thumb and the outside shell of the glove. A thin cotton or Lycra material is placed between the air bladder and the hand to prevent the hand from sweating. The outside shell of the glove can be leather, Kevlar, or any other durable material.

Test results associated with glove vibration-damping materials

Table 1 shows the ISO weighted and linear vibration transmissibility values of gloves that contain vibration-damping materials commonly used to reduce vibration. Lower transmissibility values indicate greater effectiveness in reducing vibration. Figure 5 shows the vibration transmissibility values of the gloves in Table 1 as a function of third octave center frequencies. Table 1 and Figure 5 indicate that a glove with an air bladder had the best performance. It is the only glove that was tested that met the requirements of ISO Standard 10819 for classification as an antivibration glove. A glove with an air bladder was tested at the three laboratories listed in Table 2. It met the requirements of ISO Standard 10819 for classification as an antivibration glove at all three laboratories.

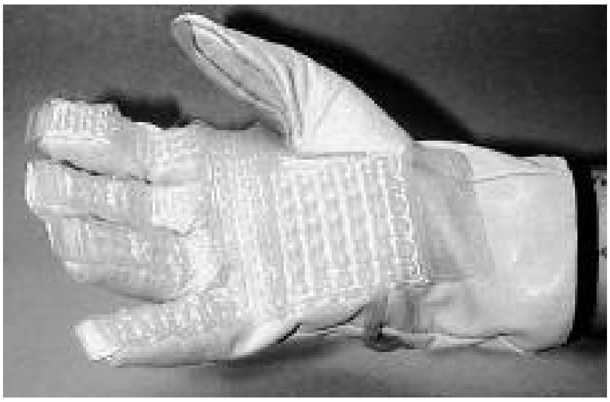

Figure 4. Air bladder placed on the palm and fingers of a glove.

Table 1. ISO weighted and linear transmissibility values of selected glove materials.

Glove material	Frequency Range	ISO weighted transmissibility	Linear transmissibility
Air Bladder	$\underline{TH}_M$	0.65 (0.06)	0.57 (0.08)
	TH_H	0.51 (0.04)	0.30 (0.03)
Gelfom	$\underline{TH}_M$	0.79 (0.02)	0.76 (0.02)
	$\underline{TH}_H$	0.76 (0.04)	0.50 (0.05)
Sorbothane	$\underline{TH}_M$	0.95 (0.02)	0.96 (0.00)
	$\underline{TH}_H$	0.99 (0.00)	1.00 (0.08)
Viscolas	$\underline{TH}_M$	0.92 (0.01)	0.93 (0.01)
	$\underline{TH}_H$	1.00 (0.00)	0.97 (0.05)
Akton	$\underline{TH}_M$	0.92 (0.02)	0.92 (0.02)
	$\underline{TH}_H$	1.00 (0.00)	0.89 (0.03)

Note 1: The ISO weighting filter specified in ISO Standard 5349 is used to obtain the ISO weighted transmissibility (2). This filter emphasises vibration at the lower frequencies within the mid and high frequency ranges and de-emphasises the higher frequencies.

Note 2: The linear transmissibility evenly weights vibration at all of the frequencies within the mid and high frequency ranges.

Table 2. ISO weighted transmissibility values of a glove with an air bladder obtained at three different laboratories.

Glove material	Frequency Range	ISO weighted transmissibility		
		CMEST	Delta	BIA
Air Bladder	$\underline{TH}_M$	0.65 (0.06)	0.72 (0.07)	0.87 (0.06)
	$\underline{TH}_H$	0.51 (0.04)	0.51 (0.07)	0.58 (0.03)

CMEST: Center for Mechanical & Environmental Systems Technology, University of Nevada, Las Vegas, USA

Delta: Delta Acoustics & Vibration, Lyngby, Denmark

BIA: Berufsgenossenschaftliches Institut für Arbeitssicherheit, Sankt Augustin, Germany

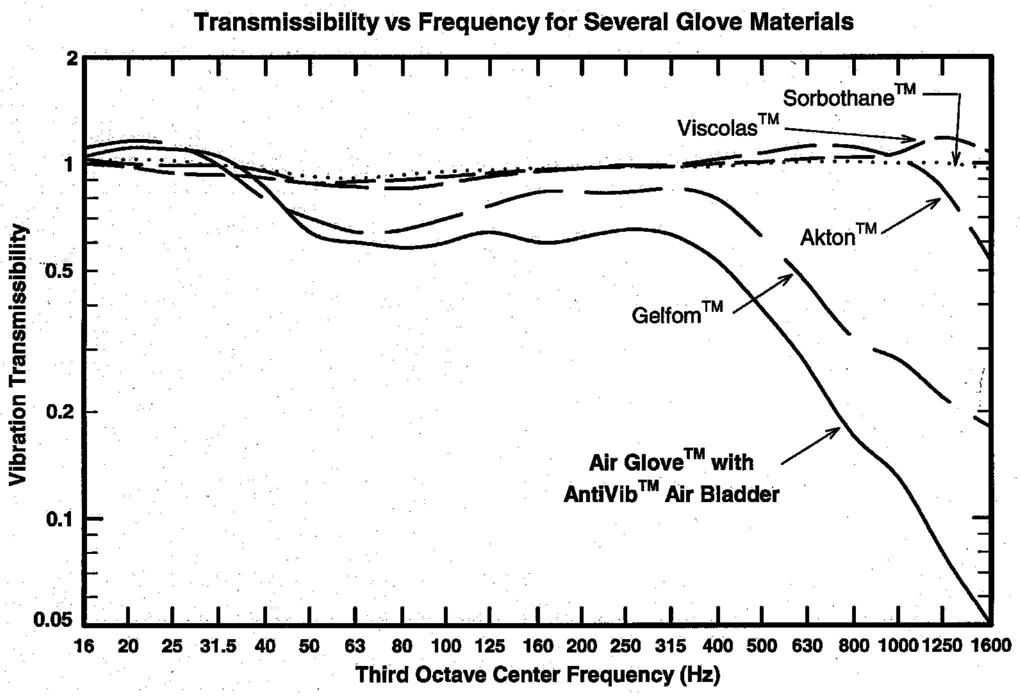

Figure 5. Third octave transmissibility values of selected glove materials.

Gloves made with viscoelastic materials, such as Gelfom, Sorbothane, Viscolas, and Akton require a significantly thicker layer of the indicated material in the palm and fingers to provide vibration protection equal to that achieved with an air bladder. Gloves that use these materials are generally stiff and/or bulky. These materials, when used in a thick configuration in a glove, result in increased muscle fatigue and intracompartment pressure in the carpal tunnel. These increase worker fatigue and reduce tactile feedback. When the vibration-damping material in a glove is too thick, the risk of developing carpal tunnel syndrome with prolong use is increased.

Summary and conclusions

A glove made with an air bladder vibration-damping element met all of the NIOSH, ISO, and ergonomic design requirements for a properly designed antivibration glove.

- It met the requirements of ISO Standard 10819 to be classified as an antivibration glove.
- It significantly reduced the vibration into the hand.
- It was thin, pliable and flexible.
- It naturally conformed to the flex-lines in the palm and fingers.
- It was comfortable to wear.
- It allowed the worker to maintain control of his tool or work piece.
- It allowed the worker to feel what he was doing.
- It was readily accepted by workers who used it.

The latency period for HAVS is the time it takes for the first symptoms of HAVS to appear. The latency period is determined by many factors. However, the most significant factor is the amplitudes of the vibration energy into the hands or the vibration exposure. Gloves with air bladder vibration-damping elements have proven themselves to be effective in reducing vibration exposure. From a research perspective, decreasing the vibration into the hands increases the latency period associated with the onset of HAVS symptoms.

When applied to gloves, air bladder technology lends itself nicely to various glove styles and applications. These styles, along with the flexibility, manipulative dexterity, and comfort associated with gloves made with an air bladder, have led to good worker acceptance of these gloves.

Air bladder technology, when used in gloves, provides credible personal protection for workers exposed to hand-arm vibration. It remains to be seen whether or not industry will utilize this technology to decrease the number of work-related hand injuries associated with exposure to hand-arm vibration. Whatever happens, it is time for the community that has extensively studied and defined disorders associated with hand-arm vibration to shift from recognition, analysis, and quantification of these disorders to intervention and prevention of work-related injuries associated with hand-arm vibration.

Acknowledgments

The authors wish to express their appreciation to ErgoAir, Impacto Protective Products, and Dielectrics Industries for their assistance and support in the research reported in this paper. The air bladder technology reported in this paper is the proprietary property of ErgoAir, Inc. and is protected by US Patents 5,144,708, 5,372,487, 5,537,688, and 5,771,490. Other US and international patents are pending.

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Auto-Balancing on angle grinders

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Introduction

This is a summary of tests carried out by Lindholmen Utveckling to establish the function of Auto-Balancing by means of reducing transmitted vibrations to the operators of hand-held angle grinders.

There are many other parameters which are of interest for the product Auto-Balancing, for instance energy consumption, efficiency, quality of work, cost savings due to service and repair, extended life and noise exposure. Many of these parameters have been investigated but will be dealt with in another forum.

Methods

There is one official method for measuring vibrations from angle grinders. The full details of this method can be obtained in the international standard ISO 8662-4 (2), which is based on the most important standard for this subject, ISO 5349 (1).

Our aim was to investigate the efficiency of Auto-Balancing, not only according to standards but also when grinding in an actual working situation. Therefore, as a complement to the standard test (2), an additional testing method was developed, which was designed in compatibility with the standard test. For this method a swing was constructed with a 50 cm (19,7”) long piece of railway track fixed at one end and a load cell connected via a string to the base of the test rig at the other end. This made it possible to measure the download feed force during grinding. The swing was adjustable in height to simulate different working heights and to adjust for taller or smaller operators.

In the standard ISO 8662-4 the positions for the sensors are described in two different sections. The sensors can either be mounted on each handle at a certain distance from the outer ends of the handles, approximately at the mid points of the handles, or at other positions found on the handles with higher vibration levels. In this case the sensors were mounted on the outer ends next to the placement of the little fingers on each handle. The majority of the measurements were made using three-axial accelerometers.

The main unbalance factor for angle grinders is the grinding disc. Discs are manufactured with various quality. For this reason the grinding discs were classified and sorted into ten unbalance groups. In the measurements presented here, discs from the worst group and from a middle group were used.

The tests were carried out on several angle grinders, both air powered and electrically powered. Each angle grinder was to be compared with and without the Auto-Balancing unit attached. In the cases where the Auto-Balancing unit was not attached, it was replaced by a dummy unit.

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Results

Both the standard test and the complementary test method showed decreased vibration for the investigated angle grinders equipped with Auto-Balancing. The reduced vibration is visible both in the vibration spectrum and in the hand-arm weighted vibration value. The efficiency of Auto-Balancing is substantial at the revolution frequency (80-100 Hz, depending on the machine size).

The $a_{h,w}$ values obtained from real grinding differs from those obtained with the ISO 8662-4 tests. The differences also depend on manufacturer and machine size. However, the relative vibration reduction obtained with Auto-Balancing was higher when measured using the ISO test, than with the complementary method. High $a_{h,w}$ values were also detected in the X and Y direction. For one of the grinders, an even higher value was detected in the X direction than in the Z, ISO 8662-4 prescribed direction.

The $a_{h,w}$ values obtained in these measurements are relatively high compared to the values normally declared. One of the reasons for this is that the rms-values are calculated from measurements in three directions. Another reason is the choice of measuring points. As a result of this, the presented values can be as much as twice as high as normally measured.

The results are presented as a reduction in percent, calculated from the hand arm vibration value, $a_{h,w}$ [m/s^2]. The measured reduction varied from approximately 10% to more than 70 %.

Discussion

The measured $a_{h,w}$ is very sensitive to the choice of measurement position and direction. Since the standard is quite liberal regarding the accelerometer placement, very different vibration values can be measured on the same item. The standard also requires that vibration values are measured in the Z direction only, but our measurements show that vibration values in the X and Y directions are frequently in the order of 50% of the measured value in the Z direction.

With this in mind, the question arises whether it is necessary to revise the standards for hand-arm vibration measurements. Is it possible to predict injuries from vibrating machines using today's standard? Are the CE-declared values trustworthy?

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Driving-point mechanical impedance of the hand-arm system at exposure to stochastic vibration

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Introduction

For the study of detrimental health effects of the hand-transmitted vibration, it is also important to know in detail the mechanical response of the hand-arm system to exposure to various types of vibration. The mechanical properties of the hand have been determined in the laboratory of NIPH Prague, with reference to exposure to sinusoidal and impulse vibration (1, 2, 3). Since the necessary measuring equipment has been available in our laboratory, it was possible to enlarge the investigation to study exposure to stochastic and other types of vibration.

The free driving-point mechanical impedance of the hand-arm system is the basic physical quantity describing the mechanical properties of the upper extremity. The mechanical impedance, which is defined as a complex ratio of dynamic force to vibration velocity, expresses, as well as other modal functions, the character and the resonance properties of the system. This has been reported in a great number of studies (4, 5, 6, 7, 8, 9, 10, 11, 12, 13).

The goals of this laboratory study were;

a) to determine the driving-point mechanical impedance of the hand-arm system under different experimental conditions at exposure to stochastic vibration,
b) to evaluate the response of the hand-arm system at exposure to impulse and stochastic vibration,
c) to compare the experimental results with the averaged data given in the standard ISO 10068 (14).

Methods

The free driving-point mechanical impedance was measured in a group of 18 experimental subjects who had taken part in previous projects (2, 3, 15). The basic data on the experimental subjects are given in Table 1. They are free from previous professional exposure to vibration. The vibration was excited in the direction of the axes X_h, Y_h and Z_h in accordance with the co-ordinate system of the hand ISO 5349 (16). In accordance with ISO 10068, it is possible to express two positions studied of the upper extremity with the sets of the angles $\alpha = 90°$, $\beta = 0°$, $\gamma = 0°^{\circ}$ and $\alpha = 15°$, $\beta = 75°$, $\gamma = 0°$. The upper arm was slightly away from the body and the angle of abduction was 15°. These positions of the hand-arm system are characteristic of work with the power tool in the vertical direction for the axes X_h and Y_h and the horizontal for the axis Z_h .

The basic parameters of the measurements were the grip force (25 N, 50 N, 75 N and 100 N), feed force (30 N, 60 N and 100 N) and their combination forming the maximum coupling force up to 110 N. The tests were performed in several days to avoid the fatigue in the experimental subjects. The grip force was transduced directly on the handle. The

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feed force was transduced by the measuring platform on which the subject was placed. Both forces were transduced by means of four-arm bridges with strain gauges. The signals from measuring amplifiers were entered in the digital form in the computer and the instant values of both forces were possible to read on the display and their time courses could be recorded.

For the study the measuring handle equipped with two force transducers and one accelerometer was used. Signals from all pick-ups were fed to the charge amplifiers. For the dynamic force measurement, the outputs of particular charge amplifiers were connected to a sum amplifier and further on the input of the frequency analyser.

The frequency responses of the driving-point mechanical impedance were determined at the excitation of stochastic vibration with the constant values of velocity 8 mm/s and 20 mm/s. These velocity values correspond weighted acceleration values of 3.7 m/s^2 and 9.2 m/s^2 (16). A two channel FFT frequency analyser connected directly to the computer was used. The impedance data were stated from the cross-spectrum and autospectrum of dynamic force and velocity signals. Measuring signals were integrated for 60 s and the tests were repeated four times. The coherence function was monitored during the measurements. Results were corrected with respect to the impedance of the measuring handle. The average responses and standard deviations were computed for the whole sample of the experimental subjects as needed for descriptive statistical processing. The results of the mechanical impedance are given for the vibration velocity of 8 mm/s at centre frequencies of the one-third octave bands from 8 Hz to 800 Hz.

Table 1. Basic Data on Subjects.

Parameter	Mean value	Standard deviation	Maximum value	Minimum value
Age, years	44.5	8.6	28	70
Height, m	1.78	0.07	1.88	1.67
Weight, kg	78.8	9.26	94	61
Distance from tip of middle finger to olecranon, m	0.47	0.02	0.51	0.43
Distance from olecranon to acromion	0.39	0.01	0.41	0.36
Upper arm circumference, m	0.30	0.02	0.33	0.27
Forearm circumference, m	0.276	0.014	0.29	0.25
Hand length, m	0.188	0.011	0.21	0.16
Hand diameter, m	0.086	0.003	0.092	0.079
Wrist diameter, m	0.06	0.01	0.071	0.055
Grip-force maximum, N	501	65.2	630	395

Results

The mean driving-point mechanical impedance frequency responses of the hand-arm system found in 18 subjects show a slight resonance dependence, see Figures 1 to 3, as sets of typical courses of the complex responses. The hand-arm system response is significantly dependent on direction and frequency of vibration.

In the left part of Figure 1, the mechanical impedance for the direction of vibration X_h and for the angle in the elbow $\alpha = 15°$ is shown. With the increasing grip force, it is possible to note in the whole frequency range a slight increase in the modulus. Two unpronounced maxima of the impedance at the frequencies of 40 Hz and 200 Hz are also obvious in the phase response. Generally, the phase is in the range from 2° to 65° and it more or less has the character of mass and resistance. The hand behaves as a damper especially at higher frequencies.

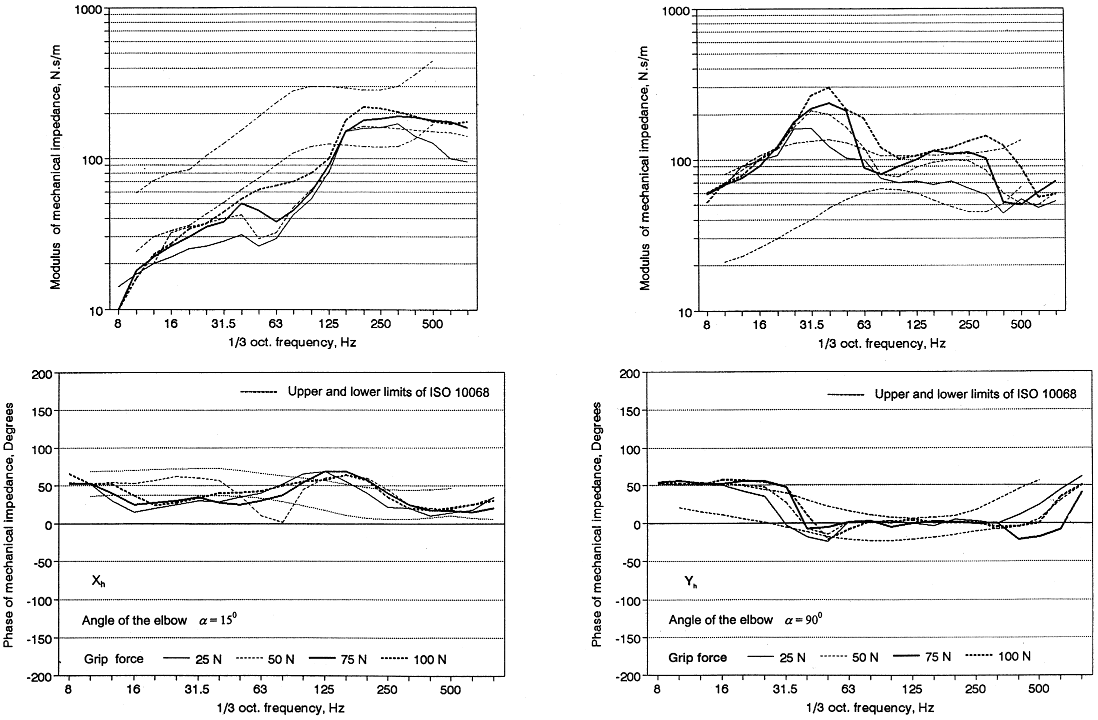

Figure 1. Mean quotient magnitude and phase of the free driving-point mechanical impedance of the hand-arm system for different grip forces in the X_h and Y_h directions.

In the right part of Figure 1, the mechanical impedance for the direction of vibration Y_h and for the angle in the elbow α = 90° is depicted. A sudden remarkable increase in the impedance and a more pronounced resonance area around 50 Hz are shown here. With increasing grip force further increase in the modulus and the frequency shift of resonance are obvious. The phase response has a very similar course. Just above the resonance the phase decreases to negative values and in the frequency range from 40 Hz to 315 Hz the whole system behaves as a simple damper. At the frequencies above 500 Hz the increase in the impedance to positive values is obvious. This fact means that the local maximum of impedance in the frequency range from 100 Hz to 400 Hz corresponds to the maximum of energy transmission and dissipation in the hand-arm system.

In the left part of Figure 2 the mechanical impedance for direction of vibration Z_h and the angle in the elbow of α = 90° is depicted. The increase in the impedance and the clear resonance maximum are very similar to those in the previous case. Just above the resonance the phase decreases to negative values and the whole hand-arm system has character of the compliance. With increasing frequency the phase response tends to reach a zero value. The hand behaves as a damper at higher frequencies again. So far the grip force effects have been presented.

In the right part of Figure 2 the feed force effect is shown. The mechanical impedance for the direction of vibration in the axis Z_h and the angle in the elbow of $\alpha = 15°$ is depicted. The magnitude of the impedance is strongly dependent on frequency. For the frequencies up to 50 Hz a mild increase in the impedance is characteristic. On the other hand, with the frequencies above 125 Hz, a high increase in the impedance was recorded. From the phase response, a resonance area at lower frequencies and the compliance character of the impedance at higher frequencies are obvious. The effect of the feed force on the magnitude of the impedance is not important. For the range of feed forces up to 100 N no substantial differences in impedance responses were determined.

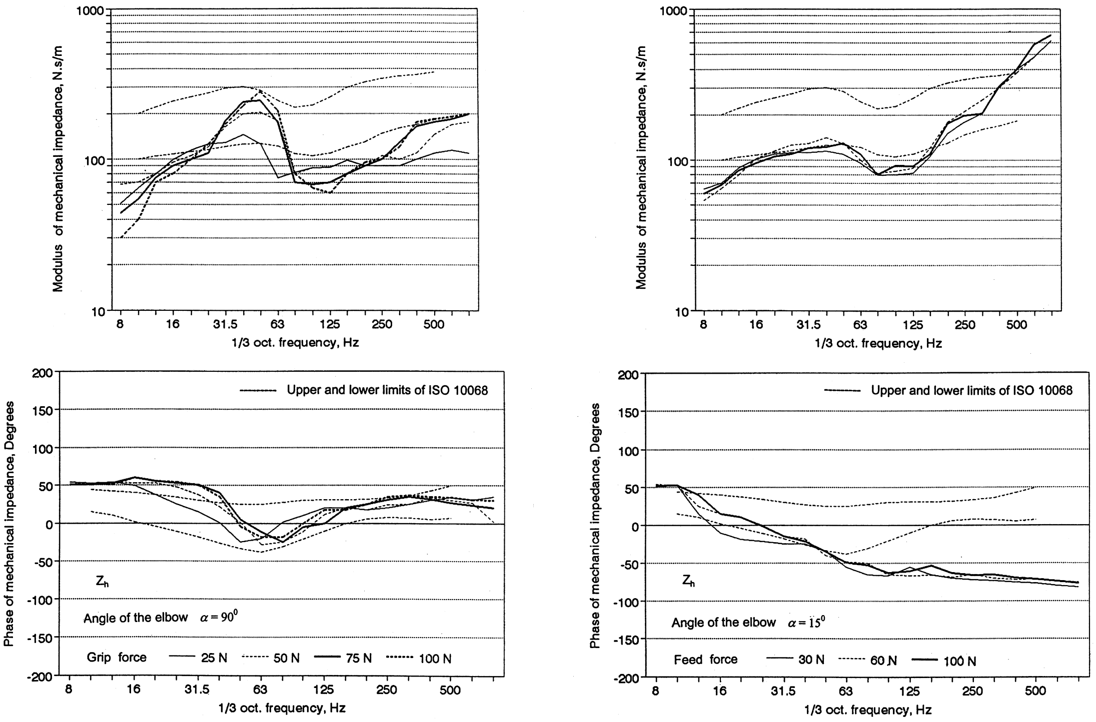

Figure 2. Mean quotient magnitude and phase of the free driving-point mechanical impedance of the hand-arm system for different grip and feed forces in the Z_h direction.

In the Figure 3 the combined effect of the grip and feed forces are shown. The position of the upper extremity and the direction of vibration in the axis Z_h were the same as those in the previous case. The magnitude of the impedance shows a clear resonance area with the centre frequency 50 Hz or 60 Hz and an increase at higher frequencies. With the increase of forces, an increase in the impedance and the frequency shifts of the local maxima were recorded. Nevertheless, the character of the impedance is given by the position of the hand-arm system. This is confirmed by the phase response. The compliance character of the impedance at higher frequencies is also obvious.

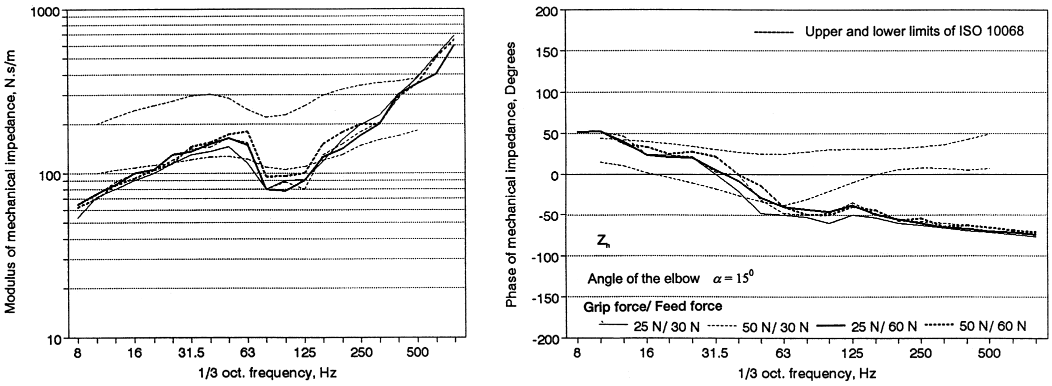

Figure 3. Mean quotient magnitude and phase of the free driving-point mechanical impedance of the hand-arm system for different combinations of grip and feed forces in the Z_h direction.

Discussion

Changes in posture of the hand-arm system lead to substantial changes in it's mechanical response. Generally, with higher grip or feed forces, it is possible to observe an increase in the mechanical impedance and a frequency shift of resonances. The effects of both force types on the mechanical response of the hand are very similar. Nevertheless, the effects of grip force are more pronounced. With respect to the principle of the feed force measurement, this conclusion is based only on the measurement in the axis Z_h. The character of the impedance is generally determined by the position of the upper extremity. With an angle in the elbow of $\alpha = 90°$, a clear resonance was always measured in the frequency range from 40 Hz to 60 Hz for all directions of vibration. If the angle in the elbow α is very low, the resonance almost disappears and it is possible to note only an impedance increase at these frequencies.

Under the same experimental conditions and using only a limited group of the experimental subjects, it is possible to compare the results of this study with those based on impulse excitation (2, 3). In the Figure 4, typical pairs of the impedance results are shown; in the left and right parts of this figure, the data are given for the directions X_h and $Z_{h,}$ respectively. The upper pairs of the impedance curves always correspond to impulse vibration and the impedance is about 3.5 to 7 times higher than that at the excitation by a random signal.

For the direction of vibration in the axis X_h the impedance responses do not have similar courses. An increasing trend is recorded for the impedance but it is not possible to compare the particular resonance areas. At this frequency range the particular phase responses do not differ, but the phase difference grows with increasing frequency. On the other hand, the impedance character is quite different at frequencies above 100 Hz.

For the direction of vibration in the axis Z_h the course of the impedance responses is very similar. It is possible to observe the resonance area from 31.5 Hz to 80 Hz and corresponding local maxima and minima of the responses. Since the phase responses do not differ, the real and the imaginary parts of the impedance are higher at the impulse excitation by the same factor as given in this part of Figure 4. This supports the assumption of the non-linear behaviour of the hand-arm system (3, 5, 8, 12).

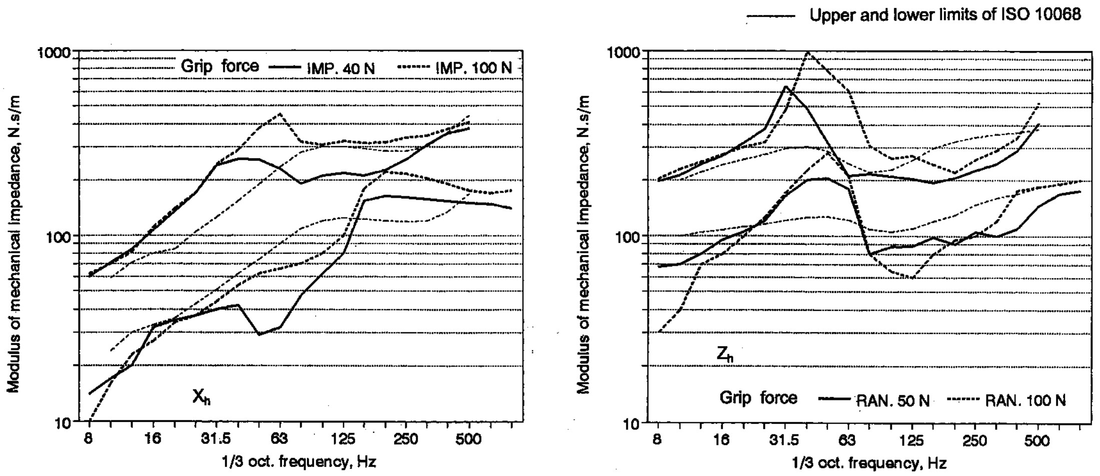

Figure 4. Mean quotient magnitude of the free driving-point mechanical impedance of the hand-arm system for two grip forces in the X_h and Z_h directions for exposure to impulse and stochastic vibration.

The hand and arm response does not differ significantly in the range of velocity from 8 mm/s to 20 mm/s. We have only found lower magnitude of the impedance at frequencies under 63 Hz in the axes X_h and Z_h with the increasing velocity.

Do the measured data correspond with the results of other laboratories (4, 6, 7, 8, 9) ISO 10068 has been used as a base for answering this question. The lower and upper limit of the averaged data according this standard were outlined by dashed lines in Figures 1 to 3 to facilitate comparison. For the direction of vibration in the axis X_h, the impedance follows the lower limit and the phase varies around the mean value. For the axis Y_h, the magnitude of the impedance more or less exceeds the upper limit in the resonance area. Generally, the magnitude follows the upper limit in this direction. The phase response is in good agreement with the stated limit responses.

For the direction of vibration in the axis Z_h it is necessary to consider different positions of the hand-arm system. For the angle in the elbow of $\alpha = 90°$ the magnitude of the impedance follows the lower limit of the averaged data, except for the resonance area. The phase response lies within the determined range. For the angle in the elbow of $\alpha = 15^{\circ}$ when the axis of the forearm is nearly identical with the axis of the generator of vibration, the important difference in phase response was stated at the frequencies above 63 Hz. Nevertheless, at the frequencies under 63 Hz the impedance magnitude follows the response for the lower limit of the averaged data.

The energy transferred and dissipated in the hand-arm system have also been calculated. Since the excitation with the constant vibration velocity was used, the maxima of the impedance, where the phase is close to zero, correspond to the maxima of energy dissipated in the hand. The increase of grip and feed forces result in the increase of the real part mechanical energy.

Conclusions

The effect of stochastic vibration on the hand-arm system is highly dependent on several biodynamic parameters (guiding forces, posture and angles in the hand and arm) and physical parameters of exposure. Moreover, the hand-arm system response is influenced by the properties of the vibration source itself, namely by the magnitude of it’s inner mechanical impedance. The laboratory experiments based on impulse or random excitation of vibration only represent two extreme cases compared to professional exposure. In practice, the question of impedance ratio (source vs. hand-arm system) is much more complicated. Further research in this field is urgently needed.

Acknowledgements

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Health and risk factor surveillance for hand-arm vibration

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Health and risk factor surveillance: in brief

Systems for health and risk factor surveillance (HRFS) aim for early detection of signs and symptoms of an incipient work-related disorder, e.g. due to hand-arm vibration exposure (HAVD). A surveillance system can for instance be a part of a health and safety programme or a stand alone activity. HRFS is therefore an important tool to preserve or improve health and productivity in the working life (8).

Surveillance has been defined as:

> ”The ongoing systematic collection, analysis and interpretation of health and exposure data in the process of describing and monitoring a health event. Surveillance data are used to determine the need for occupational safety and health action and to plan, implement and evaluate ergonomic interventions and programs” (9).

Hagberg (7) states nine goals of surveillance that are linked to the use of surveillance data in prevention activities;

1. Identify new or previously unrecognised problem,
2. Determine the magnitude of the work-related disorder,
3. Identify occupational groups, departments, work sites to target control measures,
4. Track trends over time,
5. Describe health and risk factors for management and work sites to initiate preventative changes,
6. Identify potential control measures by observing low risk groups,
7. Basis for prioritising preventative actions,
8. Evaluate the progress of preventative actions and
9. Generate hypotheses for research.

Surveillance aim for early detection of work-related symptoms and disorders and their risk factors. For the purpose of health surveillance it is therefore of outermost importance to decide upon both risk factors and surveillance case definitions as they may vary considerably. According to Last, 1986, data collection instruments for surveillance purposes can be characterised by their practicality, uniformity and rapidity rather than their complete accuracy (10). There is in principal two methods for collecting surveillance data, characterised as ”passive” or ”active”. Passive health surveillance uses existing data such as company case books, insurance records, workers’ compensations records, absentee records, grievances etc. Passive risk factor surveillance uses for instance retrospective data collected earlier at the work site in question, at a comparable work site elsewhere or surrogate measures. This method is predominantly used to survey health outcomes. Application of an active health and risk factor surveillance method imply seeking information more ”actively”, by using checklists, interviews, questionnaires, physical exams, job analysis, vibration measurements etc. Analysis and interpretation of surveillance data requires tools and methods good enough to lead to appropriate action as well as follow-up. Individuals

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responsible for accomplishing a HRFS programme also require training to ensure a proper administration.

Hand-arm vibration health and risk factor surveillance (HAV HFRS)

The employers should provide a HFRS programme for their employees occupationally exposed to vibrating hand-held tools. They should also provide necessary facilities for running the programme. The management of the HFRS programme should be under the supervision of persons with certified training in at least occupational health and risk factor evaluation.

Figure 1 show a draft schematic model of a periodic HAV HRFS programme. The programme can be broken down in to three steps. The first step uses “passiv” methods for collecting surveillance data. In step 2 surveillance data is collected by using “active” methods. The third step represent a stage where the presence of health or risk factors have been identified which requires different forms of medical or technical intervention. The model suggest that health and risk factor surveillance should be performed every two years or if changes in the workplace occurs. It has however been suggested that re-assessment should be made at shorter intervals for a period after job entry in order to detect those individuals especially sensitive to vibration, maybe every six month (6). A re-evaluation should also be offered if an increase in exposure occurs or if a person reports symptoms which may be related to the exposure.

Health surveillance

A pre-employment medical examination should be offered to a worker who will enter a job involving the handling of vibrating tools. The main objectives are to obtain baseline health data for the individual for comparison at subsequent periodical examinations and to verify presence of symptoms which can be regarded as possible medical contra-indications for hand-arm vibration exposure. An objective is also to make the worker aware of the risk for developing a hand-arm vibration disorder (HAVD). The pre-employment medical examination must be conducted in accordance to the principles and practice of occupational medicine and should include the case history (i.e. family, social, work and personal health history), a complete physical examination and if necessary also screening tests and special diagnostic investigations. Periodic health factor surveillance assessments should be conducted with a regular interval.

Risk factor surveillance

At entry of the job the worker should be offered a risk factor evaluation, which at least should be a rough estimation of expected vibration magnitude and duration of exposure. Passive risk factor surveillance methods can be used for this purpose, such as checklists, results from previous measurements conducted on the company’s vibrating tools, vibration databases or other surrogated measurements (e.g. EU-declared values) (1, 11). Workplace measurements may be necessary to carry out if no records exist on vibration levels for tools (4, 5). This is a more active risk factor surveillance method that can be used in both step 1 and 2 in the HFRS model (Figure 1). If the estimated, or measured risk factor is above an unacceptable level than a workplace or job intervention is required. Periodic risk factor surveillance assessments should be conducted with a regular interval.

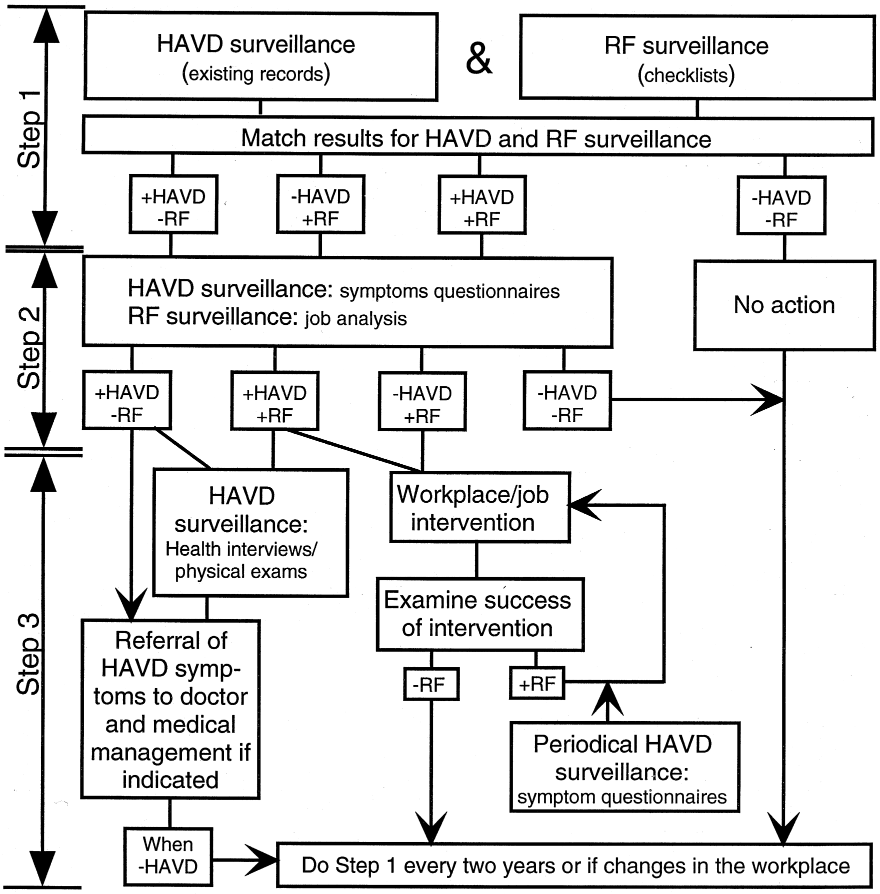

Figure 1. Draft process model for HRFS with respect to HAVD. Presence/Absence of risk factors = ±RF; Presence/Absence of HAVD = ±HAVD.

Discussion

It should be noted that this HRFS model should be considered only as a first draft. Most elements in the model require extensive discussions and consensus before a final HRFS model can be realised.

A work, with the purpose to develop guidelines for hand-transmitted vibration health surveillance has recently been initiated within the frame of an European Vibration Research Network (EU-programme: BIOMED 4, BMH4-3251-CT98-3251, G-12-SSMI). Some of the issues mentioned above will be addressed in these guidelines (12). The guidelines will include sections on current knowledge of HAV injuries, prevention measures, health surveillance (pre-employment and periodic medical examinations, screening tests and special diagnostic investigation, medical removal) and a list of relevant references. In appendices to these guidelines different health surveillance initial and follow-up questionnaires will be presented, of which some are self-administered. Other appendices will provide lists of contraindications that may increase the risk for upper limb disorders in workers exposed to HAV, clinical tests for diagnosis of upper limb disorders and criteria for clinical diagnosis of neck and upper limb musculoskeletal disorders. The guidelines do not, however, provide guidance for risk factor surveillance.

Among other important matters to discuss in this context are reporting of surveillance results as well as ethical and legal issues. The reporting of surveillance results can be done in many different ways. From a simple oral report to the employer to an extensive written report and/or detailed discussions with employer and employees in order to initiate and promote preventative measures. The ”International Code of Ethics for Occupational Health Professionals”, published by the International Commission on Occupational Health 1994 (2), provides some guidance for ethical and legal aspects on HRFS.

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Non-invasive testing of disorders of autonomic nervous system in non-smoking and smoking workers exposed to vibration by spectral analysis of heart rate variability

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Introduction

Previous studies (4,7,9,12) have reported parasympathetic (PASY) dysfunction of heart rate (HR*)* regulation in workers exposed to vibration (mainly in subjects with white finger attacks (9)).

Smoking as one of the environmental factors acting on subjects has depressive effects on the autonomic nervous system (ANS) regarding PASY responses (8).

The goals of the present study were:

1. to evaluate spectral parameters of the HR variability (HRV) in:
    - very low (VLO)
    - low (LO) and
    - high (HI) frequency bands

   in the subjects with long-term exposure to vibration (EV) and to compare them with standard values,
2. to estimate differences in the parameters between subgroups: non-smoker (NS) vs. smokers (S).

Subjects and Methods

A. Subjects

We examined 34 males exposed to vibration (EV - age 40.4±1.7y), they all were working on average 18.7±1.7y (Mean±SE) with pneumatic casting hammers and pneumatic grinders in the foundry steel alloy industry. The subjects were without any disease and drugs influencing the HRV values (3.6). The study EV group was divided to two subgroups of non-smokers (NS) and smokers (S) (Table 1).

B. Methods:

All subjects underwent complete medical clinical examination (including hematological and biochemical screening, cold test, digital rheography, LD flowmetry of the skin circulation, etc.)

HRV was evaluated by use of the system VariaPulse TF3 (fy Sima Media Olomouc, Czech Republic) with telemetric transmission of the R-R intervals to PC. The system provides spectral analysis of the R-R intervals in T1, T2, T3 periods (T1 - in the first supine position, T2 - in active orthostasis, T3 - in the following supine position -

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klinostasis of examined subject). Every period T consists of 350 R-R intervals. HRV was evaluated in three frequency bands:

VLO - very low frequency (0.003 - 0.04 Hz) related to fluctuations in vasomotor tone through sympathetic and hormonal systems,
LO - low frequency (0.04 - 0.15 Hz) reflecting baroreceptor activity,
HI - high frequency (0.15 - 0.50 Hz) determined by PASY, refection of respiratory sinus arythmia.

In the statistical analysis Student's t-test and calculation of correlation coefficients (values of HRV to the numbers of cigarettes per life, values of HRV to the years of vibratory exposure) were used with a level of significance of $p < 0.05$.

Table 1. Characteristics of the examined EV subgroups (NS and S).
Values are given as Mean±SE (non significant difference (ns), $p < 0.05$).

Subgroups	Non-smokers (NS)	Smokers (S)	p - statistical significance NS/S
Number of subjects	11	23	
Mean age (years)	41.27 ± 3.47	40.04 ± 1.9	NS
Mean exposure (years)	19.82 ± 3.10	18.13 ± 2.1	NS
Mean height (cm)	175 ± 1.5	175 ± 1.2	NS
Mean body weight (kg)	83.7 ± 3.9	77.7 ± 1.9	NS

The subgroups were matched for age and duration of exposure to vibration. The average number of cigarettes consumed was 100.753 ± l7.676 per 1 smoker (Mean±SE)

Results

The smoking habit was present in 67.5% of workers in the steel alloy industry.

1. HRV parameters in the whole EV group were not different to standard values. However, evaluation of the parameters in nine workers with the longest exposure to vibration (20.9+1.9 y) revealed a decrease of PASY activity (Power HI and CCvHI) and an increase in the sympathetic activity (rise in % VLO and decrease MSSD).
2. HRV parameters in the subgroups of non-smokers and smokers exposed to vibration are shown in Table 2 and in Figures 1-5.

Table 2. Heart rate variability (HRV) - selected parameters in workers exposed to vibration in subgroups of non-smokers and smokers.

Parameters		Values (Mean±SE)		p- statistical significance
		Non-smokers (n=11)	Smokers (n=23)	
R-R interval (sec)	T1	0.87 ± 0.05	0.91 ± 0.04	NS
	T2	0.67 ± 0.03	0.75 ± 0.03	NS
	T3	0.87 ± 0.05	0.92 ± 0.04	NS
MSSD (ms^2)	T1	1391 ± 554	2472 ± 758	NS
	T2	621 ± 210	1024 ± 405	NS
	T3	2735 ± 1770	3367 ± 1040	NS
Total Power (ms^2)	T1	2690 ± 1668	2130 ± 594	NS
	T2	8050 ± 2560	3487 ± 1041	NS
	T3	2276 ± 1093	2060 ± 594	NS
Spectral Power VLO (ms^2)	T1	449 ± 143	840 ± 407	NS
	T2	7285 ± 2344	2770 ± 1046	$p < 0.05$
	T3	657 ± 205	551 ± 77	NS
Spectral Power LO (ms^2)	T1	546 ± 291	262 ± 57	NS
	T2	541 ± 189	529 ± 122	NS
	T3	595 ± 296	278 ± 45	NS
Spectral Power HI (ms^2)	T1	1705 ± 1252	975 ± 302	NS
	T2	225 ± 85	327 ± 136	NS
	T3	1024 ± 654	1323 ± 523	NS
CCv VLO (%)	T1	2.2 ± 0.2	2.75 ± 0.6	NS
	T2	10.8 ± 1.9	6.2 ± 1.0	$p < 0.05$
	T3	2.7 ± 0.3	2.6 ± 0.2	NS
CCv LO (%)	T1	1.83 ± 0.5	1.6 ± 0.2	NS
	T2	2.94 ± 0.5	2.5 ± 0.3	NS
	T3	2.0 ± 0.4	1.65 ± 0.2	NS
CCv HI (%)	T1	2.65 ± 0.9	4.9 ± 2.2	NS
	T2	1.7 ± 0.4	4.9 ± 3.2	NS
	T3	2.3 ± 0.6	4.7 ± 1.9	NS
Ratio VLO/HI	T1	5.3 ± 2.6	3.2 ± 1.3	NS
	T2	148.0 ± 60	161.0 ± 111	NS
	T3	8.2 ± 3.5	2.3 ± 0.8	$p < 0.05$

Explanations of abbreviations:

T1 - the first supine position

T2 - orthostasis

T3 - the second supine position

MSSD = mean square successive differences R-R intervals

Total power = power VLO + power LO + power HI

CCv = coefficient of variance = $\frac{Power}{R-R}\ 100\%$

NS = non-significant difference

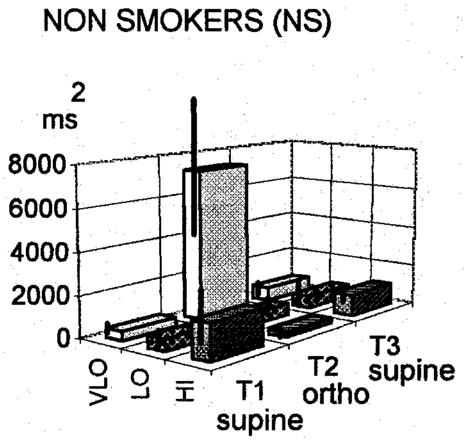

Figure 1a. SPECTRAL POWER
VLO, LO, HI

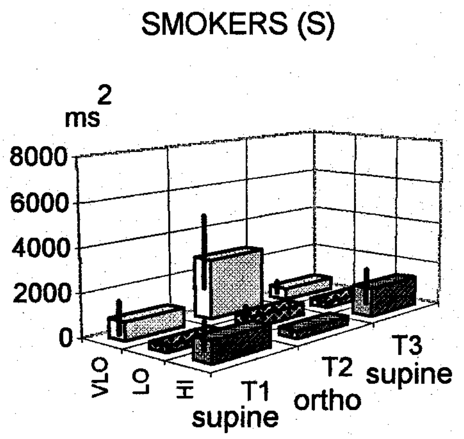

Figure 1b. SPECTRAL POWER
VLO, LO, HI

The HI power (PASY) was higher in T1 interval (tendency) in non-smokers compared to smokers. Higher power VLO was found in smokers, indicating higher initial sympathetic activity and lower VLO power during orthostasis (T2) in comparison to non-smokers. Statistically significant ($p<0.05$) difference was between VLO in T2 (non-smokers to smokers).

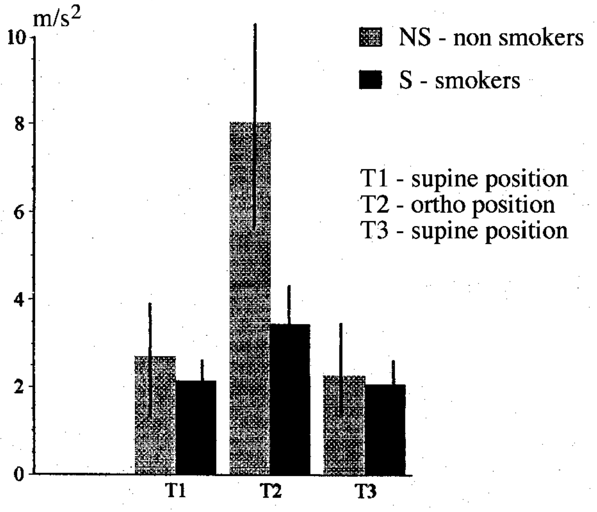

Figure 2. TOTAL POWER.
Total power has a tendency to be
HI lower in the smokers subgroup
indice of SY/PASY.

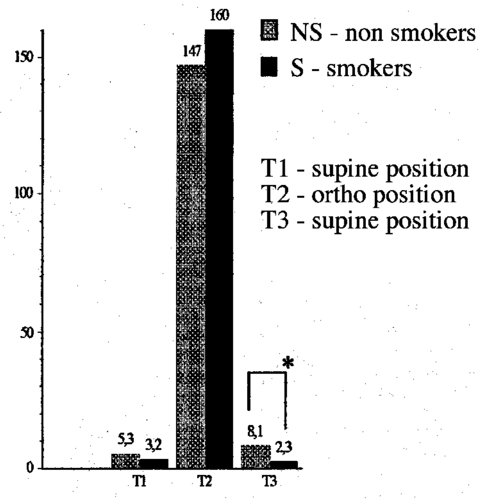

Figure 3. RATIO VLO/HI.
The ratio between power
VLO/power HI revealed that this
reactibility was decreased in
smokers during klinostasis (T3). *
$p < 0.05$

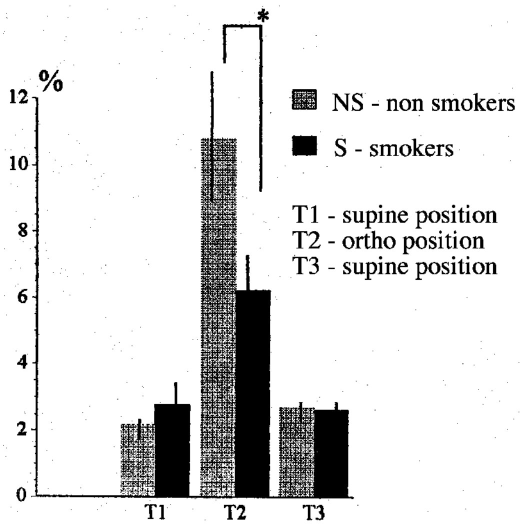

Figure 4. CC vs. VLO.
CC vs.VLO was lower in T2 in smokers, than in non-smokers. The sympathetic response to standing posture was decreased in smokers. (* $p < 0.05$).

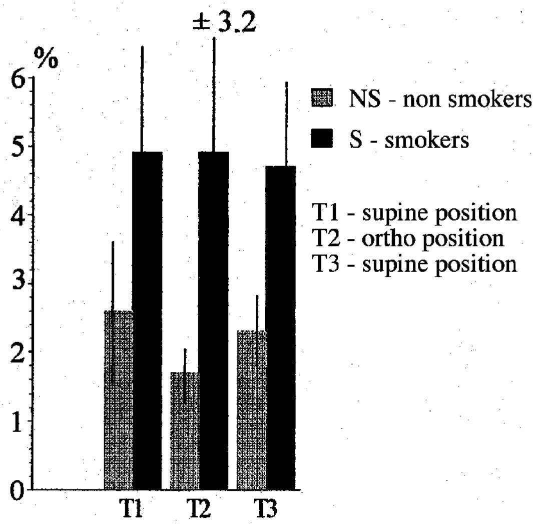

Figure 5. CC vs. HI.
In the subgroup of smokers there was a tendency to higher CC vs. HI.

We found a positive correlation between values Pr (relative pulse volume in fingers after cooling test and frequency LO in supine position (T1) $r = + 0.41$ $p < 0.05$. In EV subjects the higher the frequency of VLO in T3, the lower the relative pulse volume (Pr) in fingers was found ($r = - 0.37$, $p < 0.05$).

Discussion

Heart rate variability reflecting autonomic tone may be determined in short-term or long - term ECG (R-R intervals) monitoring. Short-term measurement (one period lasting e.g. 5 minutes) provides information about high to very low frequency variations of the R-R intervals without determination of long-term or diurnal trends in heart rate. The major advantage of the short term heart rate variability evaluation is the limited duration of the examination suitable for clinical practice.

Using Fourier spectral analysis in the frequency domain, information can be obtained about parameters in different frequency bands which reflect the balance and activities of individual divisions of autonomic nervous system (ANS). Therefore, this method is very valuable and at this time is frequently used, for example, in diabetics, patients after acute myocardial infarction etc.

As we have mentioned, previous studies (4,7,9,12) have shown a dysfunction of cardiovascular system regulation in workers exposed to professional vibration (EV). The aim of our study was to compare the parameters of the HRV in the frequency domain of the workers (EV) to standard values and to estimate the possible influence of chronic cigarette smoking on the regulation of heart rate in EV workers.

We did not find statistically significant differences in the variables of the HRV in EV workers in comparison to standard values. However, in the workers exposed for the longest time indications were found of higher sympathetic and lower parasympathetic tone, even without Raynaud's phenomenon positivity. A negative correlation was found between duration of exposure to vibration and some parameters of HRV, mainly MSSD, total power and high frequency (PASY) variables. These results are in agreement with the findings of Virokannas and Tolonen (12) in railway workers, with a significant correlation between exposure to hand-arm vibration and beat-to-beat variation in the quiet breathing test. We agree with the opinion of the authors that vibration might cause changes in the regulation of the heart rate, especially in workers with long lasting exposure.

Acute effects of smoking in the cardiovascular system are well known: increase of systolic blood pressure and tachycardia, shortening of R-R intervals. Smoking reduces baseline levels of vagal-cardiac nerve activity and resets vagally mediated baroreceptor-cardiac reflex responses (10). It reduces baseline sympathetic nerve traffic to the muscle vascular bed, but exaggerates baroreflex-mediated increases of sympathetic activity and the resulting increase of blood pressure.

Chronic effects of smoking on heart rate variability are less known. For this reason we studied HRV in workers (EV) regarding a possible interaction of vibration with the smoking habit. We found a positive correlation between the total number of cigarettes consumed per subject and the coeficient of variability in the very low frequency band, e.g. index of sympathetic activity. Ageing (11) and an expected decrease in physical and sport activities in smokers might also contribute to this correlation because the HRV depends on the regular physical activities (1).

The intensity of the smoking habit is also related to vasodilatory ability. Hashimoto (5) found impaired microvascular vasodilator reserve in chronic cigarette smokers after short-lasting occlusion in fingers. It indicates increased sympathetic outflow to vascular beds as we have reported previously using skin laser-doppler flowmetry (2). Changes in the regulation of peripheral vessels may contribute to cold induced attacks of vibration white fingers (VWF). Any basic factors contributing to this syndrome up to to this time have not been definitively established (8). One factor from accepted pathophysiological principles in VWF is increased vasoconstrictor tone preferred by centrally enhanced vasoconstrictor tone. The results of HRV evaluation support an hypothesis of generalisation of body responses to vibration.

We found that smoker (EV) workers had significantly diminished sympathetic reactions in orthostasis in comparison to non-smokers (EV). This impaired orthostatic regulation of the heart rate can worsen subjective symptoms (vertigo etc.) observed, for instance, in chain operators with over 5 years working exposure to vibration in a standing position or in sudden change of posture (13).

We conclude that long-lasting exposure to vibration may be accompanied by generalised changes in regulation of the cardiovascular system, including heart activity. Chronic cigarette smoking can contribute to the impairment of cardiovascular regulation mediated through ANS (e.g. during orthostasis).

Conclusion

Twenty years lasting exposure to vibration in dressers and grinders of steel alloy can be accompanied with a decrease in PASY activities regulating heart rate and with a tendency to increase the variability in the VLO band (sympathetic response), even in subjects without Raynaud's phenomenon.

A negative correlation was found between the duration of exposure to vibration in the EV group and selected parameters; HRV-MSSD, total power HRV-HI (PASY) values.

Chronic smoking significantly influences ANS reactions to orthostasis (decrease of total spectral power, power VLO) and diminishes sympathetic reactions.

The presented effects of smoking should be taken into consideration in the evaluation of heart rate variability in subjects, including EV workers.

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Hand-arm vibration and vibration disease in Latvia

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For the time being there in Latvia has not been paid necessary attention to hand-arm vibration as a problem of occupational health. During the time of Soviet occupation it prevailed here the tendency of reducing the number of registered occupational diseases aimed to make distorted view of high occupational culture here in Soviet Union.

In spite of existing limits on hand-arm vibration (1) here in Soviet Union, these norms and regulations have not been met. Unfortunately, this situation did not change up to now. There in Latvia more than a hundred cases of occupational diseases were registered annually. Approximately 20% of cases were diagnosed as vibration disease (see table 1).

Table 1. Occupational diseases in Latvia.

Year	Primary registered all occupational diseases, morbidity	Primary registered vibration disease, morbidity	%
1994	188	19	10.1
1995	180	38	21.1
1996	119	29	24.4

Approximately 1/5 of cases vibration disease (23,7% in 1995 and 13,8% in 1996) were hand-arm type. In total there in Latvia were registered about 160 vibration disease's sufferers, from which about ten people were chain-saw operators. However, it is thought, that the numbers shown above in reality were some 5-1 0 times higher, because many sufferers did not ask the medical help.

As vibration disease's sufferers inform, existing regulations and limits were violated in most of all cases. For instance, people involved in forestry logging work were using antiquated, low qualitative chain-sawing equipment without specific gloves. They usually worked more than 14 hours daily without regular rest heated indoors. Besides were not carried out regular medical control to give a chance diagnose vibration disease in early stages.

There in Latvia by 1996 was established the Technical Committee "Acoustic. Mechanical vibration and shock". It intends to create and implement new methods and ways to evaluate and to control noise, vibration effects in conformity with European and International Standards.

At present the ISO 5349 (2) is prepared to legislate as a National Standard and also the relevant regulations are under consideration to put it in force in Latvia.

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Vascular and nerve damages at exposure to vibrating tools related to the ISO norm 5349, appendix A

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Introduction

The use of hand-held vibrating tools is common in many different professions and the tools vary in size, weight, acceleration amplitude and frequency. Exposure to vibrating tools may cause a variety of symptoms depicted as the Hand-Arm Vibration Syndrome (HAVS). The symptoms may be of vascular, neural, and muscular origin and may appear as digital vasospasm (vibration white fingers; VWF), sensorineural disturbances, and/or as muscular weakness and fatigue (1). The interindividual susceptibility, however, varies considerably and the dose-response relationships are not fully clarified. The aim of the study was to compare different ways of exposure estimation and their relationships to the ISO norm 5349 (2).

Methods

The study comprises 19 male workers with more than three years of exposure to hand-held vibrating tools from five small metal repair workshops in Malmö, Sweden. Through a structured interview the exposure was estimated for all workers (type and number of tools, exposure time for each tool etc.). The individual vibration dose was calculated in two ways: 1) From the subjective estimation by the workers and 2) From registered grinding wheel consumption and measured vibration levels from the equipment used. For some work-tasks, the level of vibration and typical working positions were documented by video tape recordings (PIMEX-method). All workers passed the following neurophysiological investigations at the Malmö University Hospital;

1. EMG with fractionated nerve conduction velocity measurements
2. Skin temperature thresholds
3. Tactilometry in fingers, dig II and V (measurement of vibrotactile thresholds using seven fixed frequencies from 8-500 Hz).

Comparison was made with an occupationally unexposed reference group, previously studied at the department of Occupational and Environmental Medicine, Lund University Hospital.

Results

The 19 platers/grinders had a mean-age of 43 years (range 29-60 years) and a median exposure-time of 20 years (range 3-47 years). Thirteen of the workers showed neurophysiological signs of neuropathy and five of them also showed signs of VWF. Of the remaining six workers, two had developed vibration related white fingers (VWF) without concurrent symptoms and signs of distal neuropathy, four had no clinical

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symptoms. The subjective estimation of the mean daily exposure-time to vibrating tools by the workers was 192 minutes (range 18-480 minutes), while the estimated mean exposure-time calculated from the consumption of grinding wheels was 42 minutes (range 18-60 minutes). The measured frequency-weighted acceleration levels from the 10-12 tools used varied between 121 and 145 dB (1-17 m/s^2). The measurements showed variations up to 10 dB for the frequency-weighted acceleration level during work with grinding wheels.

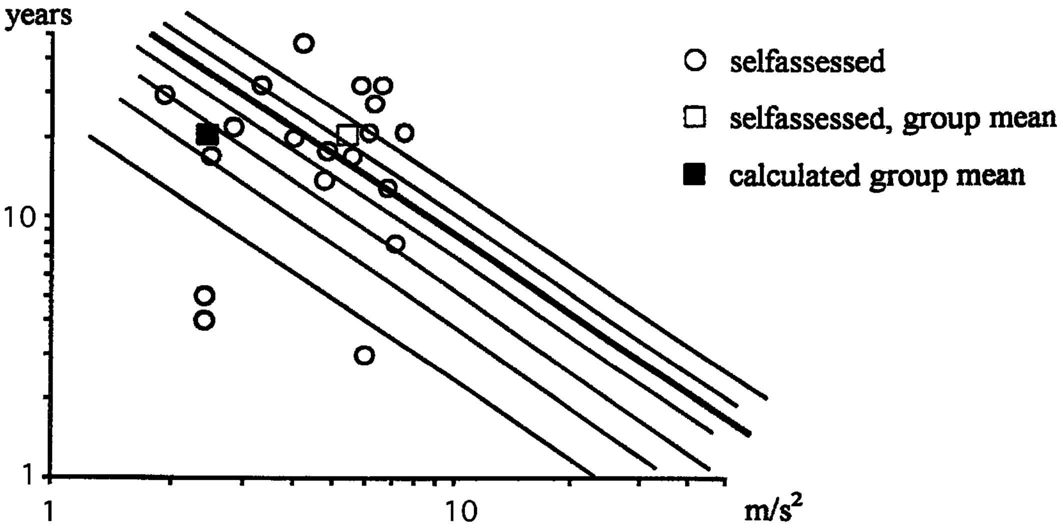

Figure 1. Risk assessment for the 19 workers according to ISO 5349, Appendix A as individuals (○), as well as group means, based on self assessment (□) of the daily exposure time respectively calculated (■) time.

Discussion and conclusions

The level of frequency-weighted acceleration varied with a factor of 2-3 during work with grinding wheels. The outcome of the risk assessment based on the ISO norm 5349, appendix A, was dependent on the method of estimation of the exposure dose. The subjective estimation of the exposure time was about four times longer than the calculated and/or measured time of exposure to the tools, and gave compared to the ISO norm 5349, appendix A, an overestimation of the risk.

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Can new materials give better protection from hand-arm vibration exposure?

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Introduction

Long term use of vibrating tools may cause vascular and neuromuscular symptoms, commonly named the Hand-Arm Vibration Syndrome (HAVS; 1). The sensorineural symptoms usually start with intermittent tingling and numbness of the fingers. If the exposure continues the symptoms will become constant and impaired tactile sensitivity and temperature sense, as well as reduced manual dexterity, may follow (2, 3, 4, 5).

Work with hand-held vibrating tools covers a wide range of vibration frequencies and amplitudes, working postures, weights and construction principles of the tools. Dental technicians commonly work with high speed grinding machines giving vibration frequencies at and above 500 Hz (6). Motor mechanics usually use impact wrenches with an impact frequency around 10 Hz and with a high energy content at frequencies above 1 kHz. Other frequently used tools in construction works and machine shops include surface grinders, keyhole saws and angle grinding machines.

To diminish the risk for developing HAVS, different personal vibration damping equipments, e.g. gloves, may be used. It has been shown that traditional gloves do not provide anti-vibration properties (7, 8). Thus, different types of vibration damping materials that may be used in protective gloves or as covers around the handle of the tools have been developed (9, 10). EU rules and regulations for Personal Protective Equipment (PPE) are given in the Directive 89/686/EEC with a later amendment 93/68/EEC. The testing procedure of resilient materials has previously been described by Voss (8).

The aim of the study was to compare the isolation effectiveness of different commercially available vibration damping materials. The testing aimed at comparing hand-arm weighted and unweighted acceleration levels for several hand-held vibrating tools covering a wide range of construction principles and vibration frequencies.

Material and methods

The vibration damping materials tested were a) a new gel and foam protection material (commercially named Gelfôm; thickness 6 mm), b) a commercially available polyurethane foam (Sylomer; thickness 6 mm), and c) a protective silicon compound, frequently used at dental clinics and laboratories in Sweden (Colgrip; thickness 6 mm).

These damping materials were tested on five hand-held vibrating tools:
a high frequency grinding instrument used by dental technicians (EWL K9), an impact wrench (Scorpio) used by mechanics, a surface grinder (Black & Decker DN 41-F2; 135 W), a keyhole saw (Black & Decker DN 531, 330 W), and an angle grinding machine (Black & Decker; BD 5; 450 W).

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The study design is shown in Table 1.

Table 1. Study design when testing the isolation effectiveness of three commercially available materials on five hand-held tools.

Tool	Vibration damping materials			
	Gelfôm	Colgrip	Sylomer	None
Dental grinding instrument	X	X	X	X
Impact wrench	X			X
Surface grinder	X		X	X
Keyhole saw	X		X	X
Angle grinding machine	X		X	X

Measurements on the tools were performed with a small accelerometer (Brüel & Kjaer 4374) that was glued by a non-elastic epoxy resin to a thin metal plate attached to the handle of the tool by hose clamps (tools no. 1 and 2). For tools no. 1 and 2 hose clamps were also used to attach the metal plate with the accelerometer to the handle when it was wrapped with protective materials. The results were analysed by the Viblab program enabling determinations of unweighted acceleration levels (2 Hz–20 kHz), octave band analysis and hand-arm weighting (ISO 5349; 11).

For tools no. 3–5, the accelerometer was glued to the handle of the tools when testing without damping materials. Then it was glued to a thin metal plate that was positioned between the palm of the hand and the protective materials covering the handle of the tool. Similar analyses were performed by using the Hewlett-Packard analyser (HP 3569-A). For tools with higher isolation effectiveness of the protective materials than 5 dB, octave band analysis was performed.

Results

The outcome of the field testing is shown in Tables 2 and 3. As seen in Table 2, the isolation effectiveness of the materials tested was low when applying the hand-arm (H-A) weighting. A better damping was observed without H-A weighting for Colgrip on the dental grinding machine, and for the Gelfôm and Sylomer materials when tested on the keyhole saw and the angle grinding machine.

Two of the tested tools, the impact wrench and the keyhole saw, had an isolation effectiveness of the protective materials exceeding 5 dB. For the impact wrench (Scorpio), the damping effect of Gelfôm seemed to be most prominent for the 2 and 4 kHz octave bands (Table 3). For the keyhole saw both Gelfôm and Sylomer showed the highest isolation effectiveness for the 8 kHz octave band. For Gelfôm, a bimodal pattern was indicated with a peak also for the 1 kHz octave band.

Table 2. The isolation effectiveness of protective materials when tested on different types of hand-held vibrating tools. + denotes attenuation (dB) and – denotes amplification (dB).

Tools and materials	H-A weighted acceleration level		Unweighted acceleration level	
	L_{aw} dB re 10^{-6} m/s^2	Attenuation	L_{lin} dB re 10^{-6} m/s^2	Attenuation
EWL K9				
No damping material	105.3	---	142.8	---
Gelfôm	105.6	-0.3	142.4	+0.4
Sylomer	105.1	+0.2	143.2	-0.4
Colgrip	108.4	-3.1	140.9	+1.9
Surface grinder				
No damping	132.6	---	152.6	---
Gelfôm	135.4	-2.8	153.9	-1.3
Sylomer	134.9	-2.3	153.8	-1.2
Keyhole saw				
No damping	133.9	---	164.4	---
Gelfôm	132.3	+1.6	155.2	+9.2
Sylomer	136.3	-2.4	161.2	+3.2
Angle grinding machine				
No damping	127.6	---	154.9	---
Gelfôm	128.7	-1.1	150.3	+4.6
Sylomer	128.0	-0.4	152.3	+2.6

Table 3. Isolation effectiveness of protective materials when tested on an impact wrench and a keyhole saw.

Tools and materials	Damping in octave bands			
	≤1 kHz	2 kHz	4 kHz	8 kHz
Scorpio				
Gelfôm	0	15.4	14.8	7.3
Key hole saw				
Gelfôm	12.4	7.2	11.6	19.7
Sylomer	6.2	8.2	15.7	16.7

Discussion

The tests indicate that these damping materials reduce high vibration frequencies, which can be of importance for the prevention of HAVS. As evident from the results section, the hand-arm weighting does not display this improvement. These results, however, must be interpreted with some caution as the use of hose clamps or the hand grip force may compress the damping materials tested and thus reduce the isolation effectiveness of the material. Furthermore, this way of attaching the accelerometer may give some uncertainty in our measurements.

Similar results have previously been reported by Griffin (12) who studied the isolation effectiveness of 10 different types of protective gloves exposed to medium (16-400 Hz) and high frequencies (100-1600 Hz) of 20 different hand-held tools. He found that for only two high frequency tools (the etching pen and the pneumatic rotary file) there was a significant attenuation of vibration for three of the ten protective materials tested (glove isolation efficiency 64-68%) when applying frequency weighting. These three gloves were made of more compliant materials than the others. For all other combinations of tools and gloves the isolation effectiveness was negligible or within the measurement error. Without the frequency weighting the same three gloves and a fourth one gave a significant attenuation for most tools. Accordingly, as observed in our field study, the use of protective materials, e.g. gloves, seems to be more effective for tools whose vibrations are dominated by high frequency components. Thus, a protective glove may be used if the testing does not show an increase of the overall magnitude of vibration when evaluated with the frequency weighting and a clear decrease of the overall magnitude of vibration when measured without the frequency weighting (12).

It must be remembered, however, that most tools are dominated by low frequencies where the attenuation of anti-vibration materials in such things as gloves is very limited.

For a tool with a single dominant frequency below 1 kHz the question of frequency weighting is less problematic. For tools with a wider vibration spectra however, it can be discussed whether a hand-arm weighted or unweighted measure would give the best description of the effectiveness of the damping material. The weighted values would often indicate less attenuation than the unweighted ones, as is the case for the keyhole saw and the angle grinding machine in our field study. None of these weighting alternatives will be optimal when dealing with tools causing HAVS by mainly intermediate frequencies. In our study the differences between the H-A weighted and unweighted acceleration levels were above 20 dB, indicating that these tools gave a significant contribution to higher frequencies (>100 Hz).

For some tools it has been shown that the dominant frequencies in the spectra are more or less the same before and after the hand-arm weighting (13). Even if the weighting were to decrease the magnitude of the vibration, the weighting does not seem to alter the frequencies that contribute most to the rms magnitude in a considerable way.

To increase the generality of our conclusions the study was designed to include tools with varying vibration frequencies and amplitudes, tool weights and construction principles. Furthermore, the working positions as well as the push and grip forces vary when using these tools. In our study, the damping of the protective materials differed considerably between the tools but all seemed to give a more efficient attenuation at higher frequencies. It must be remembered however, that the measurements were undertaken in a field study situation and that the number of measurements had to be limited for practical reasons.

The isolation effectiveness of a specific material is influenced by several factors, e.g. the grip and the push forces. A high push force may alter the anti-vibrating properties of the compressed damping material. Also, the orientation of the hand-arm and the direction of the vibration must be considered. As shown by Paddan and Griffin (14), the inter-individual variation between subjects can be larger than the inter-individual differences between many gloves, especially in the medium frequency region. Thus, all these factors must be considered in risk assessment.

Conclusion

In summary, the damping of the protective materials tested was low for vibration frequencies below 1 kHz (H-A weighting). These materials gave a more efficient attenuation at higher frequencies.

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Passive mechanical systems and actuators for reducing vibration emission

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Introduction

Many hand-held tools and machines with an impact mechanism or a high speed rotating mass still have weighted acceleration values of more than 2.5 m/s^2 nowadays. In some cases it is neither possible nor practicable to reduce the vibration emission at the source. Therefore, secondary systems are useful. This study presents a method of numerical simulation and confirming measurements for passive mechanical systems like isolation handles aimed at reducing vibration emission. In addition, the use of an actuator is also demonstrated.

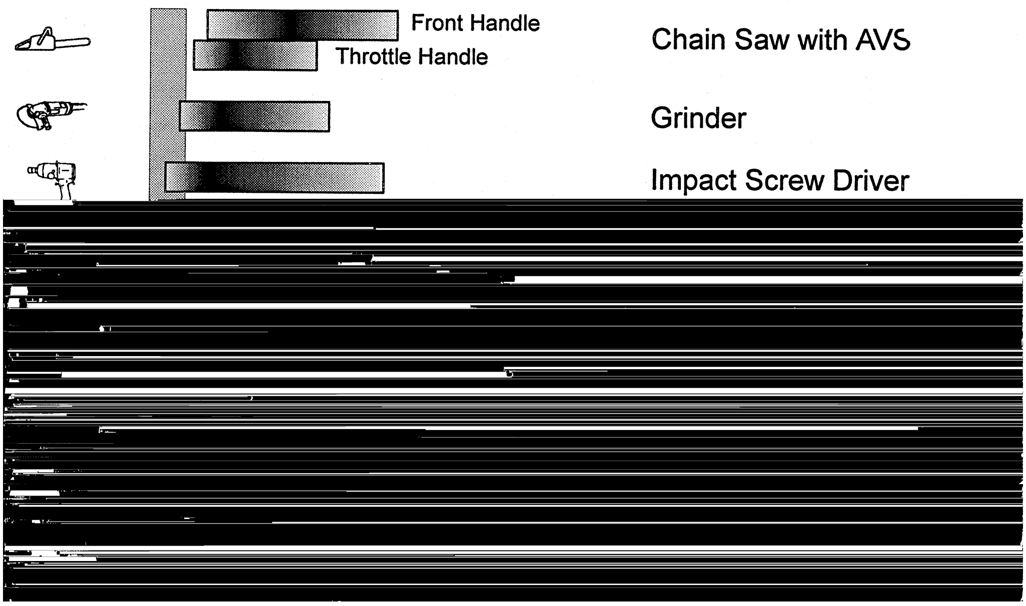

Figure 1. Ranges of the weighted acceleration of different hand-held tools.

Methods

Vibration isolation handles represent a suitable possibility for some tools. Due to the wide range of variable parameters, e.g. the spring stiffness, the damping rate, the masses or the geometry, vibration isolation systems can only be adapted in consideration of the vibration characteristics of the respective machine. A numerical simulation is a helpful tool for finding an effective system. With this simulation, different systems can be tuned to a selected machine for an optimal result. But the theoretical results also have to be verified. For this purpose a universal test rig is necessary.

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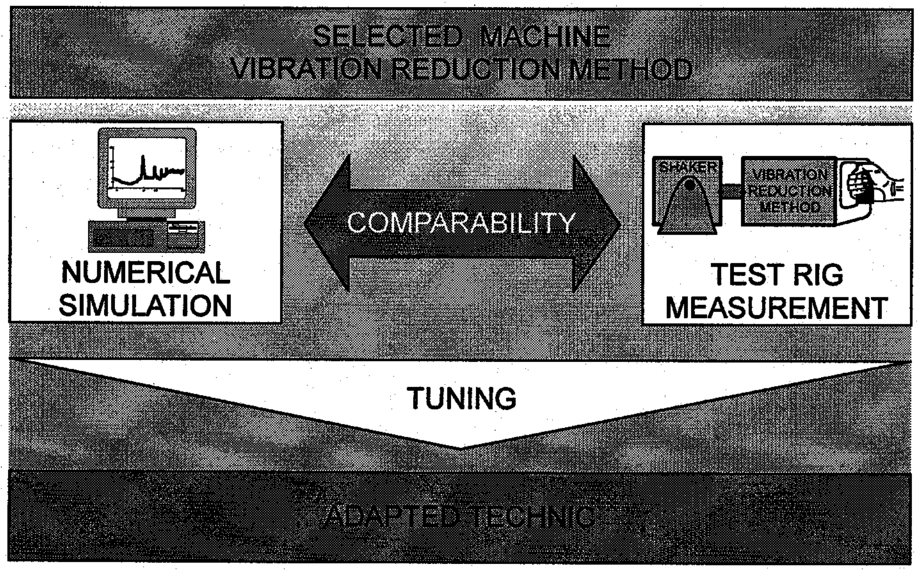

Figure 2. Investigation method: numerical simulation and measurements

To simulate the different vibration isolation handles on the test rig in combination with various hand-held tools, an electromagnetic shaker was used. The vibration characteristics of the tools were generated with several signal generators. Using this test rig it was guaranteed that the power input for the vibration isolation systems was constant for the different handles. The measurement of the weighted acceleration was only performed in the z-direction on the inside and in the middle of the palm. The power of the shaker was sufficient to produce a range of weighted acceleration values comparable to real machines.

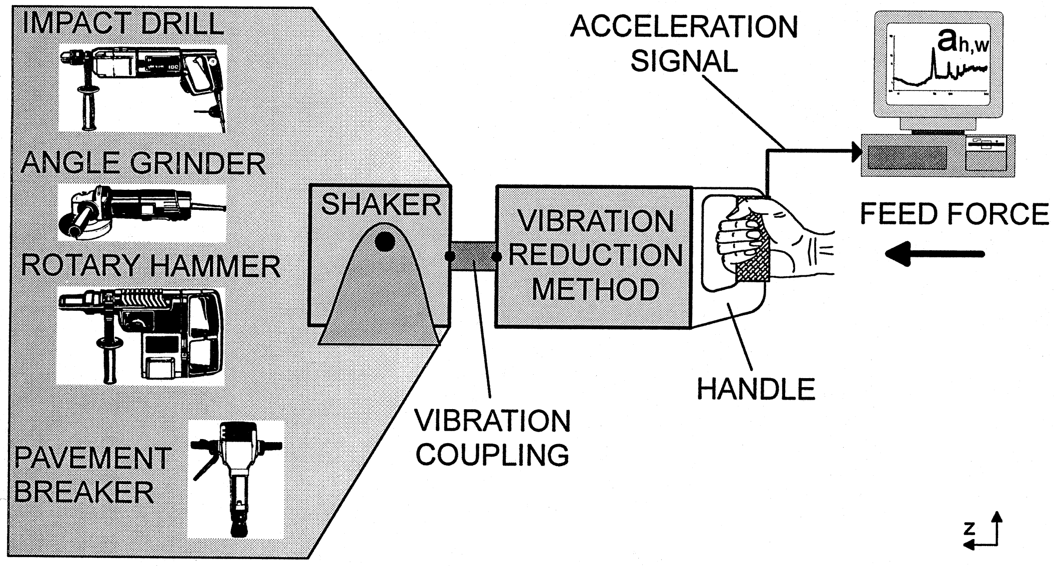

Figure 3. Test rig for different anti-vibration systems.

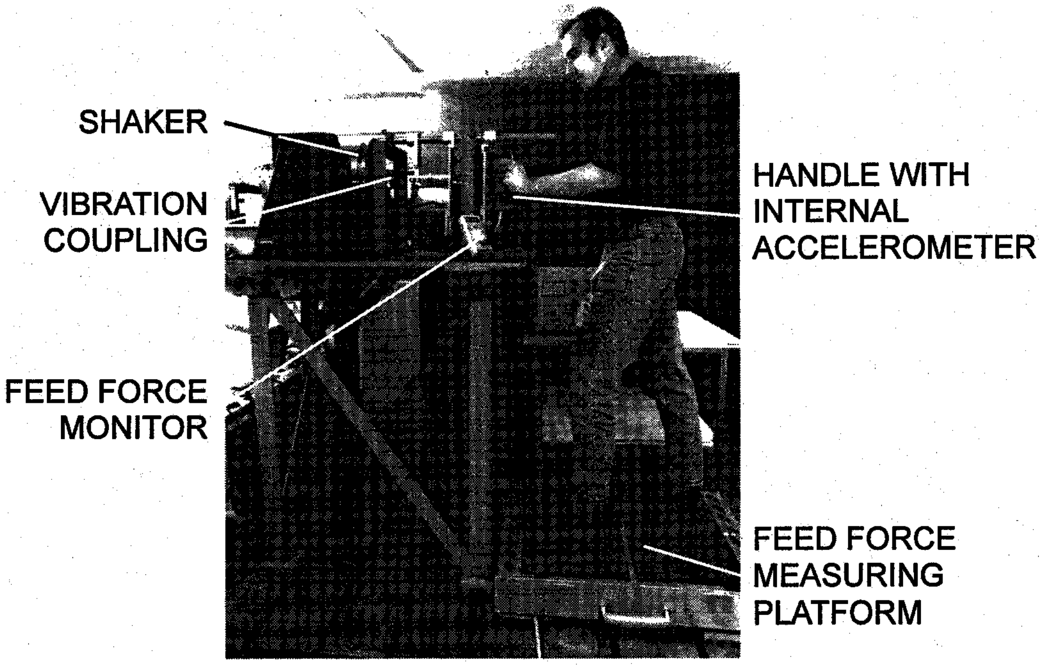

Figure 4. Test rig with operator.

The test included three different passive mechanical systems and an hydraulic actuator with three different controllers:

- a simple isolation system with spring and damper (M/S)
- an isolation system with spring, damper and absorber mass (MT/ST)
- an isolation system with spring, damper and a specially coupled “integrated” absorber mass (MIT/SIT)
- an actuator tuned to the impact frequency (ACT 1)
- an actuator with an analog PID-controller (ACT 2)
- an actuator with a PC based fuzzy controller (ACT 3)

Four different machines were generated using several signal generators in order to include a wide range of vibration characteristics. The signals were tuned to obtain a good approximation of measured machine acceleration spectra. A pavement breaker and a rotary hammer were chosen to represent machines with lower frequency emissions. For higher frequency accelerations, an impact drill and an angle grinder were used. The weighted acceleration values were measured with the blocked handle inside the palm of the hand and mounted on the vibration coupling of the shaker. The synthetic vibration spectra of the tools was also used for the numerical simulations.

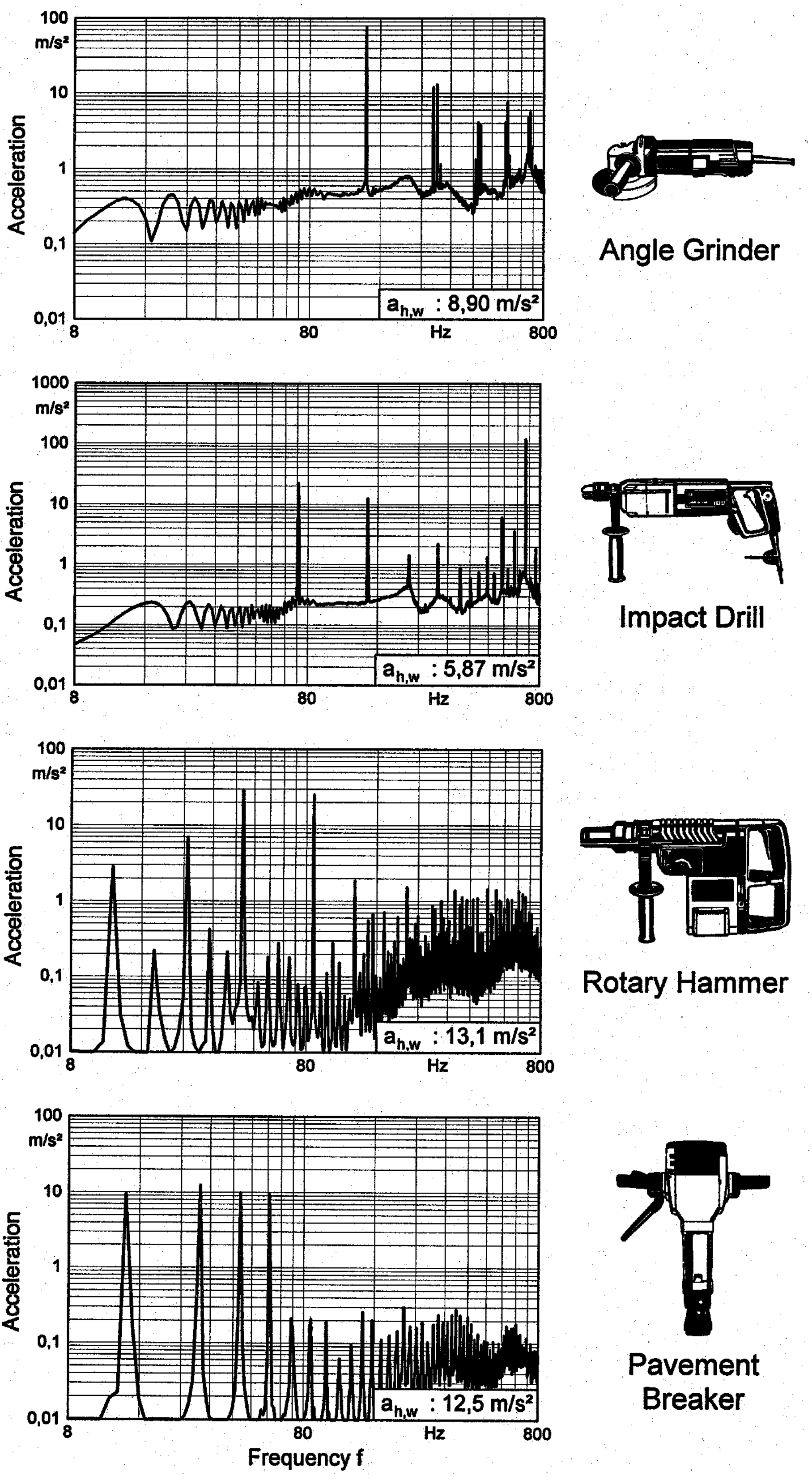

Figure 5. Generated signals of different tools at the test rig.

The investigation was divided into two separate sections. First, the mechanical models with the different vibration isolation handles were simulated on a PC. The program also included the calculation of the weighted acceleration value and the mechanical impedance of a selectable hand-arm system. Utilising model 3 of ISO 10068 resulted in the best correspondence with the measurements. Secondly, the different systems were reproduced on the test rig and measured. To improve the reproducibility, the same operator was used throughout the tests, working in the same posture and with the same coupling force.

Results

Figure 6 shows the results of the measurements on the test rig and the numerical simulation. The total spring stiffness of the isolation system in N/m serves as the test number.

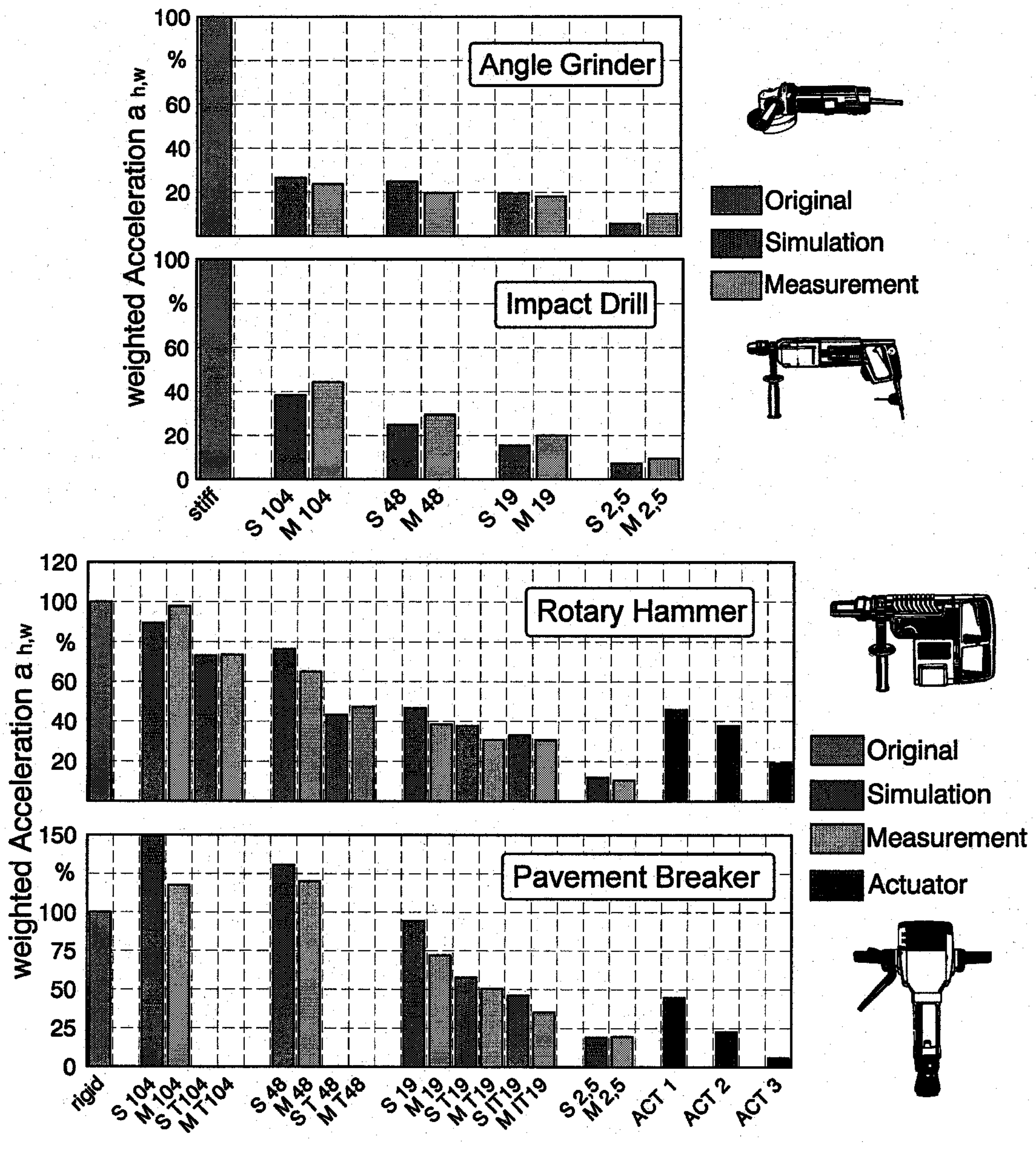

Figure 6. Results of the numerical simulation and the measurements at the test rig.

Discussion

The result of the numerical simulation and the measurements on the test rig showed a good correspondance for the impact drill, the angle grinder and the rotary hammer. The deviation is only higher for the pavement breaker. Overall, the numerical simulation tends to produce higher values.

For the lower frequency machines the passive vibration handles were more effective when an absorber mass was attached. The handle with the coupled integrated absorber mass also had good effect.

The actuator reduced the weighted acceleration down to 20% of the original values for the rotary hammer and down to less than 10% for the low frequency pavement breaker.

Conclusion

The study showed that numerical simulation is a valid method for developing and tuning anti-vibration systems. We also see that passive systems are able to efficiently reduce vibration emission.

With the development of simpler sensors and low cost controllers and actuators, new ways of vibration isolation systems will be possible.

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Vibration white finger in different groups of workers exposed to hand-arm vibration in the metallurgical industry

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Introduction

In the metallurgical industry workers use hand-guided and hand-held vibrating tools to prepare forms in moulder boxes and to clean casting. After a certain amount of time of using these tools vibration-induced white fingers (VWF), called Raynaud's phenomenon of occupational origin, may occur in the workers (7,11,12). The probability of appearance of VWF can be calculated from the dose-response relationship shown in the ISO 5349-1986 (8). This relationship between the energy equivalent frequency-weighted acceleration for a period of 8 h ($a_{w,eq,8h}$) and the total duration of vibration exposure (T in years) and the prevalence rate of VWF does not consider other occupational environment factors modifying the development of disturbances in upper limbs (4,9). They included: noise, physical effort, the way a tool is used, the applied grip forces, etc. This is why the probability of expected prevalences of VWF is not always in accordance with the observed prevalences (2,3,10). The aim of the study was to assess the risk of VWF in different occupational groups of workers employed at the same plants.

Methods

The study was carried out at seven metallurgical factories located in one geographic region, Upper Silesia. The assessment of vibration exposure was made under normal working conditions. Vibration exposure measurements were performed according to ISO 5349 (8) using a set of hand-held and hand-guided vibrating tools as a representation sample. The frequency-weighted acceleration magnitudes were measured in three orthogonal directions with Vibration Meter type 2231 (Brüel and Kjaer) for the following tools: pneumatic rammers, chipping hammers, swing frame grinders and portable grinders. The spectrum analyses in one-third octave band with Vibration Analyser type SWAN 910 (SVANTEK) were conducted for the chosen tools. For each worker the energy equivalent acceleration (8h) was calculated.

Medical examinations were carried out in the factories in which workers were employed. 297 vibration exposed male employees were examined. Among them were 77 grinders, 93 rammers and 127 chippers. An interview was conducted to obtain the full occupational history of each of the workers, past and present medical history and finally the symptoms.

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Results

Table 1. Characteristics of hand-arm vibration exposure.

Occupational group	Tools (n)	Mean (SD) frequency-weighted acceleration (m/s^2)				Dominant frequency of 1/3 octave band (Hz)	Mean (SD) daily exposure (min.)
		X	Y	Z	Vector sum		
Rammers	Pneumatic rammers (12)	6.3 (2.6)	23.0 (9.4)	3.8 (1.0)	24.2 (9.8)	10.0 12.5	120 (90)
Grinders	Portable grinders (14)	3.1 (1.6)	3.9 (1.4)	3.0 (1.5)	5.8 (2.6)	125 and above 500	212 (117)
Chippers	Portable and swing frame grinders (22)	3.3 (1.8)	3.6 (2.6)	2.6 (1.5)	5.5 (4.3)	from 63 to 1000	139 (80)
	Chipping hammers (14)	3.1 (2.1)	7.5 (3.2)	2.8 (1.8)	8.6 (4.2)	31.5 and above 50	

Table 1 gives the results of vibration exposure at work-places in three occupational groups of workers, namely rammers, chippers and grinders. The highest magnitudes of vibration, dominant in one direction, are generated by pneumatic rammers. They have a low frequency spectrum. Portable and swing frame grinders generate the lowest acceleration magnitudes with no dominant values in any direction. Chipping hammers are characteristic of dominant values of acceleration in one direction. These values are more than twice as high as the acceleration values generated by grinders.

Table 2 shows both observed and determined prevalence rates of blanching fingers in three examined professional groups according to ISO 5349 (8). The mean energy equivalent acceleration magnitudes at work places of rammers were almost five times higher than at work places of chippers and grinders. The mean life time exposure to vibration in years in chippers was about two times shorter than in the two other occupational groups. All rammers were exposed to vibration exceeding safety limits and equalling $a(8) = 2.8$ m/s^2. Eighteen percent of the chippers reported blanching symptoms, but only three percent of the rammers and five percent of the grinders had these vascular disturbances.

Table 2. Assessment of vibration-induced white fingers in three groups of workers.

Occupational group (n)	Life time exposure Mean ±SD (years)	Percent of workers exposed to vibration above safety limit (%)	Energy equivalent acceleration (8h) Mean ± SD (m/s^2)	Percent of workers with vibration-induced white fingers (%)	
				Observed	Expected according to ISO 5349
Rammers (93)	14.5 _ 12.0	100	14.1 _ 6.2	3	> 50
Grinders (77)	15.2 _ 11.7	30	2.7 _ 1.2	5	40
Chippers (127)	8.8 _ 7.1	19	3.1 _ 2.3	18	17

Discussion

The results of this study showed that the relationship between exposure to vibration and vascular disorders can be predicted quite well using the ISO 5349 standard in only one group, i.e. in chippers. Characteristically, this group of workers had been employed for half the time of the other occupational groups. The chippers usually use two types of vibrating tools: chipping hammers and swing frame grinders, as well as hand grinders (1). They must use substantial grip and push forces to clean casting and are exposed to low, middle and high frequency acceleration magnitudes. Therefore, substantial hand grip and push forces applied to a tool handle can play a role in the development VWF in chippers (5). The rammers operate pneumatic rammers which produce low frequency vibration, below 16 Hz, with very high acceleration magnitudes. Their work does not require the application of grip forces to their tools (6). Although the safety limits are exceeded many a time, the probability of blanching finger occurrence is very low in this group. The grinders are exposed to vibration with dominant acceleration in high frequencies above 100 Hz. The acceleration magnitudes recorded at the handle are of the lowest values in comparison with acceleration values of other tools and do not exceed 4 m/s^2. One third of grinders work in the conditions of exposure to vibration above the safety limit. Nevertheless, this fact did not seem to contribute to the frequency of occurrence in these workers of vibration-induced white fingers.

Conclusion

Not only do vascular disorders in the hand depend on the intensity and frequency of vibration, but to a significant extent also on how the vibrating tools are used. It is especially true in cases where substantial grip and push forces have to be applied to hand-held tools. In the case of workers exposed to low frequency acceleration generated by hand-guided pneumatic rammers at workplaces not requiring the use of grip forces, the probability of occurrence of Raynaud's phenomenon is low. Workers exposed to wide-band frequency acceleration generated by grinders and chipping hammers, applying substantial grip and push forces show vascular disorders predicted by standard ISO 5349. It seems that the determination of safety limits for hand-arm vibration on the basis of the assessment of blanching finger occurrence must also consider the different character of exposure to vibration in different occupational groups.

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Medial plantar nerve conduction velocities among patients with vibration syndrome due to chain saw work

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Introduction

Some patients with vibration syndrome (VS) complain of tingling, numbness and coldness in the lower extremities, especially in the foot (1, 2). These symptoms suggest an effect of VS on the peripheral nervous system (PNS) of the lower extremities. Some Japanese researchers have reported hyporeflexia and hypoesthesia in the lower extremities among VS patients in neurological examinations (3, 4), but they did not use nerve conduction velocity (NCV) as an objective indicator.

The involvement of VS in organs other than the hand and arm has long been a controversial matter (5). From the 1970’s, many researchers used NCVs to investigate the involvement of PNS in hand and arm symptoms among VS patients (6, 7, 8, 9, 10, 11). However, except for the work of Juntunen et al., (12), there has been little research done on the PNS of the lower extremities.

In order to clarify the effect of VS on the lower extremities we have examined sensory nerve conduction velocities (SCV) in the sural nerve and the medial plantar nerve (a peripheral branch of the posterior tibial nerve) of patients with VS and control subjects (13). We reported that SCV in the medial plantar nerve (PSCV) in patients with VS was significantly lower than that in the controls, but not the SCV in the sural nerve. We also discussed the possibility of the relation of circulatory disturbance to PSCV reduction.

Patients with VS and VWF have been reported to show significant reduction of the skin temperature in the big toe compared with those of the controls, while patients with VS and without VWF did not (14). This suggested that VWF in the upper extremities is an indicator of circulatory disturbance in the feet of VS patients.

In the present study we analysed the PSCV for all the patients exposed to vibration from chain saw work and controls whom we had previously examined in order to clarify the effect of the circulatory disturbance on PSCV as indicated by VWF.

Subjects and methods

Subjects

Thirtyeight patients with VS and 55 control subjects were examined in the summer of 1993 and 1994 and in the spring of 1996. All lived in the Shikoku, Kyushu and Hokuriku areas of western Japan. The patients were of a mean age of 60.0 years with a duration of exposure to vibration averaging 21.9 years.

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They had been on sick leave an average of 4.12 years after the diagnosis of VS. They were not suffering from other diseases or injuries which might have affected the PNS function, had no past or current exposure to neurotoxicants including pesticides, organic solvents, etc., did not smoke more than 40 cigarettes per day (some patients smoked in spite of a prohibition of smoking by their physicians), and were not consuming more than 80 ml of alcohol a day. This information was obtained from anamnesis and the reports of their clinical physicians. The patients were divided into two subgroups, one of those with VWF in the last winter (VWF(+)) and the other without VWF in the same season (VWF(-)).

Fiftyfive normal controls from the same region were included in the study using the same criteria as the patients. Their ages were matched to within 3 years to those of the patients (Table 1). The job title of the patients was chain saw operator (n = 38). The control subjects, except for three pensioners, had the following jobs:
office worker (n = 19), driver (n = 13), carpenter (n = 3), cleaner (n = 3), engineer (n = 4), farmer (n = 3), wood worker (n = 3), teacher (n = 1), merchant (n = 1), cook (n = 1), and wooden mask carver (n = 1).

Table 1. Age and duration of exposure to vibration and its removal among patients and controls (mean + SD)

	n	Age (years)	Duration of exposure (years)	Duration of removal (years)
Controls	55	59.6 + 4.07 (49 - 65)	-	-
Patients with VWF	19	60.8 + 4.10 (48 - 64)	23.0 + 7.82 (9 - 33)	1.95 + 2.35 (0 - 7)
Patients without VWF	19	59.3 + 5.09 (49 - 65)	22.5 + 7.51 (9 - 32)	3.30 + 2.94 (0 - 9.75)

( ): Range

SCV measurement:

The subjects, in an air-conditioned room with the temperature maintained at 24 to 27°C, were asked questions regarding the symptoms of VWF, tingling and numbness in the extremities, their past medical history, and drinking and smoking habits. They were then asked to lie in an electrically shielded box for examination of SCV in the medial plantar nerves (PSCV) from the first toe (stimulation point) to the medial side of the ankle (recording point) through needle electrodes, orthdromically placed. The evoked nerve action potentials were amplified with a band path from 20 Hz to 2 kHz. Using an electromyograph (Sapphire 4EM, Medelec Co., UK), evoked nerve action potentials were amplified with a band path from 20 Hz to 2 kHz. Sixty-four to 256 nerve action potentials were averaged for PSCV.

In order to adjust PSCV, which is easily affected by temperature, the skin temperature was measured at the midpoint between stimulation and recording points using an infrared ray thermometer Type IT340S (Horiba Manufacturing, Kyoto, Japan). The PSCVs measured for the lower extremities were also corrected for PSCV at 31 C of standard skin temperature using de Jesus’ method (15).

Statistical analysis

The differences of PSCVs among the two patient groups and the controls were tested by analysis of variance (ANOVA) with multiple comparison by Scheffe's method. The difference of skin temperature among the three groups was also tested by ANOVA.

Results

Figure 1 shows typical wave of nerve action potentials among control and patient.

Table 2 shows the skin temperature and PSCV for all patients, VWF(+) and VWF(-) groups and the controls. ANOVA of PSCV for the three groups showed F = 10.65 (dF = 2, 89, p <0.0001) with the difference being significant between the controls and the VWF (+) group (p < 0.0001), but not between the controls and the VWF (-) group (p = 0.0503) using Scheffe's method. ANOVA of the skin temperature showed no significant difference among the three groups (dF = 2, 89, F = 0.729, p = 0.456) with no significant difference between the three groups by multiple comparison.

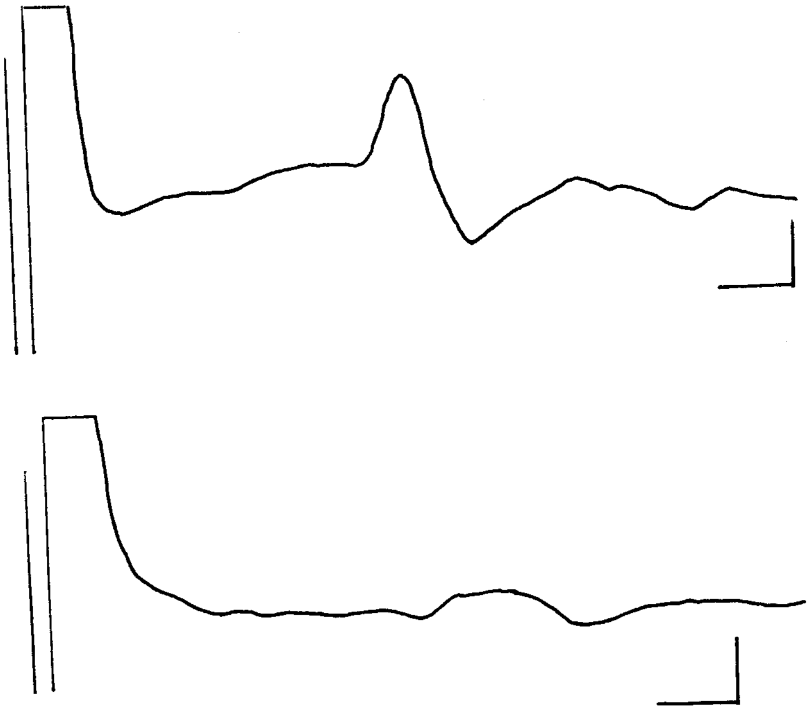

Figure 1. Nerve action potentials of the medial plantar nerve. Top, control; bottom, patient with VS. Calibration: 20μv, 1msec.

Table 2. Skin temperature and SCV of the medial plantar nerve among patients and controls (mean + SD).

	n	Skin temperature (C)	PSCV (m/s)
Controls	55	29.3 + 1.82	42.8 + 3.93
Patients with VWF	19	28.7 + 1.82	38.1 + 4.05#
Patients without VWF	19	29.2 + 1.53	40.1 + 4.30

#: p<0.0001 by Scheffe's method in multiple comparison of ANOVA

Discussion

The present study showed significant lowering of the PSCV in the lower extremities among patients with VS and VWF due to vibration exposure from chain saw work.

The reduction of NCVs in the upper extremities among VS patients agreed with the findings of many researchers, as well as the histopathological changes in the nerve fibers of the fingers (16, 17). This also agreed with the finding of sciatic nerve damage in experimental animals with a foot exposed to vibration (18). These studies established the occurrence of PNS disorders in the part due to direct exposure to vibration.

Changes in PNS in the upper extremities in previous studies have been conventionally considered to be a localised effect due to vibration, in other words, a "direct effect" without intermediation of other factors, e.g. circulatory disturbance. However, the reduction of PSCV can hardly be considered a “direct effect” because of the distance from the hands, the location of the vibration site, especially for chain saw operators. The independence between the lowering of PSCV and the lowering of finger SCVs suggests that the mechanism for the PSCV reduction differs from that for SCVs in the upper extremities (13).

There is some evidence of circulatory disturbance in the feet of patients with VS, that is, VS patients with Raynaud's phenomenon in their toes (19, 20, 21) and dermal blood flow reduction in the legs of patients with VS measured by 133Xe washout method (22). Sakakibara et al (14) observed that when the right foot of each subject was immersed in cold water at 10°C for 3 minutes the skin temperature of the left toes of patients with VS and VWF significantly decreased compared with that of the controls before and after immersion, but that of patients with VS and without VWF did not. They concluded that these findings indicated that patients with VS, especially those with VWF, had circulatory disturbances in the foot as well as in the hand. Consequently, VWF may be an indicator of circulatory disturbance in the foot of a patient with VS due to vibration exposure from chain saw work.

There is also some evidence that circulatory disturbance causes neuropathy, that is, a widening of nodal gaps and alteration of juxtanodal myelin in the posterior tibial nerve among rats with chronic ischemia due to arteriovenous shunt (23), and a slowing of motor conduction velocities in the peroneal nerve among patients with peripheral vascular diseases and without neurological signs (24). In the present study the lower PSCV of the patients with VWF compared with those of patients group without VWF suggest the effect of circulatory disturbance represented by VWF.

The lowering of PSCV must be differentiated from the tarsal tunnel syndrome (TTS), which is accompanied by pain at the ankle and foot (25). In our study no patient complained of such pain. Also, post-traumatic trouble at the tarsal tunnel is part of TTS, but we excluded patients with a history of injury of the lower extremities. Consequently, we could exclude TTS from the etiology of the reduced PSCV.

According to these considerations, the results of the present study suggest that the lowering of PSCV in the patients with VS and VWF was caused by circulatory disturbance.

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A comparison of vibration magnitudes of hand-held tools using the dominant single axis and the root-sum-of-squares of the three orthogonal axes method, in the Japanese case

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Introduction

The magnitudes of hand-transmitted vibration, 297 vibrating tools and work-pieces, were measured at the workplace in Japan to control the exposure level and to assess the risk of occupational diseases or disorders from 1988 to 1996. The object tools and work-pieces were used mainly in the construction and manufacturing industries. The present standard for the evaluation of hand-transmitted vibration has been based on dominant axis method; International standard ISO 5349-1986 (1), and also in the Japanese Industrial Standard JIS B 4900 (2). According to the proposal of ISO/CD5349-1 (3), the results of measurement (462 points of data) were recalculated by the method of frequency-weighted acceleration sum (root-sum-of-squares of the three orthogonal axes (4)). This paper shows the increasing ratio of the weighted acceleration sum method to the current dominant axis method and the typical case of this ratio.

Method (Measurement and Analysis)

The instruments used to measure vibration acceleration were a vibration pick-up (tri-axes piezoelectric type, 29.3 gr, PV-93T RION Co. Japan), a vibration meter (3ch. VM-19A, RION) (5) and a data recorder (4 ch. DAT type, RD-120T TEAC Co. Japan). The pick-up was mounted firmly with steel belts and a fitting base on the handle of the object tools (1 point or more measured respectively). The fitting accessories are about 15 gr in weight.

The vibration acceleration signals were measured simultaneously and were analysed with the data recorder and a one-third octave band real time analyser (SA-27, RION). The frequency-weighted energy-equivalent acceleration levels were obtained by the system. The average time varies from 30 seconds to 90 seconds depending on the type of tools and work conditions (6). The acceleration magnitudes of the tools were determined by the ISO 5349 method and Japanese standard JIS B 4900. The weighted acceleration sum is a combined value of three orthogonal axes defined in the following equation.

$$a_{hws} = (a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2)^{1/2}$$

where a_{hwx} , a_{hwy} and a_{hwz} are the frequency-weighted root-mean-squared acceleration magnitude for the x, y and z-axes respectively.

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Results

The ratio of the root-sum-of-squares (sum) to the dominant axis magnitude (dom) is in the following table 1.

1. The grand average value of the sum/dom ratio (7) is 1.32 per 462 points (297 tools).
2. 20% of the dominant axis data (the frequency-weighted acceleration) exceeded twice in other two axes.
3. 140 tools were measured at two points respectively (e.g. side handle and rear grip), and the estimation points were swapped in 17 tools (12%) by applying the weighted acceleration sum method, (e.g. from side handle to rear grip).
4. 1.79% (8 points) of the sum/dom ratio were exceeded 1.7 (maximum level).

Several data of pneumatic wrenches (large models) were rejected by the saturation of impulsive signal or repetitive shock. Therefore, there is a possibility that the data of impact wrenches were composed by a comparatively low vibration group.

Table 1. The ratio of the root-sum-of-squares to the dominant axis magnitude. (sum/dom ratio in the frequency-weighted acceleration)

Type of tools / work-pieces	Mean	S.D	Max	Min	Num
<u>Percussive tools</u>					
Electric hammers	1.31	0.18	1.65	1.07	14
Vibration drills	1.37	0.19	1.73	1.03	15
Impact wrenches	1.27	0.14	1.57	1.05	94
<u>Internal combustion engine powered tools</u>					
Engine cutters (cutting disc)	1.27	0.14	1.55	1.09	12
Plate compactors (asphalt-work)	1.40	0.09	1.55	1.31	6
Mowers	1.37	0.14	1.55	1.14	13
Sod cutters	1.30	0.21	1.61	1.17	4
<u>Grinders</u>					
Hand-held grinders	1.24	0.13	1.55	1.02	66
Pedestal electric cutters	1.32	0.14	1.48	1.12	9
Angle grinders, cutting disk	1.18	0.12	1.42	1.08	5
Sander & polishers	1.22	0.16	1.49	1.03	18
<u>Drills</u>					
Hand-held drills (iron-work)	1.34	0.14	1.66	1.04	72
Hand-held drills (wood-work)	1.38	0.19	1.73	1.08	18
Drilling machines (fixed)	1.26	0.20	1.58	1.03	6
Screw drivers	1.36	0.14	1.61	1.15	7
Planers, elec. (woodwork)	1.37	0.15	1.56	1.13	10
Routers, elec. (woodwork)	1.41	0.17	1.61	1.17	8
Circular saw elec. (woodwork)	1.31	0.12	1.56	1.14	18
Concrete vibrators	1.47	0.15	1.71	1.10	23
Miscellaneous tools	1.44	0.12	1.57	1.26	9
<u>Work-pieces</u>					
Pedestal grinders	1.36	0.16	1.70	1.12	29
Miscellaneous work-pieces	1.39	0.13	1.52	1.22	6
Total	1.32	0.16	1.73	1.02	462 points (297 tools)

Conclusion

The frequency-weighted acceleration sum method conveniently gives a workplace estimation where the direction of primary vibration force is varied by the condition of working posture, the change of gripping angle, the contact force, the shape of object etc. The average ratio of the weighted acceleration sum to the dominant axis is 1.32. It is likely that with the present dominant axis method, the vibration magnitudes are underestimated in those variable cases. In addition, the average value of the sum/dom ratio is affected the data component (the type of tools and its number), therefore, the field data should be widely collected for the new method.

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Test room temperature effects on the recovery of skin temperature, vibrotactile threshold and thermal pain perception in cold provocation test

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Introduction

The cold provocation test is one of the objective tests for evaluating hand-arm vibration syndrome (HAVS). It has been widely conducted for the diagnosis of HAVS in Japan and its standard procedure has been prescribed (1). However, the validity including sensitivity and specificity of this test could be low in comparison to measurement of finger systolic blood pressure. On the other hand, the prevalence rates of vibration-induced white finger (VWF) decreased in recent years in Japan and European countries because of general improvements in medicine and engineering (2, 3). The prevalence of VWF in workers exposed to mild vibration was not different from that in the general populations (4). In this background a new significance of cold provocation test should be proposed.

ISO has started to establish an international standard for a cold provocation test as a peripheral circulatory function since 1996 (5). Several investigators have reported that the ambient temperature in a test room strongly influenced the response of skin temperature (6-8). The validity of the skin temperature during a cold provocation test should be evaluated under proper ambient temperatures. The aim of this study is to clarify the effects of test room temperatures on skin temperature, vibrotactile and heat pain threshold under strictly controlled room temperatures, and to propose a new significance of the cold provocation test.

Methods

Twenty male students with a mean age of 22 yr (range 20 - 24 yr) participated in this study. All subjects were healthy without complaints of peripheral circulatory and nervous disorders. The protocol was carefully explained to the examinee before the study and each signed a written consent form.

Five conditions of room temperature were applied; 17°C, 20°C, 22°C, 24°C and 27°C. Relative humidity was kept at a constant of 50%. Each room temperature was precisely controlled within ± 0.3°C by using artificial climate equipment. The cold provocation test was carried out using two methods: one was the immersion of the left hand up to the wrist in 5°C water for 1 minute (hereafter, 5°C-method), the other was immersion in 10°C water for 10 minutes (hereafter, 10°C-method). Finger skin temperature was continuously measured at the back of the middle phalanx of the 3rd finger of the left hand using a thermometer (HD-111, Takara, Japan) before, during and after cold water immersion. For evaluating the rewarming activity a recovery rate was calculated by the following formula:

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Recovery rate at X min = $(T_x - T_{finish} / T_{before} - T_{finish}) \times 100\ \%$

T_{before} : skin temperature before immersion
T_{finish} : skin temperature immediately after cessation of immersion
T_x : skin temperature at the time after cessation of immersion

The vibrotactile and heat pain threshold as the peripheral neurological functions were examined at the palmar distal phalanx before immersion, immediately after, 5 minutes, 10 minutes, and 15 minutes after immersion, respectively. For measuring vibrotactile threshold at 125 Hz, a vibration sensimeter (AU-02, RION, Japan) was used. The heat pain threshold was determined by the method of limits, using an automatic increase in temperature of 0.25°C/sec (UDH-104, Unique Medical, Japan). The probe (10 mm x 10 mm) was gently applied to the second fingertip. The subject pressed a switch whenever he felt the on set of heat pain sensation.

Before starting the experiment the subjects were asked to sit on the chair in the artificial climate room for at least 20 minutes to acclimatize to the room temperature. The subjects were asked to prohibit smoking 2 hours before the examination. The number of clothes was controlled as same in each room condition. The subjects were requested to dress in the same kinds of clothes including an undershirt, a shirt, underpants and trousers.

The statistical evaluation of the data involved analysis of variance with multiple comparisons. Differences were considered to be significant at $p<0.05$.

Results

Figure 1 (A) shows the rewarming processes of finger skin temperature during two kinds of cold water provocation tests under different room temperature conditions. The recovery of finger skin temperature in the 5°C-method was more progressive than those in the 10°C-method at the same room temperature. The effect of room temperature was significantly observed in the finger skin temperature at the time before and 3 minutes after immersion in both tests (ANOVA, $p<0.05$). Figure 1 (B) shows the recovery rate at different room temperatures in both tests. In the recommended range of room temperature (20°C - 24°C), the recovery of finger skin temperature depended linearly on the room temperature. Although the recovery rate at 5 minutes in the 10°C-method had a rapid increase over 24°C, a gradually increase was observed in those of the 5°C-method in accordance with room temperature. In contrast, the recovery rate at 5 and 10 minutes in the 10°C-method were scarcely enhanced at 22°C of room temperature. The test room temperature in the 5°C-method and 10°C-method may be recommended to be 20-27°C and 22-27°C, respectively.

The changes of vibrotactile and heat pain threshold under different room temperatures during both provocation tests are shown in figures 2 and 3. The vibrotactile threshold in the 5°C-method was not affected by different room temperatures. There was a significant negative relationship between room temperature and thresholds except the initial one in the 10°C-method. A similar tendency was observed in the changes of heat pain. Heat pain thresholds apparently differed at each room temperature. Compared with the types of cold provocation test, the changes of thresholds in the 10°C-method were bigger than those in the 5°C-method. The recovery of heat pain threshold was apparently slow in comparison with vibrotactile threshold. The vibrotactile and heat pain thresholds may be recommended in the 10°C-method.

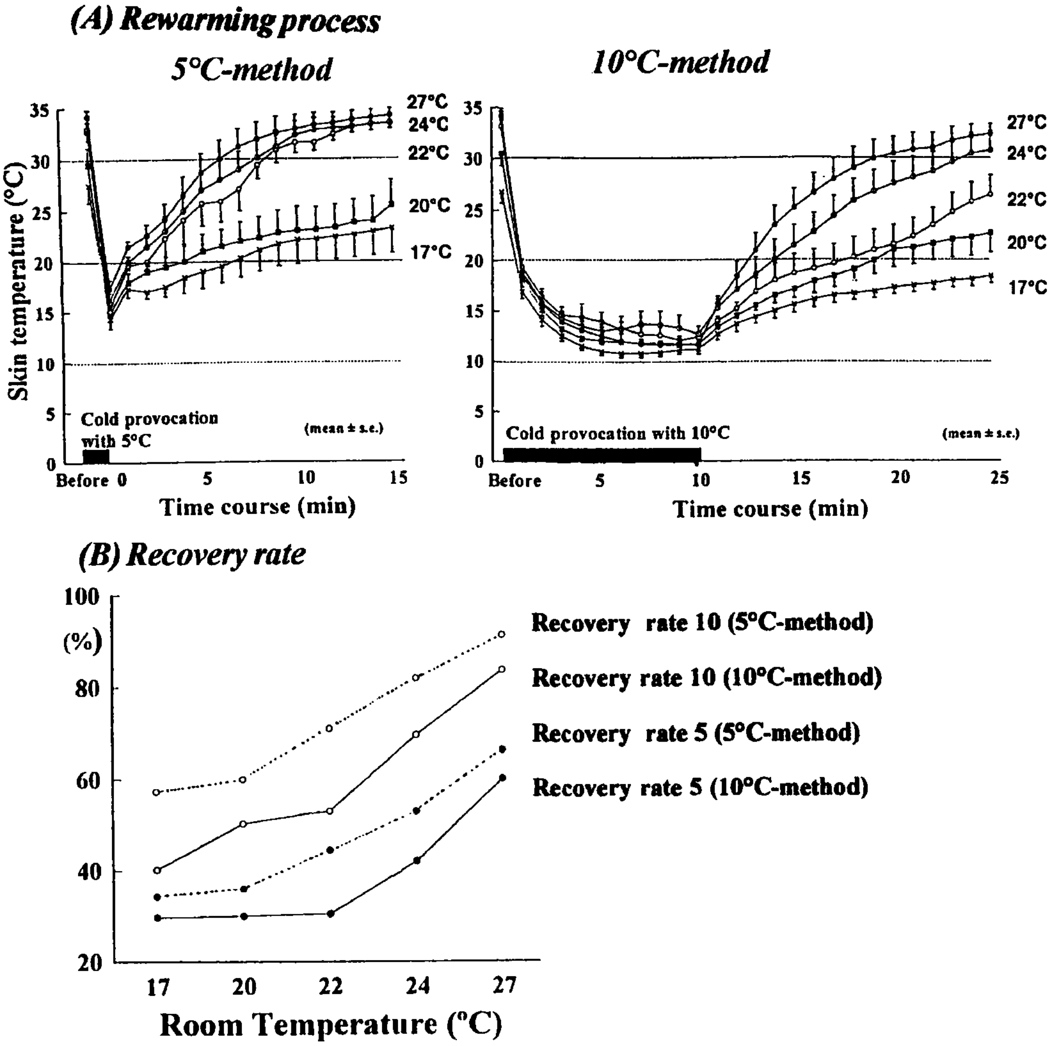

Figure 1. Rewarming process (A) and recovery rate (B) of finger skin temperature under different room temperatures during two kinds of cold provocation tests.

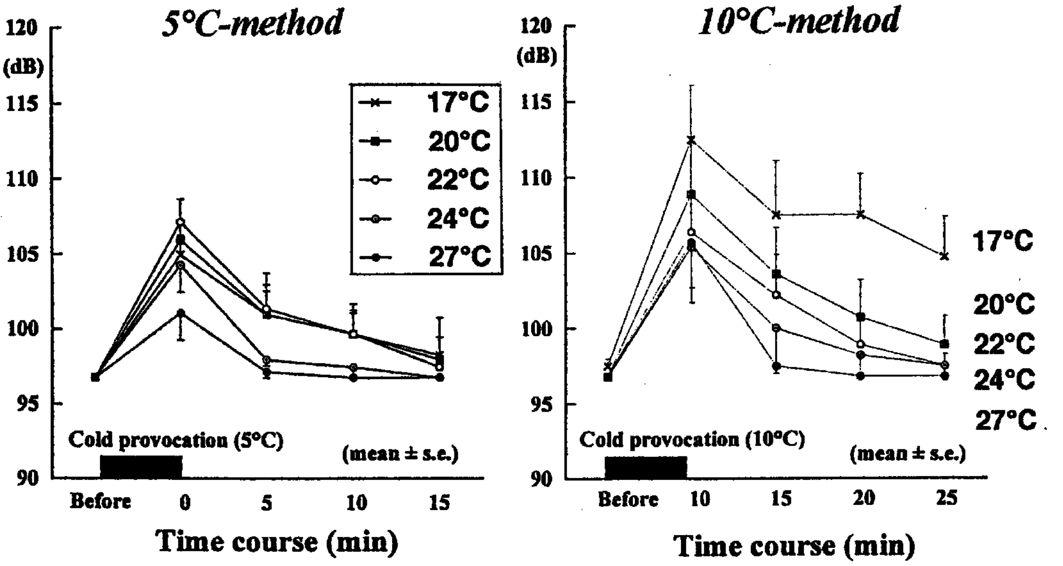

Figure 2. Changes of vibrotactile threshold under different room temperatures during two kinds of cold provocation tests.

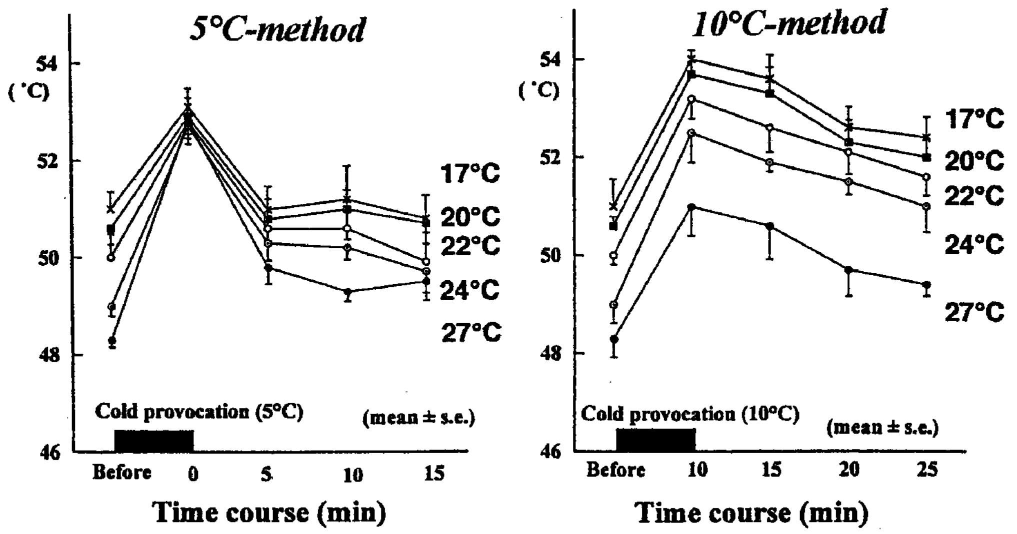

Figure 3. Changes of heat pain threshold under different room temperature during two kinds of cold provocation tests

Discussion

Strong effects of different room temperature ranged from 17°C from 27°C were observed on responses of skin temperature, vibrotactile and heat pain thresholds in the two types of cold provocation tests under strictly controlled ambient temperature.

Our results suggest that the room temperature should be strictly maintained for evaluating the peripheral circulatory function using finger skin temperature. Harada et al. (8) have reported that room temperature may affect finger skin temperature during the cold provocation test for healthy subjects. In Japan the conventional 10°C-method of cold provocation test has been carried out under a test room temperature of 20°C-22°C (1). This recommended range of room temperature may be useful to diagnose the peripheral circulatory function (6). Gautherie (9) recommended that a well controlled and designed cold provocation test (15°C-method) could produce useful information for the follow-up of asymptomatic patients. He proposed the room temperature should be controlled within 21°C ± 1°C. However, the cold provocation test has been carried out in a wide range of room temperatures, in Japan from 17°C to 26°C. Our results indicate that the recovery of finger skin temperature may depend on the room temperature and the type of cold provocation test. The prevalence of VWF in workers exposed occupationally to vibration gradually declined and was not different from that in the general population (2, 4). This suggests that discrimination of VWF is difficult by cold provocation test. In the process of making an international standard for a cold provocation test we should emphasize the significance of room temperature to choose an adaptable room temperature according to the type of cold provocation test.

It is also very important to evaluate neurological disorders in workers operating hand-held vibrating tools. Tingling and numbness of neurological disorders are early symptoms in workers exposed to vibration. If exposure to vibration is reduced or stopped, the circulatory disorders would tend to diminish. However, the numbness and paraesthesia evidently persisted (2, 10). It means that early detection of neurological disorders may be a main interest. For evaluating the neurological function, several objective tests such as vibrotactile thresholds, aesthesiometry, thermal thresholds and grip strength have been used in special investigations. Although many studies have been done on vibrotactile thresholds, there was little research concerning heat pain threshold. Nilsson et al. (11) examined the effect of vibration on thin unmyelinated sensory fibers for vibration-exposed and non-exposed workers. There were no positive results of increased heat pain threshold among vibration-exposed workers. However, in our study the increase of pain threshold was much bigger and it took longer time to recover in comparison with the vibrotactile threshold. The large myelinated (A-a, A-b) fibers mediate impulses from tactile perception (vibration) while the small diameter fibers (A-d, C) conduct thermal stimuli and pain. In our results the recovery of vibrotactile threshold after the cold provocation test was faster than that of the heat pain threshold. Each of them may closely relate to the room temperature. This indicates that the conduction velocity may be associated with room temperature. The heat pain threshold may be easily affected by cold stress. There is some possibility of early diagnosis for neurological disorders using heat pain sensation.

Conclusion

The responses of skin temperature, vibrotactile and heat pain thresholds in the two provocation tests were strongly related to room temperature. According to the types of provocation test, an adaptable temperature of the test room should be considered. The simultaneous measurement of heat pain threshold and skin temperature can provide some useful information for evaluating the peripheral nervous system.

Acknowledgement

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Sensory nerve function in vibration-exposed workers studied by SCV and SSEPs

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Introduction

An objective evaluation of sensorineural complaints is one of the essential problems in the diagnosis of vibration disease (VD, HAV syndrome), especially in deciding a worker's accident compensation. With the development of electrophysiological techniques, methods for evaluating the sensory nerve function have been introduced into the field of trauma or occupational diseases for accident compensation. Although the determination of sensory nerve conduction velocity (SCV) has a long history, it has now become possible to analyse the components of the (short-latency) somatosensory evoked potentials (SSEPs) in humans with signal averaging techniques. This capability has been extended to sequences of SSEPs generated in the brachial plexus, spinal cord and subcortical structures (1).

The aims of the present study are to determine the reference values of antidromic sensory nerve conduction velocity (SCV) and SSEPs components and to objectively evaluate sensory disturbances in hand-arm vibration-exposed workers and in patients with diabetes mellitus.

Subjects and Methods

Two hundred and thirty-seven males aged from 40 to 69 years were investigated. Experimental subjects and mean age (±SD.) were as follows: 34 healthy controls (45.7 ± 8.1 years), 125 VD subjects (55.8 ± 7.3 years) and 40 vibration-exposed non-VD subjects, and 38 diabetics (NIDDM) (55.7 ± 11.5 years).

Electrophysiological studies were carried out in a supine position in a dimly lit shielded room using Cadwell CA-7400, (Cadwell Lab Inc, Washington, USA). The room temperature was kept at 25 - 27°C.

SCV at the palm segment of the right median nerve was measured using the antidromic technique. Electric supramaximal stimuli were delivered by a stimulator at 2/s and the electrical responses were recorded at the index finger by a ring electrode. Usually 32 responses were averaged with a sweep duration of 10 ms. SCV was determined by dividing the distance of the palm by the latency to the first negativity (m/s).

SSEPs were measured as follows. Electric stimuli were delivered by a stimulator at 2.11/s to the median nerve of the right wrist. N9 potentials at Erb's point, N13 potential at C2 point of the cervical spine, and N20 potentials at the post-Rolandic area were

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determined with the reference electrode placed at the standard mid-frontal location (Fz). Usually 512 responses were averaged with a sweep duration of 50 ms. The latency of N9 and the interpeak conduction times (N9-N13 and N13-N20) were standardised by the body height (ms/m body height).

Student’s t-test was adopted for the statistic analysis of the present investigation.

Results

1. Determination of normal limit values of SCV and SSEPs

The normal limit values obtained were SCV 46.7 (M - 2SD) m/s, N9 6.20, N9-N13 2.77 and N13-N20 4.17 (M + 2SD) ms/m body height (Table 1). In this group, subjects with cervical spondylosis had been excluded beforehand by radiographical diagnosis (2-4). There was a negative correlation between SCV and N9 in healthy control subjects (r= -0.391, p<0.05).

Table 1. Normal limit values of neurologic parameters.

Antidromic SCV			M - 2SD	46.8 m/sec (N=33)
SSEPs				
	N9	M + 2SD	6.18 ms/m	Body height (N=34)
	N9-13	M + 2SD	2.77	¨
	N13-20	M + 2SD	4.18	¨

2. Determination of SCV and SSEPs parameters in each experimental group

Three SSEPs parameters (N9; N9-N13; N13-N20) in 3 experimental groups (non-VD; VD; DM) were significantly prolonged and SCV in these 3 experimental groups were also significantly delayed when compared to those of the control group (Table 2). However, there were no statistically significant differences in all these parameters between VD and non-VD groups.

Table 2. Determination of SCV and SSEPs (N9, N9-13, N13-20).

	control	non-VD	VD	DM
SCV[a]	55.14 ± 4.52	51.02 ± 7.17**	50.94 ± 6.9***	48.75 ± 8.72***
N9[b]	5.67 ± 0.31	5.83 ± 0.37*	5.92 ± 0.34***	6.08 ± 0.56***
N9-13 [b]	2.36 ± 0.22	2.56 ± 0.39**	2.43 ± 0.26	2.70 ± 0.38***
N13-20 [b]	3.63 ± 0.35	3.75 ± 0.32	3.72 ± 0.39	3.59 ± 0.41

a: m/sec; b: ms/m body height *p=0.05, **p=0.01, ***p<0.001 vs control

3. Distribution of sensorineural disturbances studied by SCV and SSEPs

Sites of sensorineural disturbances were divided from the index finger to sensory cortex as follows: peripheral (SCV), distal (SCV + N9, N9), proximal (N9-N13) and central (N13-N20). In comparison with our reference values, the number of subjects with sensorineural disturbances were studied (Figure 1, Table 3). Localisations of sensorineural disturbances were mainly “peripheral and distal” in all three groups, and N9-N13 in non-VD, N9 and N13-N20 in VD, and N9 in DM were second frequent sites.

Table 3. Sites of sensorineural disturbances

Sites of disturbances				Experimental groups		
				Non-VD	VD	DM
SCV				4 (19.0%)	19 (35.2)	4 (15.4)
SCV	N9			3 (14.3)	8 (14.8)	5 (19.2)
	N9			2 (9.5)	8 (14.8)	5 (19.2)
SCV		N9-13		2 (9.5)	3 (5.6)	-
		N9-13		4 (19.0)	3 (5.6)	4 (15.4)
			N13-20	2 (9.5)	6 (11.1)	2 (7.8)
others				6 (28.6)	10 (18.5)	6 (23.1)
Total findings				21	54	26
Number of subjects				40	125	38

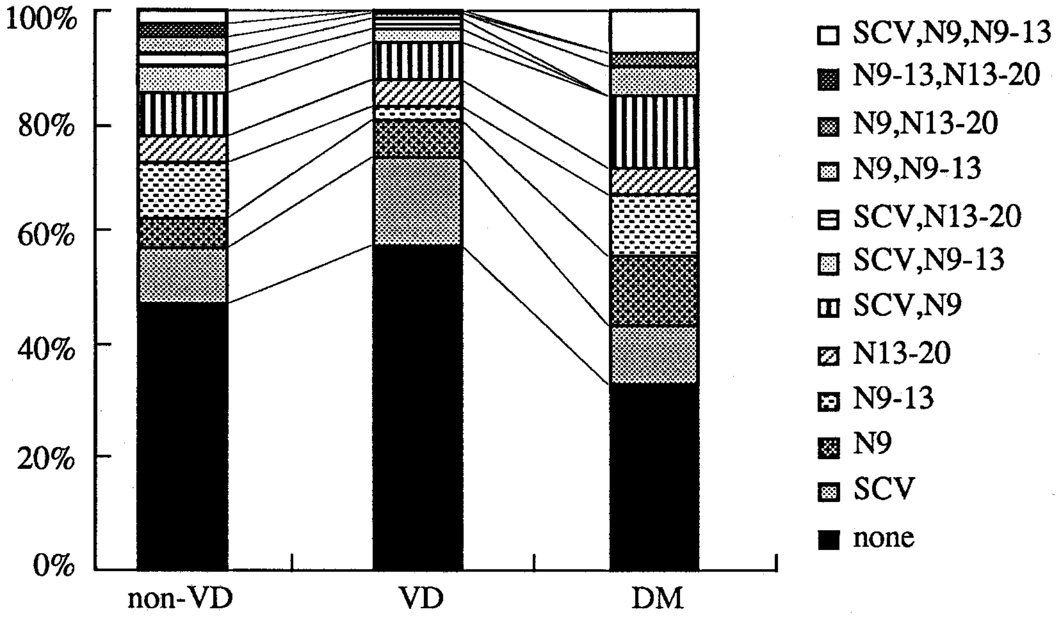

Figure 1. Distribution of sensory nerve disturbances determined by SCV and SSEPs.

4. *Practical availability of electrophysiological parameters and relevance to cervical spondylosis*

Since some SSEPs parameters showed statistically significant differences between subjects with and without cervical spondylosis (CSP) in our earlier study, we again divided each experimental group into two groups with or without CSP by 6 plain radiographs of the neck (2-4). This time, there was only a statistically significant difference of N9 in diabetics between those with and without CSP ($p<0.02$)(Table 4).

Table 4. Statistical difference of parameters between each experimental group vs. healthy control

	CSP	N	SCV	N9	N9-N13	N13-N20
Non-VD	without CSP	19	52.2 * (n.s.)	5.64 (n.s.)	2.56 (n.s.)	3.69 (n.s.)
	with CSP	21	49.4 r**	6.01 t	2.56 q	3.81 p
VD	without CSP	47	51.9 r	5.85 r	2.45 (n.s.)	3.67 (n.s.)
	with CSP	78	50.4 t	5.96 t	2.42 (n.s.)	3.75 p
DM	without CSP	21	49.5 q	5.86 p ùq	2.59 s	3.51 (n.s.)
	with CSP	17	47.7 s	6.34 s û	2.84 s	3.68 (n.s.)
Control (without)		34	55.6	5.64	2.34	3.62

* Mean (S.D. value was omitted in this table);

** P value: p<0.05; q<0.02; r<0.01; s<0.001; t<<0.001.

Discussion

Since most of the sensorineural clinical tests presently available as a screening test or a close examination for HAV syndrome are theoretically subjective in nature and data are strongly influenced by the responses of the examinees, utilization of the combination of nerve conduction velocity and parameters of the somatosensory evoked potentials is necessary. When nerve conduction velocity is studied in the ulnar nerve, we must be careful to rule out influences caused by common complications such as osteoarthritic changes of the elbow joint and the cubital tunnel syndrome in workers using vibrating tools. Considering the distribution of the sensori-neural complaints of vibration-exposed workers, electrophysiological examinations of hands and fingers should be performed in the median nerve, even though it will also be influenced by the existance of carpal tunnel syndrome.

In the present study, an objective evaluation of sensori-neural disturbances of hands and fingers in vibration-exposed workers was performed by means of antidromic SCV and short-latency SEPs parameters. By the standardisation of SSEPs parameters by arm length or body height, such parameters can be used for the objective evaluation of sensorineural disturbances of the vibration-exposed subjects. In comparison with the normal limit values we obtained, significant delay of SCV and N9 were observed in all 3 experimental groups and disordered N9-N13 was observed in non-VD and DM groups (Table 1). According to the segmental analysis, localisation of electrophysiological abnormalities were also studied in each experimental group. Peripheral and distal sensorineural disturbances such as SCV, SCV + N9, and N9 were the representative abnormalities and the total number of these findings reached 42.8% in non-VD, 64.8% in VD and 53.8% in DM (Table 2).

Cervical spondylosis (CSP) and diabetes mellitus are popular conditions after the age of 40 years and SSEPs are subject to the influence of such a pathological state. In the case of DM with CSP, N9 was especially more prolonged than that in DM without CSP (Table 3). Although the effect of CSP on SSEPs parameters in this study was not as evident as that found in our previous investigation (2-4), the hypothesis of double crush syndrome should always be kept in mind in the sensori-neural diagnosis of VD (5,6).

Conclusion

1. Objective evaluation of sensorineural disturbances of the median nerve in vibration-exposed workers was possible by means of the combination of antidromic SCV and SSEPs' parameters.
2. The main sites of sensorineural disturbances in VD subjects seemed to locate at finger, palm and arm, and electrophysiologically SCV, N9, and SCV + N9.
   Diabetes mellitus and/or radiographical cervical spondylosis, as well as carpal tunnel syndrome, should be checked prior to the electrophysiological examinations in the median nerve.

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Hand-arm vibration: Technical and medical prevention

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Introduction

Hand-arm vibration exposure

Hand-arm vibration exposure occurs in working conditions where intensive vibration is transmitted to the worker's hands and arms from vibrating tools, vibrating machinery or vibrating workpieces. The vibration exposure required to cause disorders depends on different parameters, the most important ones being the vibration magnitude, the frecuency spectrum and the daily and cumulative exposure duration.

Hand-arm vibration syndrome

Group of disorders associated to vibration exposure of fingers, hands and arms:
Vascular diseases: vibration-induced white finger
Musculoskeletal diseases: Kienbocks's disease
Neurological disorders: Carpal tunnel syndrome.

Preventive measures

The prevention of the injuries caused by the vibration transmission to the hand-arm system requires the implementation of technical, medical and management procedures.

- Technical procedures
  Identification of the main sources of vibration and assessment of exposure
  Selection of low vibration machinery and anti-vibration systems
  Personal protection
- Management measures
  Reduction of vibration exposure
  Information and training
- Medical issues
  Pre-employment screening
  Medical surveillance
  Workplace health promotion

Hand Arm Vibration transmitted machinery

The processes and machinery which transmit vibration to the operator's hands and arms are widely extended in several industrial activities. Some examples of this type of tool are chipping and riveting hammers, rock drills, rotatory hammers, grinders, pavement breakers, impact drills, stone working tools, saws, rammers, polishers.

Technical prevention

Technical prevention is strongly supported by the European Legislation, both in machinery and personal protection. The approximation of the European Legislation in

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terms of machinery obliges us to look for a reduction of vibration magnitude at source. Nevertheless, taking into account technical progress and the availability of means of reducing vibration, it can be necessary to use personal protective equipment.

The Technical procedures to reduce the exposure include :

a) Identification of main sources of vibration and assessment of exposure
b) Selection of low vibration machinery and anti-vibration systems
c) Personal protection.

Assessment of hand-arm vibration exposure: Identification of the risk (1)

To assess the hand-arm vibration exposure we should measure the “Vibration Total Value” of the weighted r.m.s acceleration in m/s^2:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$

a_{hwi}: r.m.s acceleration frequency weighted for i axe (m/s^2)
This value gives equal importance to all components.

The acceleration values in the different directions are measured in the frequency range between 8 Hz and 1000 Hz, which are supposed to be the frequencies that affect the human hand-arm system.

The “Daily Vibration Exposure” is derived from the magnitude of the vibration and the daily exposure duration.

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}}$$

T: vibration exposure duration (hours)
T_0: reference time (8 hours)
t is based on the 8 hour energy equivalent frequency weighted acceleration.

In the case of several exposures at different vibration magnitudes:

$$A(8) = \sqrt{\frac{1}{T_0}\sum_{j=1}^{n} a_{hvj}^2 \quad T_j}$$

<u>Estimation of exposure</u>

Values of $A(8)$ which may be expected to produce episodes of finger blanching in 10% of workers exposed for D_y years.

D_y (years)	1	2	4	8
$A(8)$ m/s^2	26	14	7.1	3.7

Interpolation for exposure conditions allows the use of the following relationship.

$$\left(\frac{A(8)}{1 \ m/s^2}\right)^{1.06} = \frac{D_y}{1 \ year} = 31.8$$

Selection of low vibration machinery

Limiting vibration should be considered as part of a strategy to achieve safety by design of machinery in conformity with the EC machinery Directive 89/392/EEC.

A Legal Machine is a CE Marked Machine and the CE marking is the sole responsibility of the manufacturer and/or supplier.

The hand-arm vibration requirement established in the machinery Directive says (2):

- If the a_{hw} measured on the machine handle is bigger than 2.5 m/s^2 then the data of acceleration values obtained using an adecuate method of testing shall be given in the instruction book.

  If this is the case, the machine must go through a CE type examination. For the CE type test should be used standardised methods (3, 4) if they do exist. The CE type test:
  a) Is designed to give information on the vibration performance of a given power tool
  b) Should give results as close as possible to the real work conditions
  c) Should be repetitive and reproducible.
- If the a_{hw} measured on the machine handle is smaller than 2.5 m/s^2 then this fact shall be said in the instruction book.

Personal protection (5)

As the last resort personal protection may be necessary. Any personal protection equipment should be CE marked according to 89/686/EEC Directive. The efficiency of a glove to reduce the hand vibration exposure is measured by its transmissibility. Gloves suppliers must provide vibration transmissibility data obtained according to EN ISO 10819.

Transmissibility is the ratio of the accelerations measured at the surface of the hand and the handle.

$$\overline{TR}_S = \frac{TR_{sg}}{TR_{sb}} = \frac{a_{wsPg}/a_{wsRg}}{a_{wsPb}/a_{wsRb}}$$

a_{ws} : r.m.s frequency-weighted acceleration for spectrum S (S= M or H)
R: at the handle, P: at the palm of the hand, b: bare hand, g: gloved hand.

Transmissibility values greater than 1 indicate that the glove amplifies the vibration. Values lower than 1 indicate that the glove attenuates the vibration.

ANTI-VIBRATION GLOVE: it is a glove complying with the following criteria:

$\overline{TR}_M < 1.0$ $\qquad$ $\overline{TR}_H < 0.6$

$\overline{TR}_M$: mean corrected transmissibility of glove for spectrum M.
$\overline{TR}_H$: mean corrected transmissibility of glove for spectrum H.

The M and H spectrum are defined in the standard.
Frequency interval: 31.5 to 1,250 Hz.

In any case, the use of gloves may alter the grip and feed force which act over the transmissibility increasing the risk of harmful effects. Be sure the gloves do not increase the vibration transmitted to the hand by selecting the appropriate one and giving the right information to the user and training.

Medical surveillance

In Spain notified cases of occupational diseases related to absenteeism associated with vibration have increased progressively from 1991 to 1996, as a result of a growing concern about these conditions. As medical prevention, besides health education and workplace health promotion activities, we propose a medical surveillance guide. It's goal is to provide occupational physicians with a useful and managable tool to prevent, as much as possible, hand-arm vibration injuries due to the working use of hand-held, hand-guided or other vibrating machinery, and to avoid worsening conditions when discovered at an early stage.

Medical surveillance guide is supported by a form comprising three main sections:

1) Identification and personal data of risk

Sex..... Age.....
Height........ Weight........ > Body Mass Index ....
Industry..................................... [I.S.C.I.] Occupation........... [I.S.C.O.]

Despite the difficulty in some cases, we want to highlight the importance of using the Standard Clasifications of Industries and Occupations to make possible studies among centers from different countries.

2) Risk factors (Appendix I)

This section proposes to record the worker RISK PROFILE, even before being exposed, in order to allow us to assess the association between risk profile and the different clinical stages and to summarise the profile of a whole group as a basis for epidemiological studies. We include:

a) Working conditions data: the type of tool, the cumulative time of exposure, the position and movements of hand and arm at work, and other work environment risks linked to the HAV exposure or syndrome (9, 10).
b) Background factors: exposure antecedents (previous jobs or hobbies with HAV exposure), previous diseases (peripheral vascular or rheumatic antecedents, mobility disorders in upper limbs), habits (smoking) or treatments and family antecedents of peripheral vascular disorders or rheumatic syndromes (10, 11, 12, 13, 14).
c) Preventive measures: management or personal protective equipment (thermic and/or anti-vibration gloves) (15).

3) Symptoms and signs (Appendix II)

In this section we will record the data to make the worker's CLINICAL ASESSEMENT which allows us to compare it with other workers or with other stages of his working life. We include:

a) neurovascular symptoms, questions about changes of the colour (blanching, cyanosis, blushing, pallor/rubor) and sensibility (coldness, tingling, numbness, swelling) in his fingers will be addressed (16, 17, 18). If he has got symptoms in any finger, it's final score will be calculated regarding the proposed figure in Appendix II, as the total sum of each affected phalanx score (15, 18).

b) osteoarticular symptoms: inflammation, mobility restriction, pain or rigidity in any joint of hand and arm (shoulder, elbow, wrist, carp or fingers) (13, 19).

c) situations that produce symptoms, or their changes, will be asked and recorded: cold weather, work schedule, seasons, rest or dampness (15).

d) Since the absence of symptoms does not exclude an early diagnosis through objective or functional exploration, we propose a set of simple tests to verify the presence of any sign when the worker has not mentioned any symptom: the cold provocation test, the Allen test, the Phalen test, the Tinnel test (14, 20, 21).

To summarise, the clinical stage we recommend is the Stockholm workshop scale, by regarding the finger score (14, 17).

We expect this medical surveillance guide make easier pre-employment screening in order to discover workers specially susceptible to this risk and to control the personal evolution of the exposed ones. We also propose this guide as an epidemiological tool to be applied in studies whose target will be to analyse the occurrence and prevalence trends or the association risk-hazard stage in a group of workers and, moreover, to test the efficiency of the preventive measures we have implemented.

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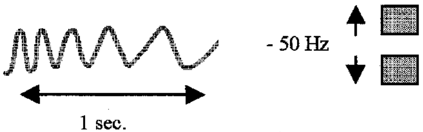
APENDIX I

RISK FACTORS

WORK- CONDITIONS

TYPE / USE OF TOOL

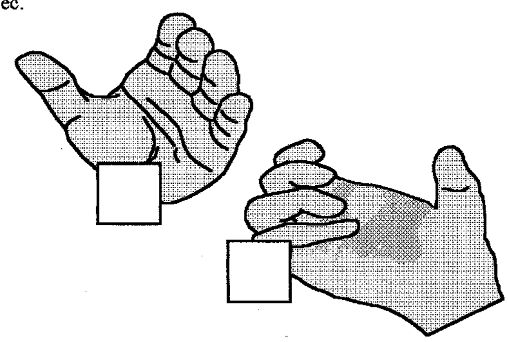
- Frequency (Hz)



- Acceleration (m/s^2)
  - Hours per work day
  - Worked days per year
  - Total of years exposed

POSITION & MOVEMENTS

- Repetitive wrist and finger motion
- Tool beating
- Forced deviated position of arm/wrist/hand
- Strong tool gripping



WORK ENVIRONMENT

Cold (< 21°C)
Noise

BACKGROUND FACTORS

EXPOSURE ANTECEDENTS

Previous occupational antecedents
Extra-labour vibration exposure (hobbies)

PREVIOUS DISEASES

Peripheral vascular antecedents
- Hiperreactivity to cold
- Raynaud's phenomenon
- Chilblain

Rheumatic or arthritic antecedents
- Scapulo - humeral periarthritis
- Painful flexion/extension wrist
- Synovitis

Mobility disorders in upper limbs

HABITS AND TREATMENTS

Smoking
Drugs for treatement
- Ergot derivates
- Oral contraceptives
- ß blocking agents

FAMILY ANTECEDENTS

- Peripheral vascular disorders
- Rheumatic syndromes

PREVENTIVE MEASURES

MANAGEMENT MEASURES

Appropiate worksite design
Job breaks
Workers turnover

PERSONAL PROTECTIVE EQUIPMENT

Antivibration gloves
Thermic gloves

RISK PROFILE

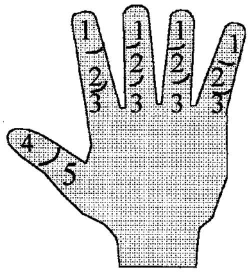
APENDIX II

SYMPTOMS & SIGNS

NEUROVASCULAR

COLOUR
Blanching
Cyanosis
Blushing
Pallor / Rubor

SENSIBILITY
Coldness
Tingling
Numbness
Swelling
Dexterity



Does it change with...

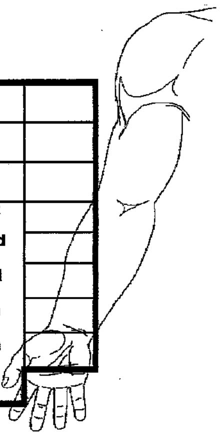
cold weather
work schedule
season
rest
dampness
?

FINGER	THUMB	2nd	3rd	4th	5th
SCORE	*	*	*	*	*

* FINGER FINAL SCORE RESULTS FROM THE TOTAL SUM OF EACH AFFECTED PHALANX SCORE

OSTEOARTICULAR

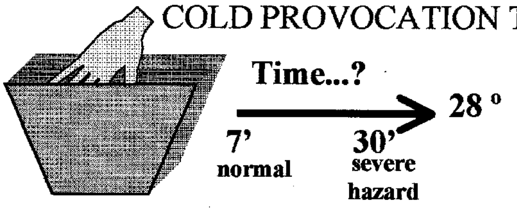
Inflammation
Mobility restriction
Pain
Rigidity



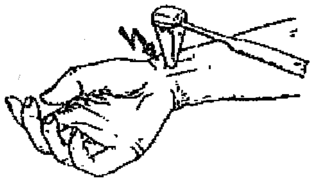
SHOULDER		
ELBOW		
WRIST/CARP		
FINGER	1st	
	2nd	
	3rd	
	4th	
	5th	

! ABSENCE OF SYMPTOMS DOES NOT EXCLUDE AN EARLY DIAGNOSIS THROUGH OBJECTIVE EXPLORATION OR FUNCTIONAL TESTS

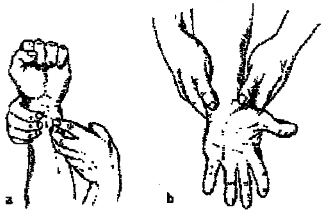
COLD PROVOCATION TEST



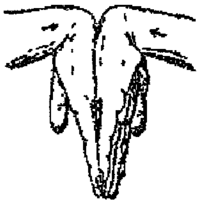
TINNEL TEST



ALLEN TEST



PHALEN TEST



STOCKHOLM WORKSHOP SCALES

VASCULAR			NEUROSENSORIAL
No attacks	0	0	Exposed, no symptoms
Occasional attacks & finger score = 1	1	1	Intermittent numbness
ccasional attacks & finger score = 2-4	2	2	Numbness reducing sensory perception
Frequent attacks & finger score > 4	3	3	Numbness reducing discrimination/dexte
Stage 3 & trophic changes	4		

CLINICAL ASSESSMENT

Comparison of three different quantitative measures for vibrotactile perception thresholds - Acceleration, force and absorbed power

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Introduction

Registration of vibrotactile perception thresholds (VPTs) is a commonly used method for diagnosis of sensorineural disorders caused by different types of diseases (eg. diabetes, carpal tunnel syndrome) or as result of agents in the working environment (eg. exposure to solvents, mercury, vibration, electromagnetic fields, heavy manual work). VPTs are also an important ingredient for grading of sensorineural disorders in to symptomatic stages (2). Several different methods for VPTs have been developed and used (for an overview, see 5). It is clear that the outcome of a VPT measurement is, for instance, strongly related to measurement set-up, experimental procedure and individual factors. There is also relatively large inter- and intra-individual differences which quite often cause difficulties in the interpretation of obtained results. Clearly, the effect of these factors have to be fully examined before measurement of VPTs can be accepted and established as a tool for clinical diagnostic purposes, for screening, or in research.The aim of this pilot investigation was to compare three different quantitative measures for VPT, namely acceleration, dynamic force and absorbed power.

Methods

VPTs were measured on the right index finger tip on 10 healthy subjects. None of them had used vibrating hand-held tools professionally.

The experimental set-up for VPT measurements consist of a computer based system (LabView^{TM}) for both stimulus excitation at six discrete frequencies (8, 16, 32, 63, 125, 250 Hz) and for data acquisition and analysis. Vibration was delivered as 5 s long bursts which were ramped on and off at the beginning and end, respectively. Between each burst a 3 s long pause was inserted. The acceleration level for following bursts were decreased or increased in steps of 1 dB depending on perceptive responses (by pressing a button on a hand switch) respective lack of perceptive responses from the subject, respectively. A forced choice algorithm for VPT has thus been used.

An impedance head (Brüel & Kjær 8001) was mounted on the shaker which enabled registration of time signals for acceleration a(t) and dynamic force F(t). The collected acceleration signal was integrated to get the velocity v(t). Time-averaged absorbed power (P_{Abs}) was determined as: $P_{Abs} = v(t)\ F(t)$. The static force and skin temperature were continuously monitored during VPT measurements.

The subjects were asked to sit on a chair with their forearm and hand resting extended and relaxed on a testing table. The position of the stimulator probe (diameter: 5 mm; no supporting surround) covered the pulp of the finger. The subject was instructed to press the button on the hand switch as soon as the vibration burst was

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perceived. The threshold at each frequency was defined as the lowest stimulus level perceived by the subject.

Results

The results from this pilot study showed VPT curves with different shapes (Figure 1). The graph for acceleration shows a typical shape which is in agreement with most other studies (eg. 1, 3, 4). The VPT graph for force indicates that the dynamic force required for perception decreases with frequency. The absorbed power threshold graph shows an inverted U-shaped form which has a peak at 16 Hz. The inter-individual variability is however comparable for all three categories.

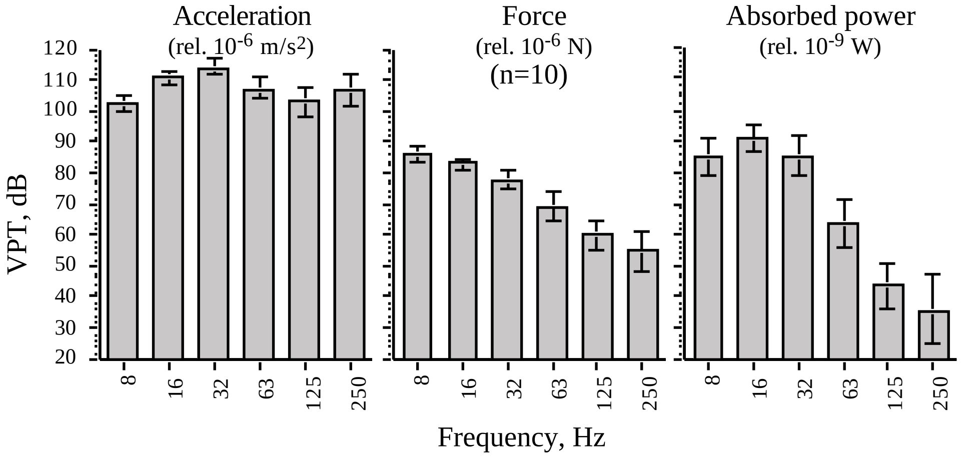

Figure 1. Mean (±1 Sd) VPT quantified as acceleration, dynamic force and absorbed power.

Discussion

The results obtained in this study are based on measurements taken using only ten subjects. To be able to draw any far-reaching conclusions regarding preference for any of the three VPT categories, this study has to be extended, i.e. with respect to number of healthy and symptomatic subjects, influence of age, intra-individual variability, sensitivity, specificity etc. Methods for VPT measurement which include the dynamic force must however be considered as interesting and well worth further exploration since this component mirrors the mechanical coupling and physical strain on tissues in contact with the stimulus probe.

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Hand-arm database on the Internet

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Introduction

Among others, officials from social insurance offices, company health services, clinics in occupational medicine, research departments in the field of occupational health, labour inspectorates, buying departments, engineering industry often asks for information regarding vibration levels measured on handles of specific hand-held power tools. Some reasons for this are a need;

- for health risk assessment due to past and/or present vibration exposure
- to constitute a basis for decisions in worker compensation cases
- to procure ”user friendly” tools in order to prevent vibration-induced disorders
- for data in research and development projects.

A long-felt want has therefore been that reported measurement results should be put together in a database. The format for such a database should fulfil at least the following requirements;

- data must be presented in a clear, understandable and useful way,
- the database should be easily accessible for a large number of interested users,
- measurement data must pass through a quality control before insertion,
- included data must be based on measurements conducted in accordance with a generally accepted standard, such as an ISO or a CEN standard,
- new data inserted in the database should be accessible for users as quickly as possible,
- corrections and additions must be easy to carry out,
- the database must be easy to manage and maintain and not involve to heavy expenditures.

After considering different alternatives, it was concluded that a database accessible through Internet would most efficiently comply with the above stated requirements.

Data base content

At present the database contains vibration data for more than 2500 hand-held power tools, either CE-declared (1) values, i.e. vibration measured in accordance with corresponding parts of the ISO 8662 standard (3), or measured according to ISO 5349 (2, 4) during normal operation at a work site. CE-declared noise data is also included for many tools of the former category. The database is available in Swedish and English.

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Procedure for search and presentation of search results

The search is done by a step by step procedure.

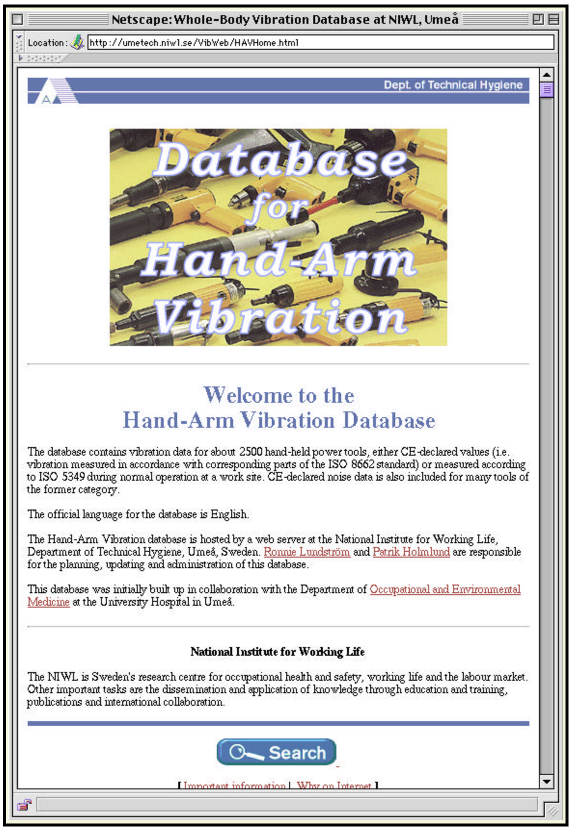
Step 1. Open the database ”Home page”

The database home page (Figure 1), reach by using a suitable web browser (e.g. Netscape Navigator, Internet Explorer), contains some general information for instance about database content, people responsible for administration and maintenance, collaborating organisations and some links to other informative pages.

On this page there is also a link to a page which provide important information which should be considered entering the hand-arm vibration database. The next step is to open the “Search page” (Figure 2).

Step 2. Open the “Search page”

A search for vibration data, CE-declared and/or measured during normal work, for a specific tool or for a category of tools is done by choosing or typing search arguments according to instructions given on this page (Figure 2). The result of this request is then presented on a separate ”Search result” page (Figure 3).



Location: http://umetech.niwl.se/VibWeb/HAVHome.html

Welcome to the
Hand-Arm Vibration Database

The database contains vibration data for about 2500 hand-held power tools, either CE-declared values (i.e. vibration measured in accordance with corresponding parts of the ISO 8662 standard) or measured according to ISO 5349 during normal operation at a work site. CE-declared noise data is also included for many tools of the former category.

The official language for the database is English.

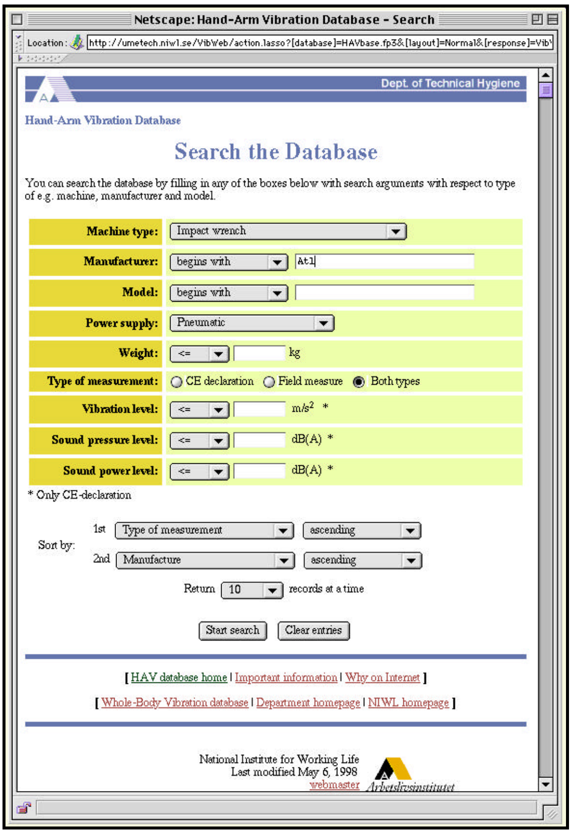
The Hand-Arm Vibration database is hosted by a web server at the National Institute for Working Life, Department of Technical Hygiene, Umeå, Sweden. Ronnie Lundström and Patrik Holmlund are responsible for the planning, updating and administration of this database.

This database was initially built up in collaboration with the Department of Occupational and Environmental Medicine at the University Hospital in Umeå.

National Institute for Working Life

The NIWL is Sweden's research centre for occupational health and safety, working life and the labour market. Other important tasks are the dissemination and application of knowledge through education and training, publications and international collaboration.

Figure 1. Home page.



Location: http://umetech.niwl.se/VibWeb/action.lasso?[database]=HAVbase.fp3&[layout]=Normal&[response]=Vib

Hand-Arm Vibration Database

Search the Database

You can search the database by filling in any of the boxes below with search arguments with respect to type of e.g. machine, manufacturer and model.

Machine type: Impact wrench
Manufacturer: begins with | Atl
Model: begins with |
Power supply: Pneumatic
Weight: <= | kg
Type of measurement: ○ CE declaration ○ Field measure ● Both types
Vibration level: <= | m/s^2 *
Sound pressure level: <= | dB(A) *
Sound power level: <= | dB(A) *

* Only CE-declaration

Sort by: 1st Type of measurement | ascending
2nd Manufacture | ascending
Return 10 records at a time

National Institute for Working Life
Last modified May 6, 1998

Figure 2. Search page.

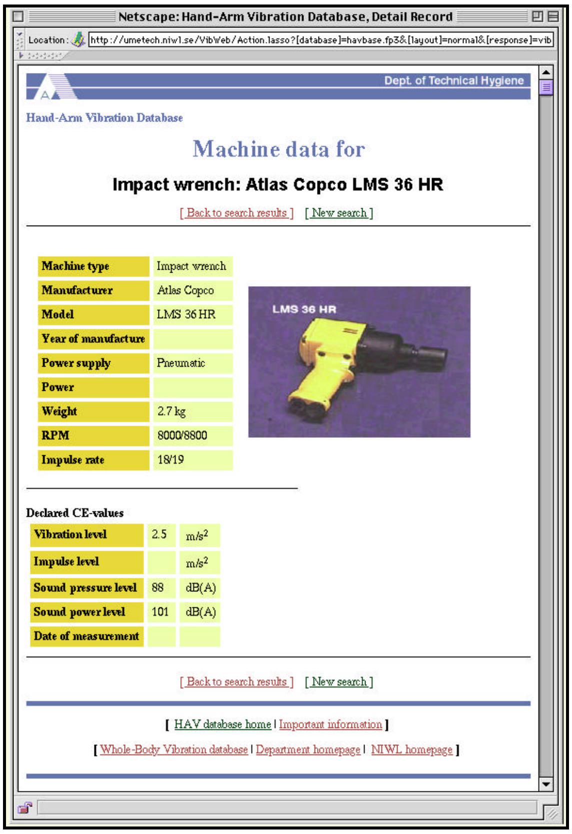
Step 3. Viewing the “Search result page”

Each row on the Search result page indicates type of tool (e.g. grinder, nut runner, drill), name of the manufacturer (e.g. Atlas Copco, Fuji, Bacho) and model. Further information and data for an individual tool on this list is then presented by activating corresponding link to a ”Tool data” page (Figure 4).

Figure 3. Example of a “Search result” page.

Step 4. Viewing ”Tool data pages”

A “*Tool data page*” (Figures 4 and 5) show some general information about the tool (e.g. model, manufacturer, weight, power), photograph, and vibration data. Noise data is in most cases also given for CE-declared tools. A reference to the source of information will also be showed.



Netscape: Hand-Arm Vibration Database, Detail Record

Location: http://umetech.niwl.se/VibWeb/Action.lasso?[database]=havbase.fp3&[layout]=normal&[response]=vib

Dept. of Technical Hygiene

Hand-Arm Vibration Database

Machine data for

Impact wrench: Atlas Copco LMS 36 HR

[Back to search results] [New search]

Machine type	Impact wrench
Manufacturer	Atlas Copco
Model	LMS 36 HR
Year of manufacture	
Power supply	Pneumatic
Power	
Weight	2.7 kg
RPM	8000/8800
Impulse rate	18/19

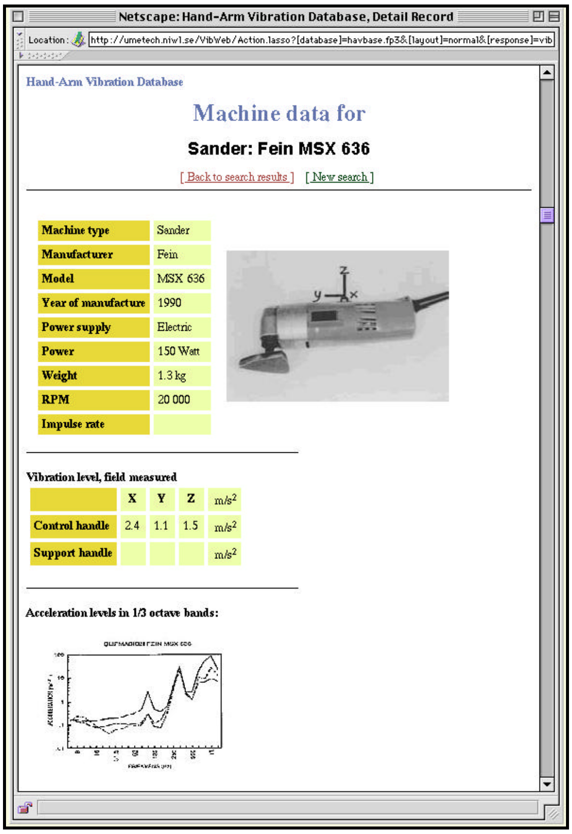
Declared CE-values

Vibration level	2.5	m/s²
Impulse level		m/s²
Sound pressure level	88	dB(A)
Sound power level	101	dB(A)
Date of measurement		

[Back to search results] [New search]

[HAV database home | Important information]

[Whole-Body Vibration database | Department homepage | NIWL homepage]



Netscape: Hand-Arm Vibration Database, Detail Record

Location: http://umetech.niwl.se/VibWeb/Action.lasso?[database]=havbase.fp3&[layout]=normal&[response]=vib

Hand-Arm Vibration Database

Machine data for

Sander: Fein MSX 636

[Back to search results] [New search]

Machine type	Sander
Manufacturer	Fein
Model	MSX 636
Year of manufacture	1990
Power supply	Electric
Power	150 Watt
Weight	1.3 kg
RPM	20 000
Impulse rate	

Vibration level, field measured

	X	Y	Z	m/s²
Control handle	2.4	1.1	1.5	m/s²
Support handle				m/s²

Acceleration levels in 1/3 octave bands:

Figure 4. Example of a Tool data page for a CE-declared impact wrench.

Figure 5. Example of a Tool data page for a field measured sander.

End notes

This hand-arm vibration database on Internet has become a centralised European hand-arm vibration database with support from the EU project “Network on Detection and Prevention of Injuries due to Occupational Vibration Exposures” (Contract No. BMH4-CT98-3251 (DG12-SSMI)). Support has also been received from the Swedish Council for Work Life Research.

The database is still in a stage of development. Changes with respect to content and format will therefore most likely be conducted in the future. An important input to this is viewpoints from different categories of users. A new routine has recently been activated which enables partners in the European Research Network to submit data to the database administrator, directly from there own terminals through Internet. This data is first stored on the database server as a temporary database. After inspection and approval from the database administrator this data is thereafter transferred to the main database.

A corresponding whole-body vibration database, covering earth-moving vehicles, has also been established which is available at the same Internet location as the hand-arm vibration database.

Internet location

The hand-arm vibration database is hosted by a web server at the National Institute for Working Life, Programme for Technical Risk Factors, Umeå, Sweden.

The Internet location is:

”http://umetech.niwl.se/”.

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4. ISO/DIS 5349-1 (1999) Mechanical vibration - Measurement and assessment of human exposure to hand-transmitted vibration - Part 1: General guidelines. International Organization for Standardization.

Design and evaluation of an inexpensive test fixture for conducting glove vibration tests per ISO standard 10819

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Introduction

In the field of personal protective equipment, gloves were being manufactured and marketed that claimed to significantly reduce the magnitude of vibration transmitted from vibrating tools to the hand. Most of these claims proved to be false. As a result, the International Organisation for Standardisation adopted ISO Standard 10819 to define test procedures that must be used to measure the vibration attenuation characteristics of gloves that were designed to reduce vibration into the hand (1). This standard also specified the vibration attenuation values that must be achieved for a glove to be labelled as an ”antivibration glove”.

ISO Standard 10819 requires that test subjects exert a push force of between 50-60 N on the handle that directs vibration into their hand. At the same time, the electromechanical shaker to which the handle is attached must generate an overall vibration amplitude per pre-defined vibration spectra of up to 92.2 m/s^2. To meet these requirements, most laboratories that perform tests per the requirements of ISO Standard 10819 have used a large electromechanical shaker capable of producing dynamic forces in excess of 2000 N. These shaker systems, along with their power amplifies, are very expensive. In addition, a horizontal load cell that is placed in a platform on which the test subject stands has been used to measure the push force.

A project was undertaken at the Center for Mechanical & Environmental Systems Technology (CMEST) at the University of Nevada, Las Vegas in the USA to develop a test system that can be used to conduct glove vibration transmissibility tests per the requirements of ISO Standard 10819. The project had three objectives:

- The test system was to be inexpensive.
- The handle push force was to be measured at the electromechanical shaker, not at a platform on which a test subject stands.
- The transmissibility test results of selected gloves that were obtained with the inexpensive test system were to be compared with corresponding test results obtained from other laboratories that had been certified to conduct vibration transmissibility tests per ISO Standard 10819.

ISO standard 10819 test procedures

ISO Standard 10819 specifies the test procedures that must be used to measure the vibration transmissibility of gloves (1). The vibration transmissibility of a glove per ISO Standard 10819 is the ratio of the vibration amplitude directed into the palm of the hand inside of a glove divided by the vibration amplitude directed into the palm on the outside surface of the glove. The vibration signals that are measured at the handle and into the palm are the overall acceleration signals that are passed through an ISO

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weighting filter that is specified by ISO Standard 5349 (2). Figure 1 shows the ISO weighting filter. The vibration transmissibility of a glove is a measure of the attenuation of vibration into the hand and arm by means of a resilient or vibration-damping material placed in the glove. The lower the vibration transmissibility, the more effective a glove is in reducing vibration energy into the hand and arm.

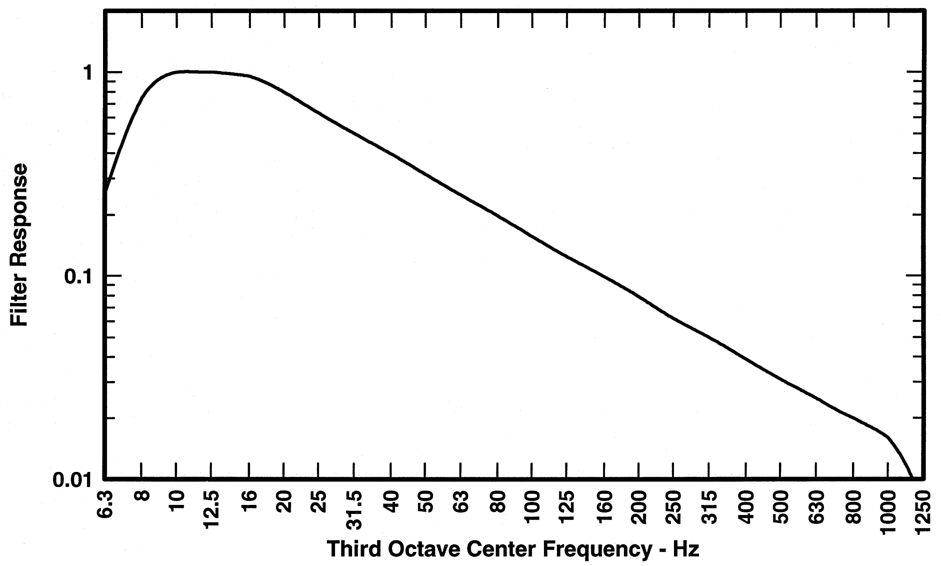

Figure 1. ISO weighting filter per ISO Standard 5349.

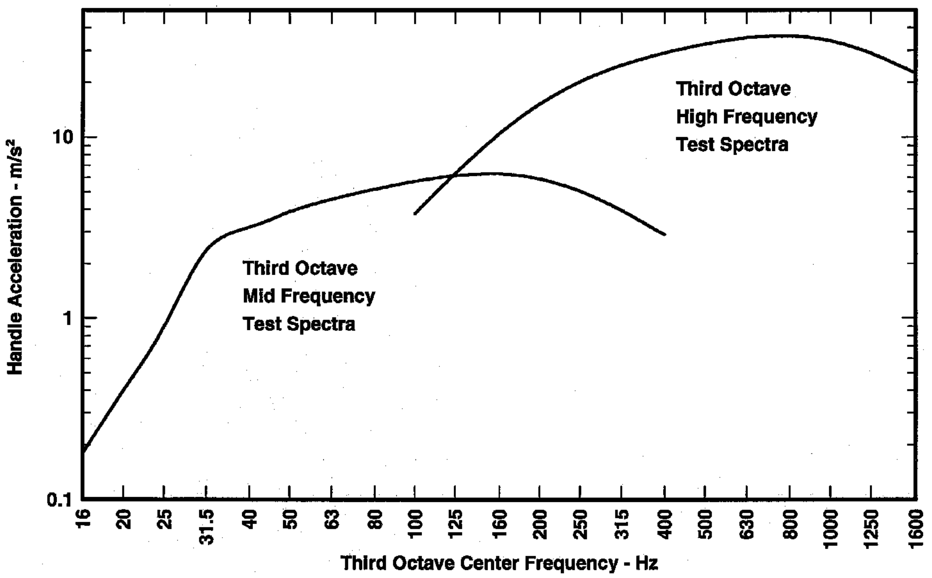

Figure 2. ISO 10819 mid and high frequency test spectra.

ISO Standard 10819 specifies the amplitude of vibration transmissibility that must be achieved for a glove to be classified as an anti-vibration glove. The standard requires the overall vibration transmissibility of a glove to be measured for mid frequencies (16-

400 Hz) and for high frequencies (100-1600 Hz). Figure 2 shows the third octave amplitudes of the vibration spectra for the mid and high frequency test signals, respectively. Vibration first corresponding to the mid frequency test spectra and then to the high frequency test spectra are directed into the hand by means of a 40 mm diameter handle attached to a vibration shaker. Sets of two measurements on each of three test subjects for a total of six measurements are made for each frequency range. Three different gloves, one for each test subject, are used for each series of tests. The six individual transmissibility values for both the mid and high frequency test signals are averaged to obtain the average ISO Standard 10819 vibration transmissibility values. The average mid-frequency transmissibility is designated $\underline{TR}_M$, and the average high-frequency transmissibility is designated $\underline{TR}_H$. For a glove to be classified as an antivibration glove:

- $\underline{TR}_M$ must be less than 1.0, and $\underline{TR}_H$ must be less than 0.6.
- The resilient or vibration-damping material must be placed in the palm and the full finger and thumb stalls of the glove.

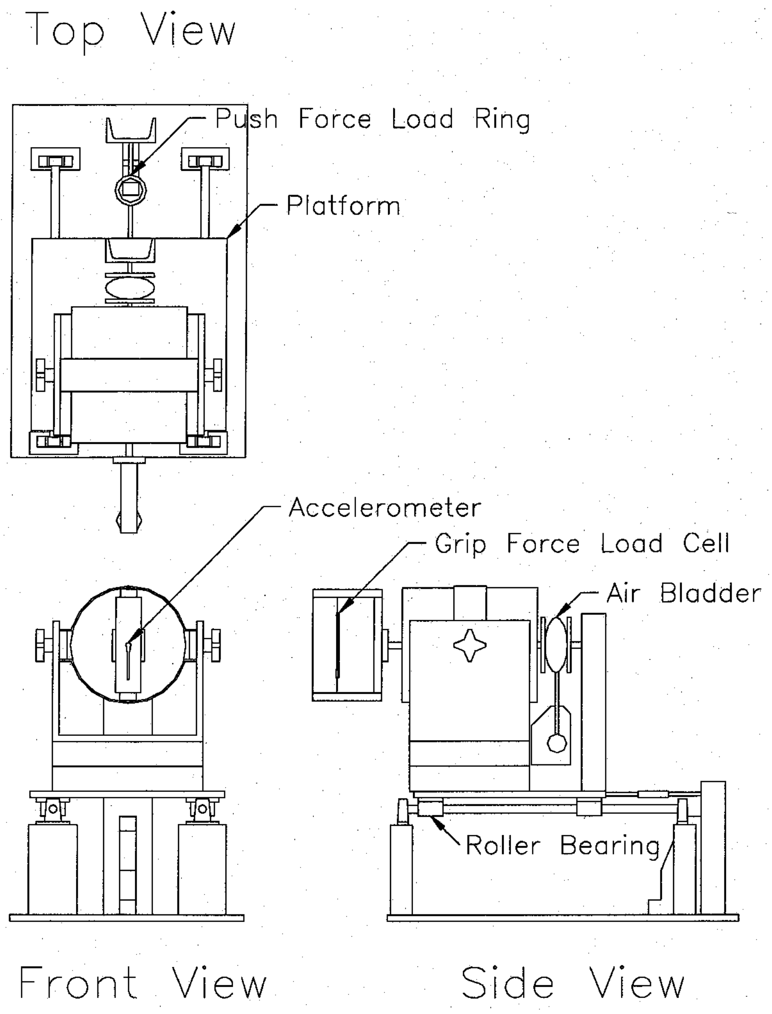

Figure 3. Electromechanical shaker set-up for ISO Standard 10189 tests.

Test set-up for ISO standard 10819 tests

One of the major objectives of this project was to use a small electromechanical shaker that generates a maximum dynamic force of less than 230 N for the vibration transmissibility tests. In the past, these small shakers could not be used because their center coil cannot resist a push force of 50-60 N without bottoming the coil into the outer casing of the shaker.

Figure 3 shows a drawing of the electromechanical shaker set-up that was designed and used for this project. The electromechanical shaker rests on top of an aluminum platform that is mounted on four linear roller bearings. In the absence of a restraining force, the platform is free to move in the direction of the push force that is applied to the shaker handle during a test. The platform is connected to a rigid aluminum post that is attached to the base of the set-up by means of a small aluminum load ring. The load ring is used to measure the push force that is applied to the shaker handle during a test. The load ring is connected to the platform and to the rigid post by means of floating pin joints. The ends of the load ring loosely fit onto the pins. The pin joints have enough play in them to allow the load ring to sense zero strain when no push force is applied to the shaker handle and to react only to a strain that is associated with a push force that acts along the axis of the load ring. To prevent the shaker coil from bottoming into the outer casing of the shaker, an air bladder is placed between an extension from the back end of the coil and a rigid post that is attached to the shaker platform. The air bladder provides a very soft resilient element between the shaker coil and post that resists the push force. The presence of the air bladder does not significantly affect the dynamic properties of the shaker coil.

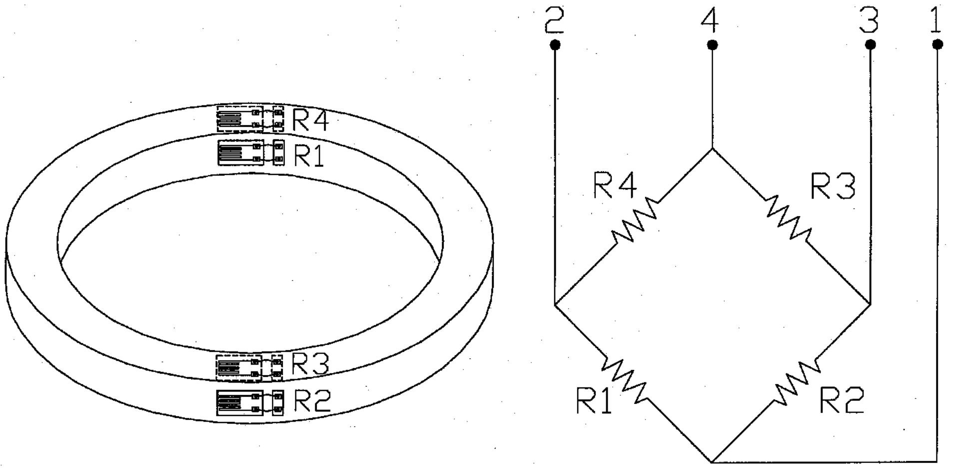

Figure 4. Load ring.

Figure 4 shows the configuration of the four-gauge strain gauge bridge that is placed on the load ring to sense the push force. The leads from the bridge are attached to a strain indicator. The output from the strain indicator is directed to a visual meter that can be monitored during a test. The meter is calibrated by applying a known static push force to the shaker handle.

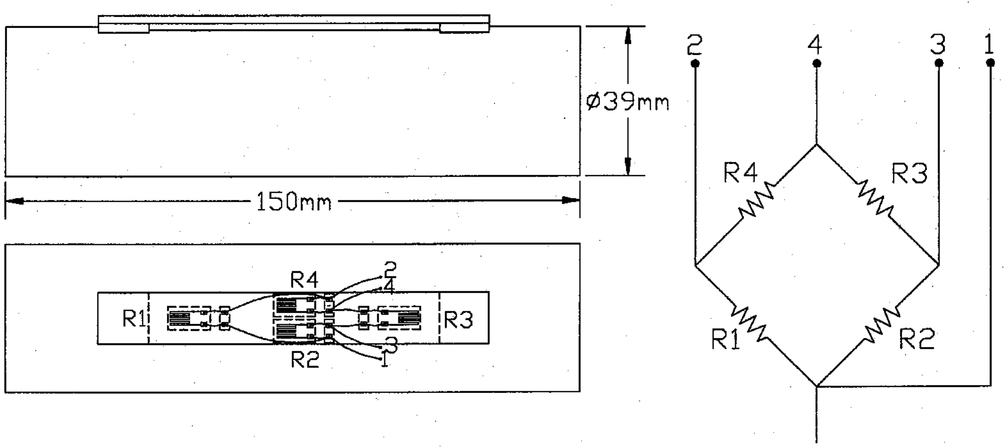

Figure 5. Handle used to measure grip force.

Figure 5 shows a drawing of the shaker handle. The handle is used to direct vibration into the hand and to measure the grip force. The handle is designed so that it does not have a resonance frequency between the frequencies of 5 - 2000 Hz. To ensure this, the handle has a minimum wall thickness of 6.5 mm. An offset strain gauge beam is inset into the handle so that the top surface of the beam is around 3-4 mm above the surface of the handle. The beam is placed into a shallow channel that is milled into the surface of the handle. A four-gauge strain gauge bridge is placed on the underside of the beam as is shown if Figure 5. The leads from the bridge are attached to a strain indicator. The output from the strain indicator is directed to a visual meter that can be monitored during a test. The meter is calibrated by applying a known point force to the center of the beam. The shaker handle is oriented so that the fingers compress the beam when the hand clasps the handle during a test. Thus, the beam is located opposite the accelerometer that is mounted in the handle to measure the acceleration amplitude directed into the hand from the handle during a test (Figure 3).

Two Endevco 2222c subminiature accelerometers were used to measure the handle acceleration and the acceleration into the hand. The accelerometer that was used to measure the handle acceleration was inset into the center of the shaker handle directly below the palm of the hand (Figure 3). The accelerometer that was used to measure the acceleration into the palm of the hand was inset into the hand adapter shown in Figure 6. The adapter is placed in the palm of the hand as shown in Figure 7 during a vibration transmissibility test. Each accelerometer was calibrated before each test with an accelerometer calibrator.

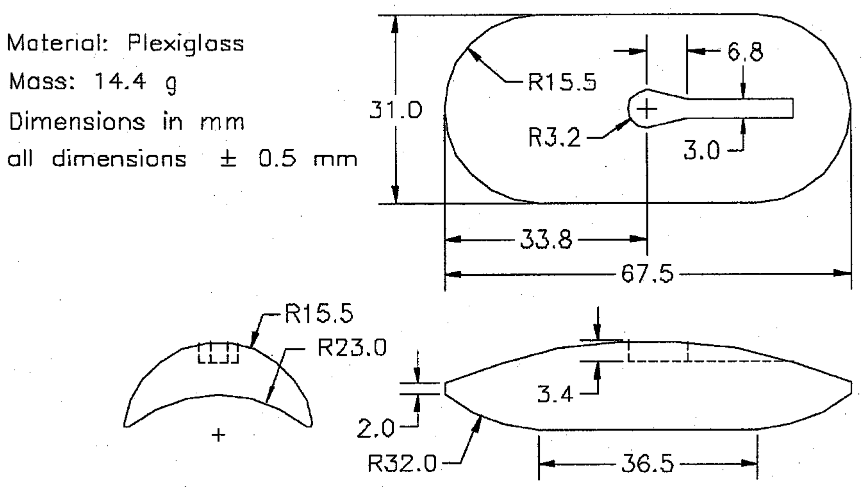

Figure 6. Adapter used to hold the accelerometer in the palm of the hand.

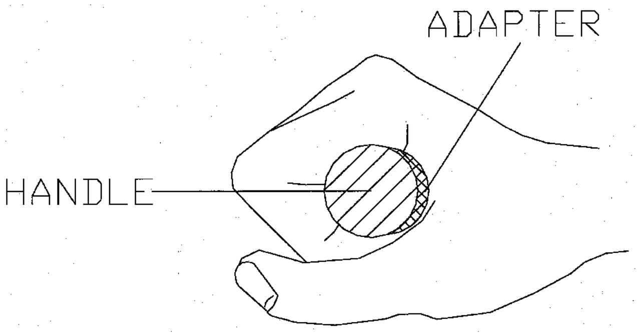

Figure 7. Placement of adapter in the palm of the hand for vibration transmissibility test.

Test protocol for the ISO 10819 tests

Figure 8 shows the system layout and Figure 9 shows a picture for the test set-up that was used for the ISO 10819 tests that were conducted during this project. The mid and high frequency test spectra shown in Figure 2 were manually adjusted for the vibration transmissibility tests that were conducted. A signal from a pink noise generator was passed through a Butterworth bandpass filter to a third octave band graphic equaliser. The Butterworth filter corner frequencies were set at 16 Hz and 400 Hz for the mid frequency test signal and at 100 Hz and 1600 Hz for the high frequency test signal. The third octave band values from the graphic equaliser were manually adjusted to achieve the mid and high frequency test signals that were required by ISO Standard 10819 for each series of tests. The signal from the graphic equaliser was then directed to the shaker amplifier and then to the shaker. With great difficulty, it was possible to maintain the test spectra shown in Figure 2 within the third octave frequency amplitude band limits that are specified in ISO Standard 10189 during a series test. Many test set-ups used a feedback vibration controller. When this is the case, the feedback vibration controller will replace the noise generator, Butterworth bandpass filter, and graphic equaliser.

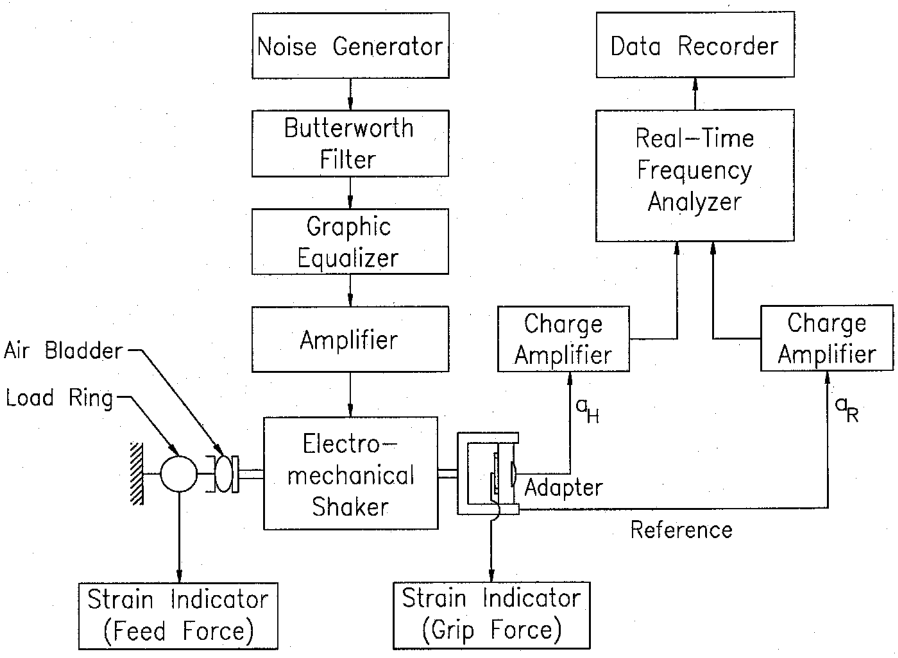

Figure 8. System set-up for ISO Standard 10819 tests.

Figure 9. Picture of system set-up for ISO Standard 10819 tests.

The signals from the accelerometers were directed through their respective charge amplifiers to a B&K 2144 Dual-Channel Real Time Analyser. The analyser was used in the third octave frequency mode. The ISO weighting filter shown if Figure 1 was programmed into the analyser for both of the accelerometer channels. The ratio of the amplitude of the ISO weighted acceleration into the hand divided by the amplitude of the ISO weighted acceleration at the handle was processed by the analyser. The test signals from the charge amplifiers were recorded on two channels of an eight-channel DAT recorder for future processing, if necessary.

All tests were conducted per the test procedures that are specified in ISO Standard 10189. Three test subjects and three separate gloves were used for each series of tests.

Figure 10. ISO Standard 10819 test underway at CMEST.

Test results

Seven different gloves that contained different vibration-damping materials were tested at CMEST using the test system set-up shown in Figures 3 through 8 and the test protocol described above. Figure 10 shows a test in progress at CMEST. The same gloves were also tested at two European laboratories: Delta Acoustics & Vibration in Lyngby, Denmark, and Berufsgenossenchaftliches Institut für Arbeitssicherheit (BIA) in Sankt Augustin, Federal Republic of Germany. Each laboratory used test protocols that were consistent with their respective interpretations of the test procedures specified in ISO Standard 10819. The test results for the tests that were conducted at CMEST, Delta Acoustics & Vibration, and BIA are shown in Table 1. The table indicates that the agreement in the ISO Standard 10819 test results from the three laboratories is very good.

Conclusions

- A test set-up for conducting ISO Standard 10819 glove vibration transmissibility tests utilising a small electromechanical shaker (maximum dynamic force < 230 N) has successfully been developed. It is possible to measure the push force applied to the shaker handle at the shaker with this test set-up.
- The ISO Standard 10819 test results that were obtained with the test system that was developed during this project agreed very well with the corresponding test results that were obtained at Delta Acoustics and Light in Denmark and BIA in Germany.

Table 1. ISO Standard 10819 glove vibration transmissibility test results (±SD).
CMEST: Center for Mechanical & Environmental System Technology, USA.
Delta: Delta Acoustics & Vibration, Denmark.
BIA: Berufsgenossenschaftliches Institut für Arbeitssicherheit, Germany

GLOVE		CMEST	Delta	BIA
Glove 1	$\underline{TR}_M$	0.85 (0.03)	0.89 (0.09)	
	$\underline{TR}_H$	0.71 (0.01)	0.69 (0.09)	
Glove 2	$\underline{TR}_M$	0.68 (0.04)	0.73 (0.12)	
	$\underline{TR}_H$	0.52 (0.03)	0.52 (0.09)	
Glove 3	$\underline{TR}_M$	0.65 (0.06)	0.72 (0.07)	
	$\underline{TR}_H$	0.51 (0.04)	0.51 (0.07)	
Glove 4	$\underline{TR}_M$	0.79 (0.02)		0.87 (0.06)
	$\underline{TR}_H$	0.56 (0.02)		0.58 (0.03)
Glove 5	$\underline{TR}_M$	0.82 (0.04)	0.87 (0.09)	
	$\underline{TR}_H$	0.80 (0.02)	0.79 (0.11)	
Glove 6	$\underline{TR}_M$	0.79 (0.02)	0.85 (0.09)	
	$\underline{TR}_H$	0.76 (0.04)	0.76 (0.13)	
Glove 7	$\underline{TR}_M$	0.86 (0.04)		0.93 (0.01)
	$\underline{TR}_H$	0.83 (0.04)		0.72 (0.02)

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Measurement and assessment of hand-arm vibration caused by fastener driving tools

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Introduction

Besides the environmental influences of noise, dust and chemical substances, vibration to the hand-arm system is a significant stress for the worker. The mechanics of vibration will distinguish between random vibration, this vibration will be generated by tools like a chain saw, chisel hammer and grinder, and shock type vibration, emited by fastener driving tools.

The present standards ISO 5349-1 (2) and ISO/DIS 8662-11 (4) mention different forms of vibration, but they disregard the different sorts of shock type and non-shock type vibration.

Until now only a few investigations about stress by shock type vibration to the hand-arm system have been done.

Dupuis and Schäfer (1) generated with a simulator sine with typical vibration from tools (nailer, chain saw, breaker) with a weighted acceleration of $a_{z,rms} = 6.3\ m/s^2$. The investigation shows that an increase of the shocks will increase the electrical muscle activity of the m. triceps brachii. For vibration with a crest factor of 10, electrical muscle activity was 85% higher than for non-shock type vibration. But there is no electrical muscle activity influence to the m. flexor carpi ulnaris and m. biceps brachii. Besides, Dupuis and Schäfer could establish for shock type vibration neither higher handle-to-wrist transmissibility nor higher handle-to-elbow transmissibility.

Schenk and Heine (7) found that shock exposure reduces the maximum grip force of the worker. They showed that an increase of the shock intensity decreased the biomechanical transmission.

Louda et al. (6) examined 23 female workers from the wood industry, who fixed wooden panels with nailers and a staple air gun. Though the weighted acceleration was smaller than $1.44\ m/s^2$ and 30% of the workers were diagnosed with carpal tunnel syndrome, Lauda et al. say that the number of impacts per day (shift) are very important. Other individual aspects are the grip force and the push force, but the push force depends on the release of the fastener driving tool (7).

To sum up, it can be said that no statement about shock type vibration stress can be made respectively of the electrical activity and the vibration transmission.

The purpose of this study was to measure the stress and the strain of hand-arm vibration caused by fastener driving tools.

Methods

Test subjects worked with different tools (chisel hammer, nailer and pinner, see table 1) on a special test rig (ISO 8662-11). The length of the nailers (5 cm, 9 cm) and the working methods under ISO 8662-11 working conditions (20 impacts per minute, single

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actuation) and under real working conditions (92 impacts per minute, contact actuation) were investigated. The study group consisted of twelve male test subjects with an average age of 26.2 (SD 5.4) years, an average height of 176.3 (SD 5.6) cm and an average weight of 73.4 (SD 9.7) kg.

Table 1. Tools and working conditions.

tool	manufacturer	type	power	nails (length)	cycle (nails/minute)
nailer	ITW Paslode	5350/100S-Q contact actuation	compressed air 7.5 bar	nails (50 mm)	20 92
				nails (90 mm)	20 92
pinner	Holzher	3405 single actuation	compressed air 4.5 bar	clamps (16mm)	20 92
chisel hammer	Red Head	747	electric	chisel in concrete	(50 Hz)

All subjects used the nailer with contact actuation. They pulled the trigger continuously and hit the work piece with the muzzle of the nailer (like a hammer). This was different to the pinner where every time they released a shot they placed the tool on the work piece and pulled the trigger. With both tools the working direction was downwards.

The duration measured was 15 seconds and the sampling frequency was 1024 Hz. Acceleration was measured in three directions on the handle of the tools and on the wrist and elbow of the test subjects. Additionally, the electrical muscle activity of the m. biceps brachii and of the m. flexor carpi ulnaris was analysed. The m. biceps brachii is needed to make the coupling force and to stabilise the arm posture. The m. flexor carpi ulnaris supports the movement of the fingers and stabilises the wrist.

The following measuring equipment was used:

Piezoelectric accelerometer (B&K Type 4393)
Amplifier (B&K Type 2635)
PC 486-33, A/D-Wandler Datalog DAP 2400-6
Software DIA/DAGO 4.0 (FFT, $a_{rms,}$ a_{hw})

Both of the fastener driving tools had special grip force measuring equipment.

Results

Vibration stress

(Abbreviations: nailer 9-20 means: nailer, length of the nails 9 cm, working cycles 20 impacts per minute)

Figures 1a and 1b show acceleration as a function of time (0.15s) for the nailer and the chisel hammer.

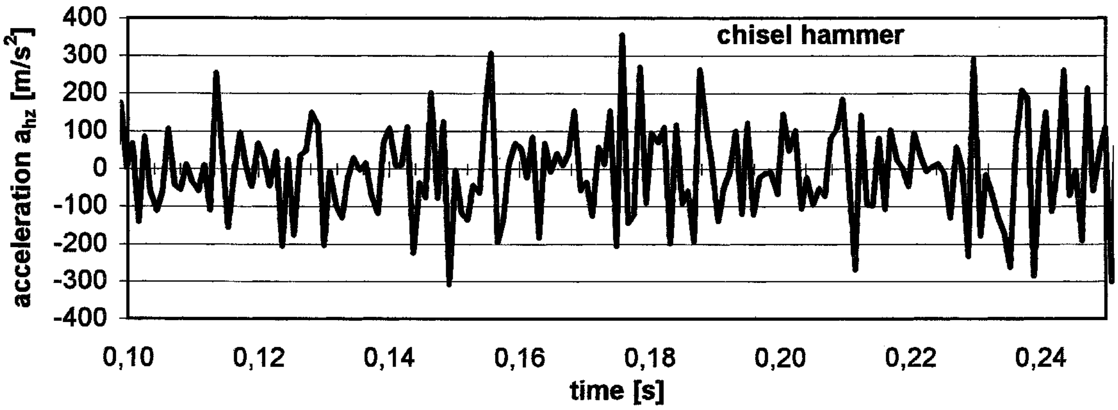

Figure 1a. Time depending acceleration (chisel hammer).

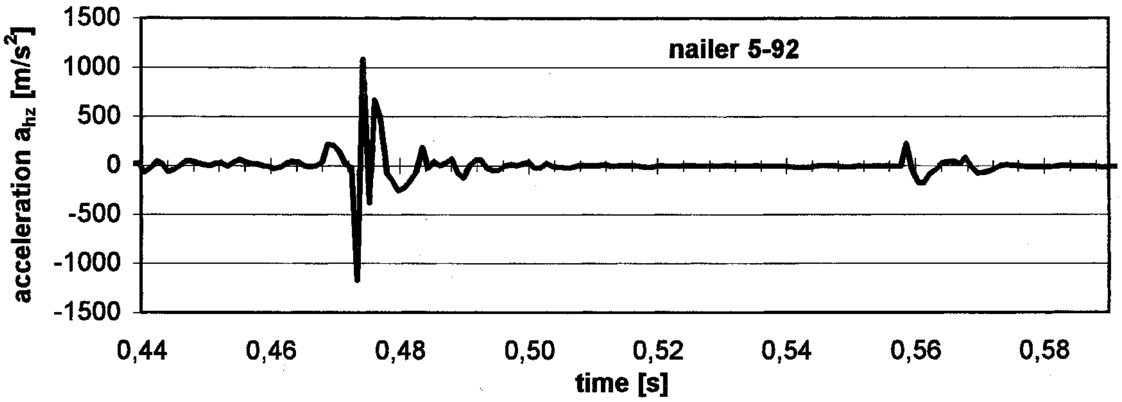

Figure 1b. Time depending acceleration (nailer 5-20).

Figure 2 compares the acceleration a_{rms} at the handle of the tools. The highest acceleration of all tools was measured in the z-direction. Of all the tools, the chisel hammer has the absolute highest vibration. It’s acceleration is $a_{z,rms}$ = 174 m/s^2. The acceleration of the fastener driving tools is between $a_{z,rms}$ = 10 m/s^2 and $a_{z,rms}$ = 69 m/s^2.

The vector sum of all directions shows that the acceleration of the nailer and pinner for the fast working cycle is two times higher than for the slow cycle and the factor between 5 cm nails and 9 cm nails is 1.4 to 1.

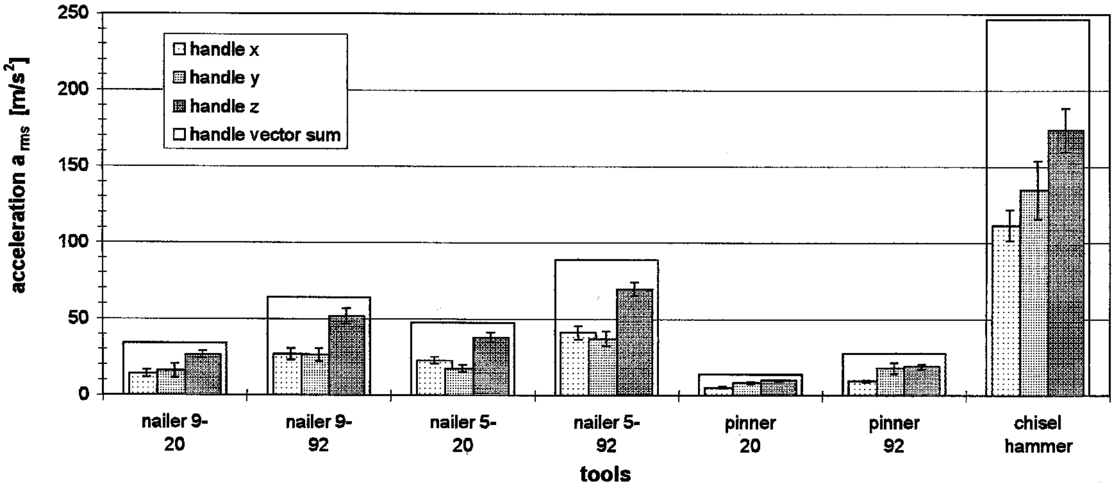

Figure 2. Acceleration a_{rms} measured on the handle of the tools.

The highest peak acceleration was measured at the nailer. The unweighted crest factor can now be determined:

Table 2. Un-weighted crest factor.

direction	nailer 5-20	nailer 5-92	nailer 9-20	nailer 9-92	pinner 20	pinner 92	chisel hammer
x	44.8	28.1	45.7	33.3	51.2	34.3	5.1
y	50.5	24.5	43.5	32.7	51.0	27.8	4.7
z	40.6	22.8	44.2	25.9	55.5	33.8	5.6

The grip force of the nailer is between 59 N (20/min) and 76 N (92/min) and of the pinner between 15 (20/min) and 25 N (92/min) (see figure 5). The working direction is downwards, therefore, the weight of the tools has to be subtracted. Now the real grip force is 19 N and 36 N for the nailer and 5 N and 15 N for the pinner respectively (see relative grip force figure 5).

Figure 3 shows the weighted acceleration. The length of the nails has no influence on the weighted acceleration, but the relation between the fast cycle and the slow cycle is two to one again.

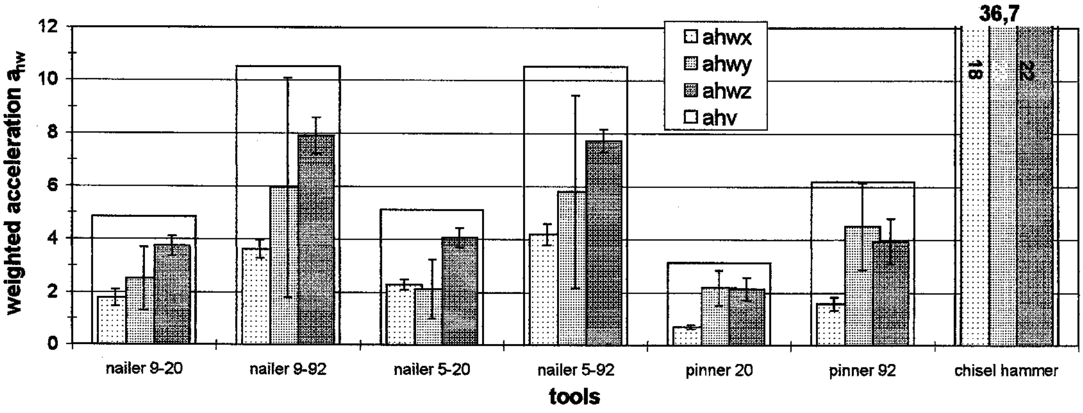

Figure. 3. Weighted acceleration a_{hw}.

Vibration strain

The handle-to-operator vibration transmissibility (z-direction) is represented in figure 4.

It was found that the transmissibility to the wrists and to the elbow for the non-impact tool is greater than for the fastener driving tools. More than 37% of the vibration energy was transmitted to the hand and about 18% was transmitted to the elbow.

Relative electrical muscle activity was created to avoid individual differences: the dynamic muscle activity EA_{dyn} was divided through the static muscle activity EA_{stat} (holding the tool). The muscle activity of the m. biceps brachii when working with the nailer is two times higher than the muscle activity when working with the chisel hammer (see figure 5).

The muscle activity of the m. flexor carpi ulnaris is nearly the same when working with the chisel hammer or with the fastener driving tools at fast cycle. Figure 5 shows the correlation between the muscle activity of the m. flexor carpi ulnaris and the grip force.

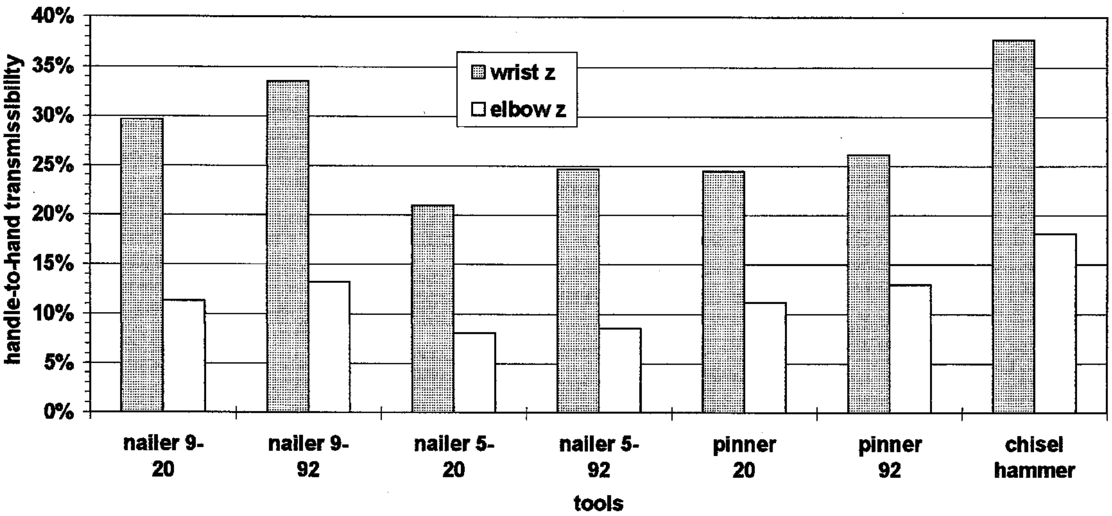

Figure 4. Transmissibility of the acceleration from the handle to the wrist and to the elbow.

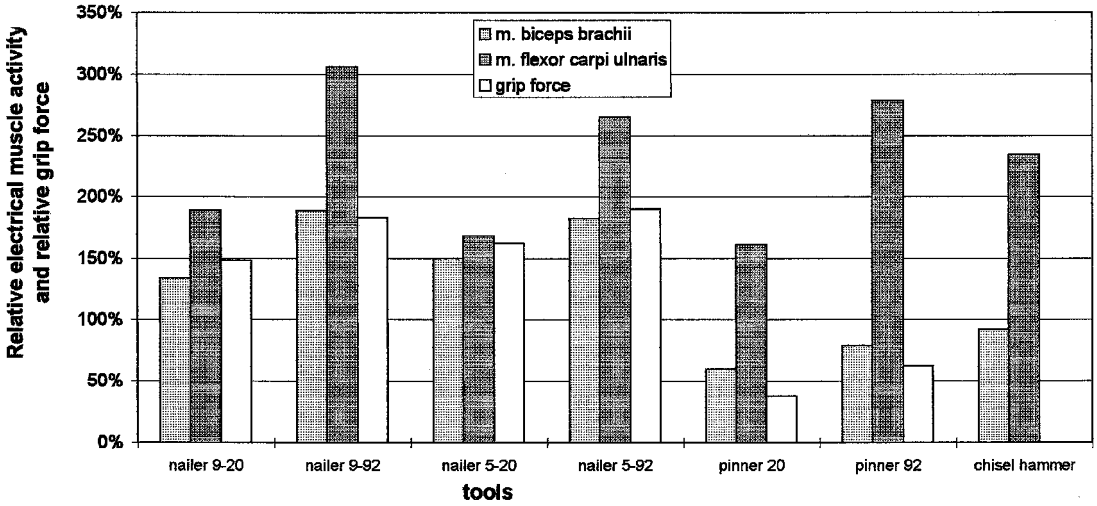

Figure 5. Relative electrical muscle activity and relative grip force under shock type vibration.

Discussion

Comparing the results of the investigation between the chisel hammer and the fastener driving tools with the varied working conditions, there are following differences:

Comparison: *Chisel hammer - fastener driving tools*

- The acceleration a_{rms}, the weighted acceleration a_{hw} and the handle-to-hand-arm system transmissibility is greater for the chisel hammer than for the fastener driving tools.
- The muscle activity of the m. biceps brachii is the greatest at the nailer because of the working conditions, rising and falling of the hand-arm system.
- The muscle activity of the m. flexor carpi ulnaris is very high for the pinner. The high muscle activity of the pinner based on the working method, using the trigger for single actuation.

Comparison: *Nailer with 5 cm nails - nailer with 9 cm nails*

- The unweighted acceleration for the small nails is higher than for the long nails. The operating pressure (7.5 bar) was probably too high when working with the small nails.
- There is nearly no influence of the length of the nails (working with the same compressed air) to the weighted acceleration and to the effects on the hand-arm system (EA, transmissibility).

Comparison: *Fastener driving tools 20 cycles - 92 cycles*

- The weighted acceleration is two times higher for the fast working cycle than for the slow cycle.
- The electrical muscle activity of m. flexor carpi ulnaris the is more than 60% higher under real conditions (92 nails per minute) than under ISO/DIS 8662-11 working conditions (20 nails per minute).

Problems with ISO/DIS 8662-11:

- The weighted acceleration in the horizontal direction (x, y) is neglected by ISO/DIS 8662-11, though the vector sum $a_{h,v}$ is 20 to 25% higher than the acceleration a_{hz} when measuring in the z-direction only. (See also Comparison: Fastener driving tools 20 cycles - 92 cycles)

Conclusion

The results of this study show that there is no significant difference of human response caused by shock type vibration from fastener driving tools and non-shock vibration.

The test procedure according to ISO/DIS 8662-11 (“Within 30 s the fastener driving tool shall be operated 10 times” = 20 cycles per minute) and the field test (92 cycles per minute) lead to nearly the same daily vibration exposure A(8) (see table 3).

Table 3. Calculation of the daily vibration exposure A(8) (ISO/NP 5349-2)

	nailer 20	nailer 92	pinner 20	pinner 92
Number of impacts per day	3000	3000	3000	3000
Measurement duration (s)	15	15	15	15
Number of impacts in the measurement period	5	23	5	23
Exposure time T (h)	2.50	0.54	2.50	0.54
a_{hv} (m/s^2)	4.96	10.52	3.13	6.18
Daily vibration exposure A(8) (m/s^2)	**2.77**	**2.74**	**1.75**	**1.61**

$$T = \frac{\text{n (nail per day)}}{\text{n (nails per measurement)}} \cdot \text{t (measurement)} \qquad A\,(8) = \text{ahv} \cdot \sqrt{\frac{T}{8}}$$

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The use of temporary threshold shifts in vibration perception as a model to assess the effectiveness of anti-vibration gloves

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Introduction

In addition to the long-term health effects of excessive exposure to vibration, commonly known as hand-arm vibration syndrome (HAVS), workers may experience immediate, short term effects in their hands and fingers. These reversible effects are experienced as numbness and tingling in the fingers. Although not proved to be associated with the development of HAVS they may interfere with manual dexterity (1). The short-term effects of vibration exposure on mechanoreceptors in the skin can be measured by a temporary increase in a subject's vibration perception threshold (VPT) immediately following the use of vibrating tools. This increase from a pre-exposure, baseline value is known as a temporary threshold shift in vibration perception (TTS_v) (2). By measuring the TTS_v in the fingertips it may be possible to assess if control measures such as anti-vibration gloves reduce the acute effects of vibration exposure. This purpose of this field study was to measure the TTS, in workers using hand-held rotary, vibrating tools in order to study the potential of one type of anti-vibration glove to ameliorate the TTS_v.

Methods

The study population consisted of 23 employees from four different UK factories, all of whom worked with vibrating hand-held tools for up to 7 hours per day. None had a history of HAVS. The tools used included hand-held rotary grinders (4 inch, 7 inch and pencil), polishers and pedestal grinders. Each employee was tested before commencing work, and a subsequent four times during the working day immediately after they had stopped using vibrating tools from Monday to Thursday of a working week. This regime gave a maximum of 4 pre-exposure and 16 post-exposure results per employee for each week studied. Workers were tested during the first week when not wearing anti-vibration gloves followed by a second week when a standard anti-vibration glove was worn. The work patterns did not vary from week I to week 2 in each factory. The VPT for each employee was tested using the HVLab Tactile Vibrometer (ISVR, Southampton, UK). The index finger of both hands was tested at 31.5Hz and 125Hz.

Results

In order to investigate whether a measurable TTS_v was present after using vibrating tools all results from each employee were standardised to their mean pre-exposure baseline value of I which allows comparison of all employees as one group both before and after vibration exposure. A significant TTS_v was measured in both hands at both 31.5Hz and 125Hz testing frequencies which increased the measured VPT by a

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minimum of 27.1% (right hand, 31.5Hz test frequency, p<0,0001) to a maximum of 82% (left hand, 125Hz test frequency, p<0,0001) from the pre-exposure baseline values. When the anti-vibration glove was worn the increase in VPT was reduced to 4.9% (right hand, 31.5Hz test frequency, p=0.0005) and 21.7% (left hand, 125Hz test frequency, p<0.0001) although it was still significantly raised.

To directly compare the effects with and without the anti-vibration glove only the 16 employees who had completed both weeks of the study were considered. The results are shown in Table 1.

Table 1. Amelioration of the temporary threshold shift by wearing anti-vibration gloves. Data were log-transformed before statistical analysis.

	- gloves mean (sd) n			+ gloves mean (sd) n			One-tailed p-value
Right hand 31.5Hz	1.315	(0.694)	n=191	1.149	(0.419)	n=180	0.07
Left hand 31.5Hz	1.526	(1.065)	n=190	1.206	(0.631)	n=180	0.0001
Right hand 125Hz	1.558	(1.067)	n=187	1.318	(0.782)	n=180	0.0316
Left hand 125Hz	1.788	(1.373)	n=192	1.217	(0.515)	n=181	<0.0001

It is apparent that wearing the anti-vibration glove does significantly reduce the magnitude of the TTSv in both hands at 125Hz and at 31.5Hz in the left hand. However wearing the gloves does not remove the TTSv completely. A significant increase in VPT from pre-exposure baseline values is still present.

Discussion

A reversible effect known as the TTSv is measurable using vibration perception testing immediately following vibration exposure from hand-held tools. This short-term effect has been described previously in volunteer studies (1,2,3). To our knowledge there are few studies which have measured the TTSv in a workforce during a normal working week and used the TTSv as an indicator of the efficiency of anti-vibration gloves to reduce the amount of vibrational energy being transmitted to the hands and fingers. The results presented in this study indicate that a temporary upwards shift in VPT does occur immediately following exposure to vibration from hand-held rotary, vibrating tools. This shift is ameliorated but not eliminated by wearing the anti-vibration glove indicating that the vibrational energy transmitted to the hands by the tools is being attenuated by the gloves. However this does not imply that the gloves will protect against HAVs in the long-term.

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Warm and cold thermal sensation thresholds in vibration syndrome patients compared with healthy controls

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Introduction

Numbness and paresthesia of the hand or finger are frequently encountered in hand-arm vibration exposed workers. These neurological symptoms often accompany damaged skin sensory perception, reduced grip force, muscle weakness and occasionally impaired manipulative dexterity. Early and exact detection of such neuropathy induced by hand-arm vibration is necessary to protect workers from vibration hazard. In the past some somatophysiological examinations were adopted for the purpose of diagnosing the vibration induced neuropathy. Measurement of vibration perception threshold and nerve conduction velocity had been recommended and generally used for that purpose (1, 2). Previously, disturbed thermal sensation in vibration-exposed workers were reported by some papers (3, 4). Recently, warm and cold thermal sensation thresholds became to be noteworthy for detection of vibration induced neuropathy.

In the present study we measured warm and cold thermal sensation thresholds of vibration syndrome patients with vibration-induced white fingers, and studied the usefulness for assessing nervous impairments among vibration-exposed subjects.

Subjects and Methods

The subjects were 25 vibration syndrome male patients under medical treatment (mean treatment period; 3.2 yrs.±2.7 yrs.). and 10 healthy male controls. The age of these two groups was from 50 to 65 years so there were no significant difference in age between the groups. To exclude the effect of neurological diseases, those with diabetes mellitus, alcohol abuse over 80 gr/day, collagenouse diseases or another diseases which might affect to peripheral nervous system were excluded from the present subjects.

Measurement of warm thermal sensation threshold (WST) and cold thermal sensation threshold (CST) on the top of the middle finger of both hands was performed by using a thermo-esthesiometer (made by Hokushin Seiki Kogyo, Japan). In the measurement, the temperature to start with was set to the skin temperature of each subject, which was measured beforehand, and then it was autonomically increased or decreased at a rate of 0.2°C/s to the point of feeling warm or cold. The measurements were performed twice, and the data closer to the skin temperature (ST) was adopted as the subject's threshold. Furthermore, vibration perception thresholds (VPT, 125Hz) and pain sensation thresholds (PST, needle method) were also measured on the same middle finger of both hands. These measurements were carried out under a controlled room temperature of 27±1°C to keep fingers warm. When the skin temperature of the subjects was lower than 30°C their hands were warmed by a heater to above 30°C and then measurements were performed.

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Results

The results are shown in Table 1. The skin temperature of these two groups was not different, but both warm and cold thermal sensation thresholds were significantly impaired in vibration syndrome patients compared with controls (P<0.001). The neutral zone (NZ= difference between warm and cold sensation thresholds), difference between warm threshold and skin temperature, difference between cold threshold and skin temperature were also significantly wider in the patients group than the controls, respectively (p<0.001). The impaired thermal sensation thresholds and expanded neutral zone tended to be more obvious among patients with numbness or paresthesia than those without. The abnormal expression of warm thermal sensation thresholds tended to be obvious compared with cold thermal sensation thresholds in the patients without numbness or paresthesia.

Table 1. Thermal thresholds of vibration syndrome patients and controls (mean ± SD). WST=warm sensation threshold, CST=cold sensation threshold, NZ=neutal zone, ST=skin temperature, VPT=vibration perception threshold, PST=pain sensation threshold.

	Controls N=10	V-S patient N=25	Numbness(-) N=4	Numbness(+) N=21
Age	58.3±4.2	60.0±3.4	60.8±2.9	59.5±3.6
(R)				
ST(°C)	32.2±1.1	33.0±1.3	33.6±1.5	32.1±1.2
WST(°C)	36.1±2.5	44.7±3.5**	43.7±3.5**	44.8±3.6**
CST(°C)	27.2±4.0	18.2±7.2**	22.7±7.2	17.4±7.0**
NZ(°C)	3.8±2.4	11.6±3.2**	10.1±3.7*	11.9±3.1**
WST-ST(°C)	5.2±4.1	14.8±7.2**	10.9±6.5	15.5±7.2**
CST-ST(°C)	8.9±5.4	26.4±9.6**	21.0±10.1*	27.5±9.4**
VPT(dB)	3.8±4.3	23.5±8.4**	18.1±3.8**	24.5±8.8**
PST(above 5g)	3(30%)	20(80%)	2(50%)	18(86%)
(L)				
ST(°C)	32.6±0.9	33.0±1.3	33.4±1.1	31.6±1.7
WST(°C)	35.9±l.9	44.9±3.6**	44.5±3.2**	44.9±3.8**
CST(°C)	28.6±3.3	18.3±7.2**	21.2±5.5*	17.7±7.5**
NZ(°C)	3.3±1.7	11.8±3.3**	11.1±3.2**	12.0±3.3**
WST-ST(°C)	4.1±3.3	14.8±7.7**	12.2±5.4*	15.3±8.0**
CST-ST(°C)	7.3±3.6	26.6±10.3**	23.3±8.5**	27.2±10.7**
YPT(dB)	3.0±3.7	24.0±8.3**	20.6±5.2**	24.6±8.8**
PST(above 5g)	3(30%)	19(76%)	2(50%)	17(81%)

* p<0.01, ** p<0.001 (t-test)

On the other hand, the vibration perception threshold of the patients group showed significant impairment compared to thermal thresholds (p<0.001), but the pain sensation threshold was not thought to be so sensitive.

Discussion

In the peripheral neuropathy due to hand-arm vibration, numbness or paresthesia appears at an early stage on the hand or finger of vibration-exposed workers, thereafter accompanied with reduced sensory perception, reduced grip force, muscle weakness and manual dexterity. These neurological symptoms become serious handicaps in working and also increase the risk of accidents. Moreover, these become a discomfort in daily life for workers.

Therefore, early and exact detection of neuropathy induced by hand-arm vibration is important for the purpose of protective procedures from vibration hazard to vibration-exposed workers.

The peripheral nerve contains nerve fibers of various size. Decreased sensory nerve conduction and dullness of vibration perception imply the impairment of vibro-tactile receptors and/or myelinated A-beta fibers with a diameter of 1015 micron, and impaired thermal sensitivity suggests damage to thermo-receptors and/or thin myelinated A delta fibers and unmyelinated C fibers with a diameter of 2-5 micron and 0.4-1.2 micron, respectively (5). Furthermore, it is not yet decided that cold receptors are connected to small myelinated A-delta fibers and warm receptors connected to slow conducting unmyelinated fibers (4).

In vibration-induced neuropathy, myelinated and unmyelinated nerve fibers are both damaged (4). Measurement of vibration perception threshold is useful for assessing sensory nerve damage induced by vibration (6, 7, 8). On the other hand, thermal sensation has been found to be impaired such as vibration perception in a few previous studies of vibration-exposed workers (3, 4). Virokannas et al. measured thermal sensation thresholds of lumberjacks and summarised that measurement of the temperature sense was useful in the prevention of nerve damage and, furthermore, it might be more sensitive to vibration than vibration perception (9).

In the present study we measured warm and cold thermal sensation thresholds of hand-arm vibration syndrome patients (all of them within VWF 1~3 in the Stockholm Workshop Scale), and compared to healthy controls. Additionally, vibration perception threshold and pain sensation threshold was measured for these subjects. In this study warm thermal sensation thresholds of the VWF positive patient group were significantly higher than the control group, and cold thermal sensation thresholds of the patient group were likewise significantly lower, and the neutral zone was significantly wide than that of healthy controls as well. Still more warm and cold thermal sensation thresholds in the patients with numbness or paresthesia were respectively more significant than without them, and warm thermal sensation thresholds tend to be more obvious than cold thermal sensation threshold in the patients without numbness or paresthesia.

Jamal et al. showed stronger decline in warm sensation with age (10). Although Helman et al. showed that the rate of decline was same for cold and warm sensation with age (11).

Virokannas et al. reported that the lumberjacks had lower cold thresholds, but had no differences for warm sensation thresholds than the controls (9). However, our study showed that the thermal sensation was seriously disturbed in the vibration syndrome patients not only in the cold thermal sensation threshold but in warm thermal sensation threshold too. On the contrary, the warm sensation seemed to be more impaired rather than the cold sensation in the patients without numbness or paresthesia. This difference may be due to the subjects researched.

Further study is necessary to clarify the interrelation of quantity of vibration exposure with thermal thresholds (dose-response relationship), and the relation of ageing to those in the same way, for the aim of practical use in assessing vibration induced neuropathy.

Conclusion

We measured warm and cold thermal sensation thresholds of vibration syndrome patients with vibration-induced white fingers using a thermo-esthesiometer. Warm thermal sensation thresholds and cold thermal sensation thresholds of vibration syndrome patients were both impaired significantly compared with healthy controls. Furthermore, the neutral zone, differences between skin temperature and warm or cold thermal sensation thresholds in the vibration syndrome patients were wider than the controls. The results showed that the measurements of warm and cold thermal sensation thresholds might be useful and for assessing vibration-induced neuropathy.

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Evaluation of threshold of vibratory sensation by cold provocation test for diagnosis of vibration syndrome

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Introduction

A cold provocation test using the 5°C 10 minutes method is included in the secondary medical examination of special medical examinations on vibration syndrome in Japan. Its standard procedures are prescribed in the notifications of Japanese Ministry of Labour (1) and other documents (2, 3). However, a cold provocation test using the 10°C 10 minutes method has been adopted to decrease pain and discomfort of patients from the 5°C 10 minutes method. Some evaluation standards have been used for the 5°C 10 minutes method (4) and for the 10°C 10 minutes method (5, 6). These evaluation standards are based on the findings from chain saw workers exposed to long-term, high level vibration in the 1970's. Now that more than 20 years have passed since they were established, vibration acceleration levels of vibrating tools decreased. As peripheral circulatory and sensory function in response to long-term exposure to lower hand-arm vibration is less disturbed, it might be inadequate to use the evaluation standards established in the 1970's. A new standard should be evaluated for the preventive diagnosis of vibration syndrome.

With respect to the point, we have already evaluated finger skin temperature by a cold provocation test (10°C 10 minutes method) for the diagnosis of vibration induced white finger (7). In this report, we evaluated threshold of vibratory sensation for the diagnosis of vibration syndrome on the basis of clinical data obtained from workers operating vibrating tools during the last 10 years.

Subjects and Methods

Subjects

The subjects were male chain saw workers who took special medical examinations on vibration syndrome between 1986 and 1995 and public service workers in Wakayama Prefecture who took special medical examinations on vibration syndrome in 1996. The special medical examinations on vibration syndrome in Wakayama Prefecture were enforced in the winter season (December - February).

The subjects were limited to those in the 40-69 year age group in this report. The subjects were classified into 3 groups. If a subject had numbness on either hand, he was assigned to the Numbness (N) group. A subject who had no symptoms on both hands, was assigned to the No-Symptoms (NS) group. A subject who did not operate any vibrating tools among the public service workers, was assigned to the Control (C) group. As a result, the number of subjects was 462 in N group, 217 subjects in NS group and 40 subjects in C group. Table 1 shows the age distribution of the subjects in each group. The mean age of the subjects was 58.9 years old in N group, 56.4 years old in NS group and 53.1 years old in C group. There was no significant difference among these mean

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ages. The mean operating careers of a chain saw were 18.5 years in N group and 15.9 years in NS group.

To identify numbness on the hand, a physician questioned a subject in detail about the site and the frequency. Numbness results from both circulatory dysfunction and neurological disorders. In this report, both types of numbness were included. Subjects who were identified as having numbness on the hand were assigned to N group.

Cold provocation test using 10°C 10 minutes method

The primary medical examination and the secondary medical examination were made on the basis of the notifications of Japanese Ministry of Labour (3). The cold water temperature was 10°C. The room temperature was set at 20-24°C. The threshold of vibratory sensation for 125 Hz at the palmar distal phalanx of the 2nd finger was measured using a vibration sensation meter (Rion, AU-02) at 4 points of the cold provocation test; before, immediately after, 5 minutes after and 10 minutes after a cold provocation test.

Statistical analyses

T-test was used to analyse the difference between each group.

The screening points for screening N group from the combined group of NS and C groups were obtained from receiver operating characteristic (ROC) curves, which show the accuracy of screening (8). A point of the left top on the ROC curve, the so called cut off point, gives the lowest false positive rate and the highest sensitivity. The point was used as a screening point in this report.

Table 1. Age distribution of the subjects in each group.

Age group (yrs)	N group	NS group	C group
40-49	43	48	16
50-59	170	81	12
60-69	249	88	12
Total	462	217	40

Results

The mean values of threshold of vibratory sensation before and after cold provocation are shown in Table 2. The mean values in N group were significantly higher than those in NS and C group. Those in NS group were also significantly higher than that in C group.

The ROC curve was drawn so that a screening point of threshold of vibratory sensation may be obtained for screening N group from other groups. Figure 1 shows the ROC curve from the threshold of vibratory sensation at 5 minutes after a cold provocation for screening N group from other groups. The screening point was 22.5 dB. The screening points of the threshold of vibratory sensation before and after a cold provocation are shown in Table 3.

The thresholds of vibratory sensation by fraction of NS group before and after a cold provocation are also shown in Table 3. The thresholds of vibratory sensation in NS group were computed to establish evaluation of standard values, because NS group had a history of exposure to vibration as long as N group and no symptoms. The screening points before and after a cold provocation were approximately between the 50th percentiles and 75th percentiles in NS group.

Table 2. Mean values of threshold of vibratory sensation in each group before and after a cold provocation.

Threshold of vibratory sensation (dB)	N group	NS group	C group
Before	12.9*◊	6.5*	-0.2
Immediately after	29.5*◊	23.4*	17.8
5 minutes after	25.3*◊	17.5*	9.4
10 minutes after	22.3*◊	14.4*	5.5

*Significant difference compared with C group $p<0.01$

◊Significant difference compared with NS group $p<0.01$

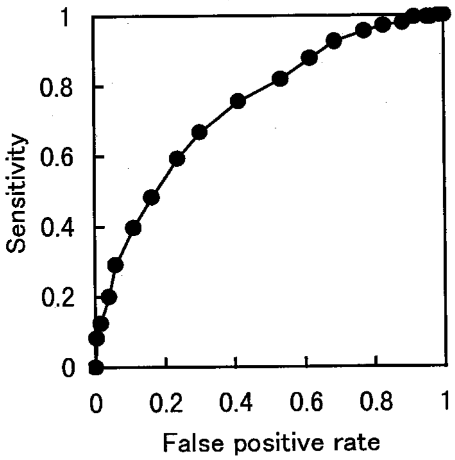

Figure 1. ROC curve from threshold of vibratory sensation at 5 minutes after a cold provocation.

Table 3. Thresholds of vibratory sensation by fraction of NS group and screening points.

Threshold of vibratory sensation (dB)	L10	L25	L50	L75	L90	Screening point
Before	-2.5	2.5	5.0	12.5	15.0	7.5
Immediately after	12.5	17.5	25.0	27.5	35.0	30.0
5 minutes after	5.0	10.0	17.5	25.0	30.0	22.5
10 minutes after	0.0	7.5	15.0	21.5	27.5	20.0

A new evaluation standard shown in Table 4 was established by judging the screening points, threshold of vibratory sensations by fraction in NS group and various evaluation standards. The Evaluation Standard Value I comes from the 50th percentiles, the Evaluation Standard Value II from the screening points and the Evaluation Standard Value III from the 90th percentiles. Here, A zone, B zone, C zone and D zone correspond to -, +, ++ and +++ or 0, 1, 2 and 3 of the conventional evaluation standards.

Table 4. New evaluation standard of threshold of vibratory sensation.

Threshold of vibratory sensation (dB)	A zone	I	B zone	II	C zone	III	D zone
Before		5.0		7.5		15.0	
Immediately after		25.0		27.5		35.0	
5 minutes after		17.5		22.5		30.0	
10 minutes after		15.0		20.0		27.5	

Discussion

There are various evaluation standards for a cold provocation test using the 5°C 10 minute method (4-6) and the 10°C 10 minutes method (5, 6, 9-17). These evaluation standards were established more than 15 years ago. Their backgrounds are not entirely clear (7). The new evaluation standards are based on the data in these 10 years, when the vibration acceleration level has been improved to the level below the allowance level and the statistical methods. The screening points for screening workers who have numbness on the hand were obtained from the ROC curves, which show the accuracy of screening. These screening points appropriately screen workers who have symptoms.

In this study, thresholds of vibratory sensation by fraction in NS group were selected to establish the new evaluation standard. Kaneda et al. (12) calculated rejection limit values at unilateral 2.5%, 5% and 10% levels of chain saw workers who had no symptoms. Saito (14) showed the mean values, standard deviations, medians and 95% confidence limit values of chain saw workers who had no symptoms. They used different statistical methods, but they also focused attention on the chain saw workers who had no symptoms, namely NS group. The threshold of vibratory sensation in NS group should also be taken into account to establish evaluation standard values, as well as the screening points, because NS group had as long a history of exposure to vibration as N group.

The screening points for screening N group from other groups were compared with the inter-quartile range in NS. Those on the threshold of vibratory sensation before and after a cold provocation were approximately between the 50th percentiles and 75th percentiles in NS group.

Kaneda et al. (12) analysed the threshold of vibratory sensation of forestry workers under 50 years old who had little or no experience of working with chain saws and no symptoms, and reported the rejection limit values at unilateral 2.5%, 5% and 10% levels. These values can not be directly compared with our results. Seventy-fifth percentiles in NS group in this report, however, approximated to the rejection limit values at the 10% level. Since the NS group in this report consisted of workers who had a chain saw for 15 years in average, the thresholds of vibratory sensation by fraction in NS group might be higher than those of Kaneda et al.

Saito (14) examined the threshold of vibratory sensation of 274 chain saw workers who showed no abnormality and reported the mean values, standard deviations, medians and 95% confidence limit values at intervals of 10 years of age from 20 to 69 years. His medians and 95% confidence limit values were higher than those in NS group in this report.

When compared with the evaluation standard of Iwata et al. (4), the 50th percentiles in NS group were lower than their evaluation standard. Their evaluation standard was established in 1978. To examine the accuracy of screening by the new evaluation standard, the threshold of vibratory sensation was measured using subjects other than those used for establishing the new evaluation standard. Thresholds of vibratory sensation of 69 forestry workers who had numbness on the hand among workers operating vibrating tools were plotted (Figure 2) and evaluated by the new evaluation standard. The Evaluation Standard Value I resulted in 16 (23.2%) false negatives before a cold provocation, 28 (40.6%) at immediately after, 20 (29.0%) at 5 minutes after a cold provocation and 18 (26.1%) at 10 minutes after a cold provocation. The false negative rates that those who have numbness on the hand are judged as normal are lower by the new evaluation standard than by the evaluation standard of Iwata et al. (6) The conventional evaluation standards are severe for workers who operate vibrating tools under present working conditions. They are suitable for detecting workers who have numbness on the hand, but lead to high false negative rates. It is, however, important not to overlook the workers who had a symptom, to decrease the false negative rate, in the preventive medical examination for the purpose of the health care of workers operating vibrating tools under present working conditions. The new evaluation standard in this report, which shows the higher accuracy of screening, will be useful.

The equipment for measuring thresholds of vibratory sensation are compared between ISO/CD 13091 equipment and the Japanese one in Table 5 (18). The measurement method and conditions typically adopted in Japan were different from those outlined in the ISO draft. Japanese equipment is not prescribed in some points that the ISO draft prescribes. The reference intensity of the vibrotactile threshold report in Japanese equipment is 10 times larger than that in the ISO draft. Consequently, to discuss internationally the new evaluation standard, the measurement equipment conditions must be considered.

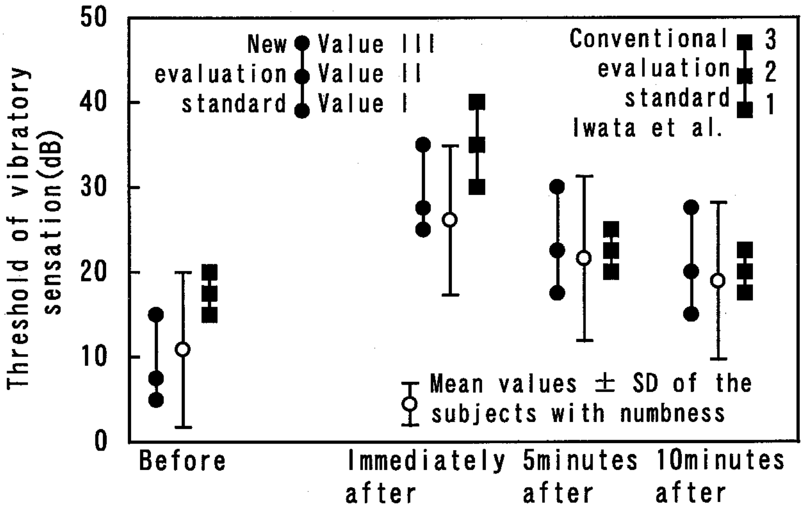

Figure 2. Distribution of threshold of vibratory sensation of those who had numbness on the hand.

Table 5. Comparison between ISO draft equipment and Japanese equipment (from 18).

Contents	ISO/CD 13091	Japanese equipment
Mechanoreceptor	SA I, FA I, FA II	FA II
Frequency (Hz)	4.0, 25, 125 Hz	63, 125, 250 Hz
Measurement method	Automatic	Manual
Stimulation	Intermittent (3.1~160 Hz)	Intermittent and continuous
Support	full length of forearm, hand and finger, seat with back rest	none
Skin temperature	26~36°C	none
Room temperature	20~30°C	none
Contact area	4.0±2.0 mm diameter	15 mm diameter
Contact force	0.1±0.05 N	none
Surround type A	probe-skin contact force, controlled directly	-
Surround type B push force	1.5±0.5 mm probe-surround gap, <0.5 N surround-fingertip force	-
Measurement algorithm	up-down method	method of adjustment
Calibration	Mandatory	-
Safety	the requirement IEC 601-1	-
Vibrotactile thresholds report	ms^{-2}r.m.s. or dB (re:$10^{-6}ms^{-2}$)	DB (re:$10^{-5}ms^{-2}$)

Conclusion

Clinical data of workers (40-69 years) operating chain saws for a ten year period from 1986 to 1995 were analysed to assess the evaluation standard of threshold of vibratory sensation for a cold provocation test (10°C 10 minutes). Screening points of threshold of vibratory sensation for screening 462 workers with numbness on the hand were obtained from receiver operating characteristic (ROC) curves. The screening points before and after a cold provocation were approximately between 50th percentiles and 75th percentiles of 217 workers with no symptoms (NS group). A new evaluation standard was prepared in reference to these screening points and threshold of vibratory sensation by fraction in NS group. The new one will be useful for the preventive diagnosis of vibration syndrome in workers operating vibrating tools of which vibration acceleration levels are below the allowance level.

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Occupational diseases due to hand-arm vibration in the Czech Republic in the year 1997

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Introduction

The total number of occupational diseases reported yearly in the Czech Republic is slowly decreasing (3,729 cases in 1988; 2,376 cases ten years later, in 1997). That chiefly applies to intoxication and infections (1, 2), whereas occupational diseases due to physical factors, especially to hand-arm vibration (HAV) are the only category with increasing numbers of reported cases. Actually, the latter diseases rank among the most frequent occupational diseases in the Czech Republic.

The purpose of the study was to analyse cases of occupational diseases due to HAV diagnosed in the year 1997.

Methods

The study was based on data from the Czech Central Registry of Occupational Diseases at the National Institute of Public Health in Prague, to which all cases of an occupational disease diagnosed in the Czech republic are reported. We have analysed each case of an occupational disease due to HAV diagnosed in the year 1997 with respect to sex, age, occupation, duration of exposure, and clinical diagnoses.

Results

In the year 1997 a total of 2,376 cases of occupational diseases were reported in the Czech Republic. Of them, 459 cases (19.3 %) were due to HAV. That corresponds to an incidence of approximately 10 cases per 100,000 employees. The situation in the previous ten years was similar.

Table 1. Occupational diseases due to HAV reported in the Czech Republic in the years 1988 - 1997.

Year	Total number of occupational diseases	Occupational Diseases due to HAV	
		Total number of cases	Proportion (%)
1988	5596	493	8.81
1989	5767	629	10.91
1990	11673	1410	12.08
1991	8680	1488	17.14
1992	3484	734	21.07
1993	3062	658	21.49
1994	2707	506	18.69
1995	2921	509	17.43
1996	2543	503	19.78
1997	2376	459	19.32

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Note: The striking increase both of all occupational diseases and of diseases due to HAV in the years 1990 and 1991 was due to a transient change in diagnostic criteria for some occupational diseases in the early period after the Czech “velvet revolution” in 1989. In consequence of the softening of the diagnostic criteria (enforced by trade unions), patients with mild or incipient health impairments were reported as having occupational diseases in some cases.

Table 2. Cases of occupational diseases due to HAV in 1997, by sex, age and duration of exposure.

	N	Age (years)	Duration of exposure (years)
Males	440	19-66, 46 ± 8	0.1-44, 19.4 ± 9.4
Females	19	23-54, 44 ± 8	0.1-37, 16.4 ± 10.5
Total	459	19-69, 46 ± 8	0.1-44, 19.2 ± 9.5

Table 3. Industry categories with the highest frequency of occupational diseases due to HAV in 1997

Industry category	Males	Females	Total
Mining	190	0	190
Metal industry	161	11	172
Forestry	32	1	33
Car industry	27	2	29
Construction	14	2	16
Other	16	3	19

Table 4. Occupations with the highest frequency of occupational diseases due to HAV in 1997.

Occupation	Males	Females	Total
Miners	178	0	178
Metalworkers	60	0	60
Smelters	54	0	54
Sawing machine operators	33	0	33
Bricklayers	32	0	32
Assembly workers	17	6	23
Cutters	13	8	21
Welders	16	0	16
Construction workers	14	0	14
Other	23	5	28

Table 5. Occupational diseases due to HAV in 1997, by the affected systems.

	Vascular lesions (VWF)	Nerve lesions lesions	Bone or joint	Total
VWF	60	11	2	73
Nerve lesions	11	302	14	327
Bone or joint lesions	2	14	70	86

Discussion and conclusions

19.3% of injuries due to HAV represented the most numerous category of all occupational diseases diagnosed in the Czech Republic in the year 1997 and in the previous ten years (Table 1). The proportion of females was only 4%. This corresponds to the fact that occupations with risk of HAV are performed mostly by males. The females with an occupational disease due to HAV were on the average 2 years younger than males, and the average duration of exposure in females was 3 years shorter than in males (Table 2). Although the differences did not reach statistical significance, they are biologically plausible given the supposed higher susceptibility of females to HAV. Most cases of occupational diseases due to HAV were diagnosed in miners (39%), and in workers in the metal industry (13%). In forestry, it was 7% (Tables 3 and 4).

Peripheral nerves of the upper extremities were the most frequently damaged system (in 71% of patients). Lesions of peripheral nerves were reported as an isolated finding in 66% of patients. Carpal tunnel syndrome was the most frequent diagnosis (3). Surprisingly, vibration white finger (VWF) was reported in only 16% of cases (in 13% of patients as a single diagnosis and in 3% of patients in combination with a lesion of another system). However, we must take into account a significant selection bias. The diagnostic criteria for VWF are relatively rigorous in the Czech Republic.

At least four white phalanges are required for reporting an occupational disease. Therefore the number of VWF cases is probably under reported.

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