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Diagnosis of injuries caused by hand-transmitted vibration – 2nd International workshop

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Abstracts

Göteborg, 6-7 September 2006

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Preface

This report contains the extended abstracts to the 2nd International workshop – Diagnosis of injuries caused by hand-transmitted vibration in Göteborg, Sweden, 6-7 September, 2006. The excellent work performed by the contributing scientists has made this book a first-class, up-to-date, state of the art review on what is known about diagnosis of injuries caused by hand-transmitted vibration today.

Financial support to the workshop and thereby to the publishing of this book was made possible by contributions from the VIBRISKS project and The National Institute for Working Life, Sweden.

We want to express our gratitude to the contributing authors, session chairmen and to the participants who presented papers and contributed in the discussions, for making the 2nd International Workshop an outstanding meeting.

Göteborg in September 2006

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Neurological disorders related to hand-arm-vibration: Etiology, pathophysiology and diagnosis

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Introduction

Long-term use of hand-held vibrating tools may result in severe disturbances in hand function characterised by sensory dysfunction, vasospastic problems, muscular weakness, impaired dexterity, cramps and pain [2]. Cold intolerance, without blanching of the fingers, may be an early and embarrassing problem. Vibration-induced hand problems are most frequently seen among young males, and the socio-economic consequences for the individual and society may be very substantial. The sensory problems may seriously jeopardise hand function and are often regarded as the most prominent symptoms. Still, the etiology of these problems is not clear and the possibilities for early diagnosis are limited. Besides, there are so far no effective treatment available for vibration-induced neuropathy of the hand.

Objectives

The objective is to study the effects of vibration not only on the peripheral nervous system, but also on the central nervous system with special reference to the functional organisation of brain cortex. Additional objectives are to develop new strategies for treatment based on recent knowledge regarding rapid and long-term plasticity of brain cortex and to define clinical tests for early detection of vibration-induced neuropathy of the hand.

Methods

Functional reorganisations in brain cortex is studied using fMRI technique. Early signs of sensory dysfunction are analysed by the use of various tests for fine sensory function of the hand including tactile discrimination and pressure perception as well as dexterity and fine motor function of the hand. Special attention is paid to the use and importance of multi-frequency vibrometry by use of a newly developed VibroSense Meter analysing vibration thresholds within 7 frequencies varying from 8 to 500 Hz.

Functional reorganisation of brain cortex

The various body parts are represented in sensory and motor brain cortex to various extents. The hand is represented within a very large area in sensory and motor cortex reflecting the specific and refined sensory- motor functions of the hand. This “cortical hand map” is not static, but experience-dependent and may rapidly change depending on changes in the sensory input [3, 4]. Normally, the cortical hand map is well organised with finger representations well separated from each other as a result of variations in sensory input associated with normal hand use. However, with monotonous, repetitive use of the hand, especially when multiple locations in the hand are stimulated synchronously, the cortical hand map may become distorted with “fusions” between individual finger representations [5]. Such a functional reorganisation of the cortical hand map, induced by vibration, may hypothetically cause disturbances also in motor function with consequent dexterity problems and impaired fine motor functions.

Diagnostic tests

From hand surgical and neurological experience it is well known that some tests on hand function respond early to sensory dysfunction, while others remain normal until a late stage. In a large number of vibration-exposed workers presenting vibration-induced hand problems the relevance and responsiveness of several tests were analysed, and a hierarchy of various useful test principles could be defined. For instance, while tests on pressure perception (Semmes-Weinstein's monofilament) responded very early, tests on tactile discrimination, such as two-point discrimination test, showed pathology first at a late stage of vibration-induced neuropathy. Test of vibration thresholds within multiple frequencies was found especially useful and showed pathology at a very early stage of sensory dysfunction. A common finding was that normal vibration thresholds within commonly tested frequencies, such as 125 Hz, often were associated with obvious pathology within other frequencies.

Treatment and rehabilitation

Vibration-induced neuropathy can sometimes be associated with carpal tunnel syndrome, and the condition can in such instances be cured by median nerve decompression. However, in the majority of cases the pathology resides at other levels, from the mechanoreceptors in the finger tips to brain cortex. We are currently focusing on the cortical reorganisation induced by vibration exposure and possibilities to normalise the cortical hand map using specific training programs in the rehabilitation phase. We have initiated a rehabilitation program based on selective de-afferentiation of the forearm of the affected extremity. Cutaneous anaesthesia of the forearm by use of anaesthetising EMLA crème will leave a corresponding silent area in sensory brain cortex, allowing the adjacent hand representation to expand, allowing refinement of its sensory functions [1]. Repeated cutaneous anaesthesia with EMLA crème will transform these periods of rapid plasticity into a more long-lasting effect, resulting in improved fine sensory functions of the hand. Preliminary clinical trials where these strategies has been applied to arms, subjected to long-term high frequency vibration, have shown encouraging results.

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Acute effects of vibration on thermal perception threshold

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Introduction

Studies of vibration-exposed workers have shown that the prevalence of peripheral sensorineural disorders varies from a few percent to more than 80% [1,2]. Recognition the importance of sensory neuropathy has entailed an increasing interest in quantitative sensory testing for screening and diagnosis of vibration induced neuropathy. One possible target structure that could be affected by vibration exposure are the smallest nerve fibres, which conduct thermal stimuli [3]. Studies have also shown that hand intensive work including exposure to vibration is associated with an increased risk of developing impaired thermal perception [4]. The most commonly used method for determining the influence of vibration, is measuring of the thresholds for cold and warmth.

Objectives

The present study focuses on the acute effects of vibration on measures of the thermal perception thresholds during different vibration magnitudes, frequencies and durations.

Methods

Ten healthy subjects, five male and five female, participated in this laboratory study. The subjects were exposed to vibration under 16 conditions with a combination of different frequency, intensity and exposure time. The vibration was produced in a vertical direction at a frequency of 31.5 Hz and 125 Hz and had a duration between 2 and 16 min. The frequency - weighted vibration intensity ranged from 2.50 to 14.14 m/s^2 corresponding to an unweighted acceleration magnitude between 4.82 and 111.36 m/s^2. The calculated energy-equivalent frequency weighted acceleration magnitude for the whole experimental time was either 2.5 m/s^2 or 5.0 m/s^2.

A measure of the thermal perception of cold and warmth was conducted before the different exposures to vibration. After completed pre-test the subjects were instructed to place their fingers on a horizontal wooden platform mounted on a vibrator. The subjects were instructed to apply a downward force of 10 N during the entire exposure time. Immediately after the vibration the acute effect was measured continuously on the exposed index finger for the first 75 seconds, followed by 30 seconds of measures at every minute up to ten minutes. If the subject's thermal thresholds had not recovered the measures continued up to 30 min with measurements for each 5 min.

Results

The total mean perception thresholds at the index finger calculated for the whole study groups for the pre-test were 33.6°C (SD 1.39°C) for the sensation of cold and 38.0°C (SD 1.69°C) for warm. Statistical analysis shows that there was a significant difference ($p<0.001$) in the thresholds due to gender and length.

The frequency of the vibration stimuli (31.5 or 125 Hz) had no significant influence on total mean perception thresholds for the sensation of cold or warmth. The thresholds were significantly effected by the exposure levels regardless if the levels were expressed in terms of the equivalent frequency weighted acceleration for a time period of 16 min, the frequency weighted acceleration or as the unweighted acceleration. An increase of the equivalent frequency weighted acceleration from 2.5 m/s^2 to 5.0 m/s^2 resulted in a mean decrease of the cold and warmth thresholds with about 0.2°C and 0.1°C respectively.

The exposure time (2, 4, 8 or 16 min) for the vibration stimuli had a significant influence on the thresholds for cold and warmth sensations. Longer exposure time resulted in a larger decreased of thresholds. The recovery of the subject's thermal thresholds was only significant on the cold threshold and only for the first min after exposure. The decrease in the threshold is within the range of 0.5-0.7 ºC. The warmth threshold was not significantly affected at all.

Conclusion

It could be concluded that prior exposure to vibration on the day of test are likely to influence the results obtained from determining the thermotactile thresholds. The test person should therefore be given a vibration free period before testing. The vibration magnitude and exposure time have on affect the cold and warmth thresholds but the frequency of the vibration stimuli does not.

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The influence of applied pressure on the thermal perception thresholds in index finger

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Introduction

Thermal testing is a quantitative sensory test (QST) to measure thin peripheral nerve function for the purpose to diagnose neuropathy. Myelinated nervfibres conduct nerve impulses faster than unmyelinated fibres. Even the diameter affects the speed. Cold stimulations, conducted by thicker myelinated fibres are perceived faster than warm stimulations.

In clinical procedures it is important to have a simple and standardized method and to have adequate reference values. However, there are different methods and types of equipment that complicates the evaluation of these values. The purpose of this study was to examine if different pressure during the measure procedure affects the results. Additional purpose was to compare two different measure procedures.

Materials and methods

The study group consisted of 36 healthy volunteers, 18 men and 18 women aged from 18 to 70 years. Thresholds for heat and cold were measured on their left index finger with "method of limits" (Somedic Sales AB). The size of the probe was 2.5 x 5 cm and the start temperature was 32°C (figure 1). The increase respective decrease in temperature (1°C/s) continued until the subject felt the changes (= warmth respective cold threshold). Then the temperature returned (3°C/s) to 32°C. Each test consisted of five warmth and five cold stimuli.

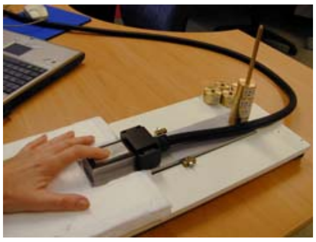

Figure 1. A specially constructed "tilt board" was used with the thermode placed at one side and weights at the other side of the board. The subject was told to keep the board in a horizontal position with his finger. By changing the weights on the opposite side of the board following pressures could be received: 200g, 400g and 600g. The measurement order was randomized.

As a further method examination the thermode was placed on an electronic scale. The subject was told to press the finger until the scale showed 200g. This procedure should resemble a method used in clinical diagnostic.

The last method was the "standard method" for Occupational and Environmental medicine in Göteborg. The thermode was placed at the table and the subject was instructed to keep the finger in an accurate position.

Results

The regression analysis showed that the highest pressure gave the lowest warmth thresholds (figure 2). The cold thresholds increased with higher pressure and women had higher cold thresholds than men. The results also showed that the measuring order was important; the first test gave the lowest warmth thresholds (figure 3). The data from cold thresholds was not statistical significant.

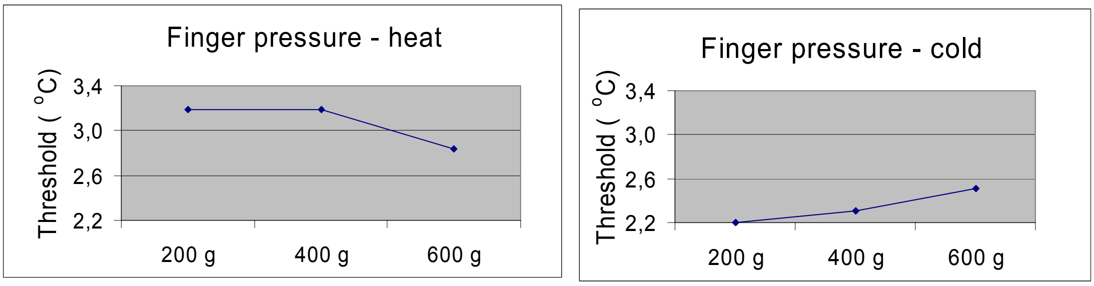

Figure 2. A regression model for finger pressure.

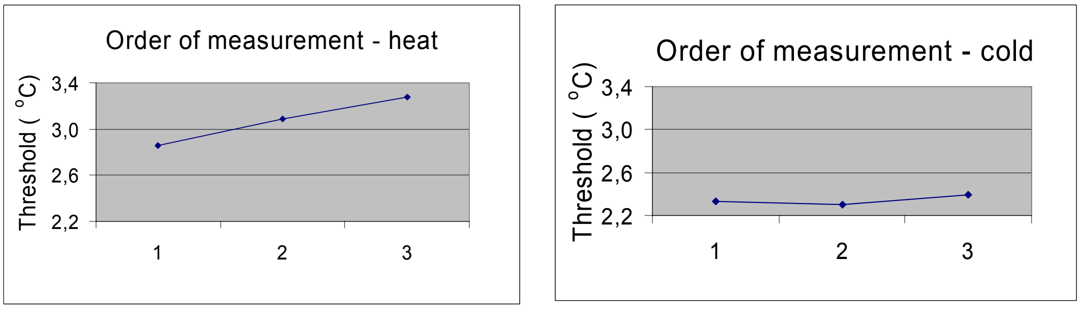

Figure 3. A regression model for order of measurement.

The regression analysis confirmed that there was no difference between the two methods “standard” and “scale. The results also confirmed that cold thresholds increased with age.

Discussion

In the literature there are different ways to compare results from sensory thresholds. The results from this study are presented as degrees of temperature changes, i.e. the difference between start- and reaction temperature. The results in this study reflect the fact that cold thresholds are on average lower than warm thresholds. It also reflects the fact that thresholds increase with age. We also found that women had slightly lower warmth thresholds but slightly higher cold thresholds than men. Earlier research has shown that a larger thermode gives lower thresholds due to the larger stimulated surface. An explanation to why the highest pressure gives the lowest warmth thresholds could be that the contact area increases [1]. The results of the cold thresholds are contradictory, but it might be harder to prove the connection since the cold thresholds are on average lower. High standard deviations indicate that there are large individual variations. An explanation to why the order of measurement is important for especially the warmth thresholds could be that the finger has been warmed up during the tests. The warm stimulations always come first in the test procedure. Since the difference between “standard” and “scale” procedure was small and non-significant it may be possible to compare results from different equipment, but it might be valuable with further studies.

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Thermal perception thresholds among young adults exposed to hand-transmitted vibration

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Introduction

Quantitative sensory testing (QST) non-invasively assesses the function of the sensory pathways from receptors to the cortex [1]. The thermal testing modality for cold is peripherally mediated by small myelinated fibres (A-delta) and warm sensation by un-myelinated warm specific C-fibres. Conventional electro diagnostic methods are not able to reveal the function of these small diameter nerve fibres [2]. The clinical diagnosis of sensory unit dysfunction of small diameter nerve fibre (SDNF) neuropathy is thus a challenge because of minor clinical signs, both hyper- and hypo-perception symptoms, sometimes associated with pain and normal conventional nerve conduction findings [3]. Experimental studies, case series of patients, and cross-sectional studies of workers exposed to vibration supports evidence that neuro-sensory hand-arm vibration syndrome also encompasses neuropathy of the small-diameter nerve fibres [4].

Objectives

To assess the risk of disturbed thermal perception developing among young adults exposed to vibration and hand intensive manual work including wearing from wet-work and heat. The aim also encompasses the study of alternative confounding factors related to SDNF neuropathy.

Methods

The study population of this cross-sectional study of 208 male and female young adults came from vocational auto mechanic, construction and restaurant school programs. They were offered to participate based on enrollment lists from the last year in vocational school programs. A postal, self administrated, baseline questionnaire, a clinical examination with medical and exposure history and additional tests were included. Quantitative measurement of thermal perception thresholds were performed, on both hands, by a modified Marstock method. A thermo stimulator was applied to the skin on the volar surface of the two distal phalanges of the second and fifth digit. The measurement of warmth and cold perception thresholds were repeated 6-times. The perceptual threshold for warmth and cold and the difference limens (neutral zone) was thus reached. The starting point was a neutral 32°C temperature.

The study population included 24 females and 184 male young adults. Three persons were excluded due to insulin-dependent diabetes 2 persons due to gastrointestinal malabsorption disease. One person lacked exposure information leaving the final study population to 202 persons. The mean age for the women was 20.5 years (S.D. 0.9). The men were half a year older. Eleven of the women had no exposure to vibration at work or at free-time. The corresponding number for the men was nine. For the exposed group the total mean vibration exposure (free-time and work accumulated) was 4887mh/s^2 (s.d. 7375 mh/s^2) the corresponding values for women were 1802 (s.d. 2187 mh/s^2). Free-time exposure was approximately 1000 mh/s^2 for both men and women.

Results

The thermal sensitivity (lower threshold for warmth and higher for cold) was generally higher for women both exposed and unexposed to vibration. When comparing never exposed men or women with vibration exposed men or women a lower sensitivity was noted for the vibration exposed groups. The mean differences were significant for the difference limens for the 2nd and 5th fingers both on the left and right hand side. The contrast between exposed and unexposed tended to be larger for cold perception compared to warmth perception. The excluded subjects had less sensitive thresholds compared to the corresponding mean values of the male group. A weak (r^2 .02 and 03), significant relation was found between reduced thermal perceptual sensitivity and length. Analysis of individual outliers gave attention to the possible influence also from pain, sequelae after accidents and vascular function.

Discussion and conclusions

The results indicate thermal sensory impairment related to vibration exposure, gender, length, and disease (e.g. diabetes). These findings are in agreement with the results from other studies. Sensory impairment despite the young adults' short vibration exposure-time and mainly low exposure calls for strict methodology and careful interpretation of results before a small diameter nerve fiber neuropathy should be diagnosed as vibration induced in individual cases. Conventional clinical and electro diagnostic investigations of subjects with neurological sensory disturbances fall short in evaluating the status of the small calibre afferent systems. Leaving QST of thermal perception as one optional diagnostic tool [3, 5, 6] in addition to pain perception.

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Normal values for thermotactile and vibrotactile thresholds in males and females

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Introduction
Thermotactile thresholds and vibrotactile thresholds are used in the diagnosis of the neurological components of the hand-arm vibration syndrome (HAVS) [1]. A hot and a cold threshold are used to assess the function of warm and cold receptors. Similarly, two vibrotactile threshold tests, at 31.5 Hz and 125 Hz, assess the function of the Meissner and Pacinian corpuscles, respectively. Tests are usually performed on the distal phalanx of the index finger and little finger (i.e. one site innervated by the median nerve and one site innervated by the ulnar nerve) on both hands. When diagnosing sensorineural disorders, thresholds are compared to normal values, but the normal values are currently not adjusted for either gender or age. The effect of age on the deterioration of the neurological function should be considered during diagnosis [2].

Objectives
This study was undertaken to compare normal values of thermotactile and vibrotactile thresholds in males and females and to compare thresholds in younger and older age groups. In addition, for thermal thresholds, the effects of the contact area (small and large) and stimulus location (glabrous and non-glabrous skin) were investigated.

Methods
Eighty male and female subjects participated in the study. Twenty males and twenty females were aged 20 to 30 years. Twenty males and twenty females were aged 55 to 65 years. Subjects were students or office workers with no regular use of hand-held vibrating tools. None reported cardiovascular or neurological disorders, connective tissue disease, injuries to the upper extremities, a history of cold hands, or were on medication likely to affect finger systolic blood pressures.

Subjects attended a 45-minute experimental session consisting of acclimatisation for 10 minutes followed by 35 minutes of testing. Warm thresholds and cold thresholds were determined with the *HVLab* Thermal Aesthesiometer using the method of limits. Thresholds were measured on the non-dominant upper limb at three locations (the distal phalanx of the middle finger, the thenar eminence, and the forearm) using two circular stimulus areas: 1 cm diameter (0.79 cm^2 area) and 2.8 cm diameter (6.18 cm^2 area). Vibrotactile thresholds at 31.5 Hz and 125 Hz were determined using the *HVLab* Tactile Vibrometer via the von Békésy method. Vibrotactile thresholds were measured on the distal phalanx of the middle finger of the non-dominant hand.

Results
Table 1 shows the hot and cold thresholds for younger female and male subjects obtained with the smaller stimulus area (1 cm diameter) and larger stimulus area (2.8 cm diameter) at three locations. Table 2 shows vibrotactile thresholds at 31.5.

Table 1. Median (IQR) hot and cold thresholds.

Stimulus area	Gender	Hot Thresholds (°C)			Cold Thresholds (°C)		
		Finger	Thenar eminence	Forearm	Finger	Thenar eminence	Forearm
1.0-cm diameter	Male	41.92 (5.40)	41.64 (4.56)	43.70 (8.34)	23.28 (9.21)	28.45 (5.51)	26.56 (7.75)
	Female	37.91 (3.54)	38.07 (3.69)	39.74 (8.43)	27.13 (5.25)	28.87 (3.39)	27.45 (3.79)
2.8-cm diameter	Male	37.29 (2.30)	35.60 (2.11)	37.16 (4.19)	26.93 (2.86)	30.52 (2.89)	30.39 (3.60)
	Female	35.89 (2.19)	34.03 (1.96)	35.62 (2.12)	29.43 (1.65)	30.80 (1.88)	30.84 (2.64)

Table 2. Median (IQR) vibrotactile thresholds.

Gender	Vibrotactile Thresholds (ms^{-2} r.m.s.)	
	31.5 Hz	125 Hz
Male	0.122 (0.09)	0.229 (0.69)
Female	0.114 (0.062)	0.232 (0.362)

Hz and 125 Hz for the groups of younger male and female subjects. The thresholds for older subjects are to be found in the paper. Females were more sensitive to temperature than males. Hot thresholds were significantly lower in females with the 1.0-cm diameter stimulus at the finger and the thenar eminence and with the 2.8-cm diameter stimulus at the finger, the thenar eminence and the forearm (p<0.05, Mann-Whitney). Cold thresholds were significantly higher with both the 1.0-cm and the 2.8-cm diameter stimulus at the finger (p<0.05, Mann-Whitney).

Stimulus area and location also affected thermotactile thresholds. Hot thresholds were significantly lower and cold thresholds were significantly higher at all locations when the larger (2.8-cm diameter) stimulus was used.

There were no statistically significant differences in vibrotactile thresholds between males and females. A significant correlation was found between vibrotactile thresholds at 31.5 Hz and vibrotactile thresholds at 125 Hz within males (p<0.001).

Conclusions

The significant difference in thermotactile thresholds between males and females suggests that different normative values might be needed when measuring thresholds at the finger. The normative values also depend on the stimulus area and the location where thresholds are measured. No differences were found in vibrotactile thresholds between males and females, suggesting that the same normal values can be applied to both genders in the age range 20 to 30 years.

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Hand symptoms among young adults in relation to vibrotactile and monofilament tests

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Introduction

Hand-held vibrating tools are commonly used in different occupations. The tools vary in size, weight, acceleration amplitude and frequency. Vibration exposure 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 [1] and/or as muscular weakness and fatigue. The interindividual susceptibility may vary between different subjects and the dose-response relationships are not fully clarified.

Objectives

To study early neurophysiological effects by monofilament testing and determination of vibrotactile thresholds, in young workers with hand-held vibration exposure.

Methods

The study consisted of 144 male and female workers with exposure to hand-held vibrating tools. Many of them had been working in machine shops. They were compared with 61 non-vibration exposed subjects, mainly restaurant employees of the same age-group. The study population started their work during the period 1998-2005. All participants passed a structured interview and answered several questionnaires with questions about e.g. working and medical history, smoking and alcohol consumption, vibration exposure and vibration related symptoms such as white fingers and sensorineural disturbances. A physical examination was performed followed by several tests, e.g. the determination of vibrotactile perception thresholds, temperature thresholds, Semmes Weinstein Monofilament, Purdue dexterity test, Jamar test and Pinch strength. Measurements of vibrotactile thresholds were performed for two frequencies (31.5 and 125 Hz). The Touch Test Sensory Evaluators (Semmes-Weinstein Monofilament) provide a non-invasive evaluation of cutaneous sensation levels with results that are objective and repeatable. Touch thresholds were assessed at the pulp of digits II and V, bilaterally. Symptoms and signs related to the vibrotactile perception thresholds and monofilament testing were related to different indices of vibration exposure.

Results

In the vibration exposed group only three subjects started their vibration exposure before 2001. 11/144 workers reported tingling sensations, 14/144 numbness and 2/144 both tingling sensations and numbness in their fingers. These symptoms, however, did not interfere with work or leisure activities. The number of subjects who displayed abnormal results on monofilament testing was 15 for digit II and 8 for digit V on the right hand, and 12 and 9, respectively, on the left hand. Three subjects showed tingling sensations and a pathologic monofilament test, one subject numbness and a pathologic monofilament test. The same tendency was noted for the vibrotactile threshold testing. Significantly increased (p=0.04) vibration thresholds in the vibration exposed group were found for dig II bilaterally (125 Hz). Two subjects displayed tingling sensations and three subjects numbness as well as increased vibration thresholds in dig II in the right or left hand. Three subjects were classified as 1SN and one as 2SN by the Stockholm Workshop Scale (SWS). In the non-exposed reference group 4/61 started to work before 2001. 7/61 reported tingling sensations and 4/61 numbness in their fingers, symptoms that did not disturb work or leisure activities. Abnormal results for monofilament testing in digits II and V on the right hand were found for 4 and 2 subjects, respectively. Corresponding figures for digits II and V on the left hand were 7 and 5, respectively. The same picture was noted for vibration threshold testing. All referents were classified as 0SN (SWS).

Discussion and conclusions

This is a young cohort with a fairly short vibration exposure. Most of them have only been working for a couple of years. This is probably the main reason for the sparse findings when performing the neurophysiologic testing as shown above. Previous micro-neurographic recordings from single mechanoreceptive afferents of the human hand indicate that frequencies in the range 5 – 50 Hz and above 50 Hz are mediated by SA, FAI and FAII units, respectively [2]. FAII units are most easily excited at frequencies ranging from 100 to 300 Hz. Thus, the chosen frequencies for the vibrotactile threshold testing, 31.5 and 125 Hz, respectively, are covering the critical response intervals of these mechanoreceptors. Earlier studies have shown that these measurements can be a reliable assessment if an initial practice is included as part of the standard administration [3]. In summary, this cohort is a unique opportunity for future investigations, as we will try to follow this group for the years to come. That will enable us to detect and evaluate early discrepancies as regards neurophysiological symptoms and signs in vibration exposed workers.

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A longitudinal study of manipulative dexterity in vibration-exposed workers

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Introduction

Occupational exposure to hand-transmitted vibration (HTV) can cause peripheral sensorineural symptoms, reduced tactile discrimination, and impairment to manipulative dexterity. This latter may be tested by means of the Purdue pegboard, which is considered an objective and repeatable test of hand function in patients affected with neurological disorders, workers exposed to HTV and personnel engaged in jobs requiring high hand-movement performance [1, 2] .

Objectives

To assess prospectively the manipulative dexterity in a group of HTV workers. The relation between manipulative dexterity and vibration exposure, ergonomic risk factors, and upper limb disorders (sensorineural, vascular and muscoloskeletal) was also assessed.

Subjects and methods

A group of 125 HTV workers (82 forestry workers and 33 stone workers) and a group of 64 control workers were examined twice over one-year follow up period. Information about personal characteristics, vibration exposure and ergonomic risk factors was obtained by means of a standardised questionnaire. Manipulative dexterity was assessed by the Purdue pegboard testing method (i.e. the number of metal pins that a subject takes from a cup and inserts into a row of holes), [2]. The exposure to vibration was assessed in terms of *A*(8), job seniority, total operating time with vibration tools (hours) and cumulative vibration dose (a^2t in $m^2s^{-4}h$).

Results

At the initial investigation, Purdue pegboard scores (dominant hand, non-dominant hand, both hands, sum of hand scores, and assembly) were significantly lower in the HTV workers than in the controls ($0.001<p<0.05$).

Over one-year follow up period, Purdue pegboard scores were found to be inversely related to age, smoking and use of vibratory tools ($0.001<p<0.05$). Deterioration of some measures of manipulative dexterity was significantly associated with neurosensorial symptoms (tingling, numbness) and vascular disturbances (white finger). No association was found for neck and upper limb musculoskeletal disorders (table 1).

Random-intercept linear regression analysis showed that Purdue pegboard scores for dominant hand, non-dominant hand and both hands (i.e. maximum number of pins inserted) decreased with the increase of vibration exposure. The reduction of assembly score (i.e. number of pins, collars, and washers assembled in a 60-second period) was significantly associated with the increase in vibration exposure and ergonomic stress (neck-upper arm posture, hand-intensive work, total ergonomic score). Some of the Purdue pegboard subtests were positively related to the follow up time in both the controls and the HTV workers, suggesting a possible learning effect over time.

Table 1. Random-intercept linear regression of Purdue pegboard scores on sensorineural, vascular and muscoloskeletal symptoms in the study population (n=179) over one-year follow up time. Maximum likelihood estimates of regression coefficients (95% confidence intervals), adjusted by age, smoking, drinking and follow up time, are shown.

	Dominant hand	Non-dominant hand	Assembly
Tingling	-0.5 (-1.0 – -0.1)*	0 (-0.4 – 0.5)	-1.5 (-3.0 – -0.1)*
Tingling score (per 10 point-score)	-0.2 (-0.4 – -0.1)†	-0.1 (-0.2 – -0.1)	0 (-0.3 – 0.2)
Numbness	-0.6 (-1.1 – -0.1)*	-0.6 (-1.1 – -0.1)*	-1.8 (-3.7 – 0.1)
Numbness score (per 10 point-score)	-0.1 (-0.3 – 0.1)	-0.05 (-0.3 – 0.2)	-0.1 (-0.6 – 0.3)
White finger	-0.5 (-1.2 – 0.2)	-0.8 (-1.5 – -0.1)*	-1.1 (-3.5 – 1.3)
White finger score (per 10 point-score)	-0.4 (-0.9 – 0.03)	-0.5 (-1.0 – -0.1)*	-0.4 (-1.2 – 0.4)
Neck musculo-skeletal disorders	0.3 (-0.1 – 0.)	0.2 (-0.2 – 0.6)	0.4 (-0.9 – 1.8)
Upper limb musculo-skeletal disorders	0.2 (-0.2 – 0.6)	0 (-0.4 – 0.4)	-0.5 (-1.9 – 0.9)

*p<0.05; †p<0.01; ‡p<0.001

Discussion

The findings of this study showed a deterioration of manipulative dexterity in HTV workers when compared with healthy controls. In the HTV workers, manipulative performance was inversely related to vibration exposure and ergonomic stress factors over one-year follow up period. The impairment to manipulative dexterity was significantly associated with sensorineural and vascular disorders. The results of this prospective study tend to confirm and to extend the findings of previous investigations which suggest an association between deterioration of manipulative dexterity and occupational exposure to hand-transmitted vibration [3, 4].

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Grading of sensorineural disturbances according to the Stockholm workshop scale using self-reports - A proposal

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Introduction

It is well known that vibration induced neuropathy in the hand, most often manifested as reduced sensibility (numbness) and clumsiness in hand movement, reduce work ability as well as life quality. In order to grade the severity of the dysfunction the Stockholm Workshop scale for grading sensorineural disorders (Table 1) has been widely used [1]. The grading scale have four discrete stages, i.e. SN0-SN3 (Table 1), based on a progression of complaints of intermittent numbness, with or without tingling (paresthesia), sensory deficiency, and reduced performance in fine motor tasks.

Table 1. The Stockholm workshop scale for grading sensorineural disorders in vibration-exposed persons [1].

Stage [a]	**Description**
0SN	Vibration-exposed but no attacks
1SN	Intermittent numbness, with and without tingling
2SN	Intermittent or persistent numbness, reduced sensory perception
3SN	Intermittent or persistent numbness, reduces tactile discrimination and/or manipulative dexterity

[a] The sensorineural stages is to be established for each hand.

However, in accordance with our experience when conducting epidemiological investigations on vibration exposed groups the practical application of the grading scale has shown some difficulties. One reason is the lack of clear case definitions for the three symptomatological stages. It is thus not clear whether the grading scale can, or should be adopted solely on the basis of symptom or if dysfunctions should be based also on quantative sensory testing (QST). Another problem is that the assumed progression of symptoms, or signs, are not followed in many cases. For instance, indication of reduced manipulative dexterity and/or reduced sensory perception may be present but without complaints of intermittent or persistent numbness. Since elevated vibration perception thresholds not necessarily coincide with numbness, either during the day or at night, such cases cannot be properly classified according to the current grading scale.

There are several available and possible methods for QST that may be used, such as vibrotactile perception thresholds (VPT), thermotactile perception thresholds (TPT), two-point discrimination test (2-PD), purdue pegboard test for manual dexterity (PPB), monofilaments (MF) and more. All these types of QST demands equipment, some of which are quite sofisticated and expensive. In general, QST is most often rather time consuming to perform and requires well-trained personnel for the testing in a clinical and/or research setting.

For all epidemiological investigations that we have conducted over the last 15-20 years we have addressed symptoms and signs of sensorineural disorders by means of individual questionnaires, physical examination and objective testing (i.e QST). For reasons mentioned earlier and our experience a modified grading scale using self-reports has been outlined (Table 2). The grading scale is based on three specific questions believed to be relatively good markers for complaints of intermittent numbness, sensory deficiency, and reduced performance in fine motor tasks. Moreover, a fifth stage (SN4) is added allowing the situation that symptoms of reduced manipulative dexterity and/or reduced sensory perception may be present without complaints of numbness.

Table 2. Proposal for grading of sensorineural disorders in vibration-exposed persons using self-reports.

	Nocturnal numbness	**Drop things easy**	**Difficulty with buttoning**
SN0	-	-	-
SN1	+ - -	- + -	- - +
SN2	+ +	+ -	- +
SN3		+	+
SN4	+	+	+

The application of the above proposed grading scale using self-reports from a vibration exposed study group will be presented. A comparison using data from objective testing will also be presented.

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Measurement, evaluation, and assessment of peripheral neurological disorders caused by hand-transmitted vibration

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Introduction

Exposure to hand-transmitted vibration is associated with a variety of signs and symptoms including, but not limited to, vascular and neurological disorders [1]. The combination of all signs and symptoms is called the 'hand-arm vibration syndrome', HAVS. The vascular and sensorineural effects are currently classified using staging systems [2,3].

The principal impetus for classifying the effects of hand-transmitted vibration into 'stages' has been the need to make decisions that depend on the severity of the disorder – for example, deciding whether to remove a person from further use of vibratory tools or deciding what level of financial compensation is appropriate. This has led to an emphasis on assessing the severity of the effects with little consideration of the precise form of the effects or how their existence is to be determined.

The quantification of phenomena may be divided into three phases: measurement, evaluation, and assessment.

The *measurement* of the effects of hand-transmitted vibration involves converting the evidence of disorder into information that can be recorded (on paper or in computers). The evidence may include both symptoms of disorder and also signs of disorder. A symptom is an abnormality in function, appearance, or sensation that is discovered by the patient – sometimes considered to be 'subjective evidence of disease'. In medicine, a sign is considered to be any abnormality which is discovered by a physician during an examination of a patient – sometimes considered to be 'objective evidence of disease'.

The *evaluation* of the effects of hand-transmitted vibration requires the use of one or more scales on which to indicate the relative or absolute severity of the effects (i.e. the symptoms and signs). It may not be appropriate to assume that all symptoms or all signs are of equal importance. An evaluation procedure will yield numbers such that the severities of the different effects of vibration can be seen. Evaluations may be expressed on either ordinal, interval or ratio scales (i.e. scales on which greater values indicate greater effects). Such scales may, or may not, be suitable for forming a single 'weighted' value representative of the overall severity of the potentially complex combination of symptoms and signs that were measured.

An *assessment* involves consideration of the overall severity (as reflected in one or more scales resulting from the evaluation) and a judgement about it. Whereas evaluation results in one or more values that are representative of the severity of the effects of vibration, the assessment judges the outcome from vibration exposure on the basis of some criterion. Assessments are required for some purposes (e.g. to decide on removal from work or compensation based on current local practice) but they are not necessary for monitoring the health of the patient. An overly simple assessment scale may obstruct the monitoring of patient health.

Objectives
The objective of this paper is to encourage and assist the improved reporting of the symptoms and signs arising from exposures to hand-transmitted vibration. The main objective is to encourage greater emphasis on the measurement and evaluation of the effects and less focus on assessment, which will vary according to the prevailing circumstances. It is hoped that improved means for reporting relevant symptoms and signs will encourage the collection of better information on the effects of hand-transmitted vibration and thereby also assist the monitoring of the health of affected workers.

Methods
The limitations of the current method of 'staging' so-called 'sensorineural' disorders caused by hand-transmitted vibration are reviewed.

Symptoms (numbness, tingling, perceived weakness, clumsiness and pain) reported to arise from exposure to hand-transmitted vibration are defined together with a means of classifying and reporting their location and severity. The method of reporting these symptoms takes into account other potential causes of the symptoms. A parallel scheme is defined for classifying the various signs of disorder as reflected in the results of currently used tests (vibrotactile and thermal thresholds, grip force and dexterity). The location of the signs is defined so that they can be related to the symptoms. The severity of the signs is expressed relative to normal values for a population of similar persons not exposed to hand-transmitted vibration. An example of the application of the method of measuring and reporting symptoms and signs for the assessment of sensorineural disorders is illustrated.

Discussion
The measurement, evaluation and reporting of symptoms and signs is required in health surveillance and in the collection of epidemiological data needed to advance understanding of the disorders caused by hand-transmitted vibration.

The means of collecting the relevant information (i.e. measuring and evaluating the symptoms and signs) may be undertaken by many suitably trained persons. The tabulated result may then assist a suitably qualified and experienced occupational physician to assess the severity of the disorder and make recommendations for the care of the patient. The tabulated information should also assist the monitoring of patients over time and assist considerations related to compensation.

Conclusions
Separating the measurement and evaluation of disorders from their assessment according to prevailing criteria may encourage a more rigorous route to individual assessments and the reporting of disorders caused by hand-transmitted vibration.

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Diagnosing soft tissue rheumatic disorders of the upper limb in vibration research

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Introduction
Exposure to hand-transmitted vibration (HTV) has been linked with several health effects in the upper limb. Among these, soft tissue rheumatic disorders (ULDs) appear relatively to have been neglected. Of concern is whether a lack of assessment tools is discouraging research. Proper classification is a pre-requisite to meaningful inquiry, but the diagnosis of ULDs is notoriously challenging.

Objectives
To investigate approaches adopted to diagnose ULDs in HTV-exposed workers and in other more general settings, and to compare their methodological qualities.

Methods
Two systematic searches were made of the Medline, Embase and CINALH databases from inception to April 2006. In the first, key words and medical subject headings for the exposure and the outcome(s) were combined using Boolean strings and the search was supplemented using several other sources (textbooks, reviews, proceedings, workshops, personal files). Qualifying papers were scored in terms of their adequacy of documentation, standardisation, reliability, criterion-related and content validity. The second search covered the same databases, time periods, and outcomes, but focussed on classification, diagnosis, diagnostic criteria, and the repeatability, validity and measurement properties of schemes. This search was also supplemented with authoritative reviews, textbooks, the records of diagnostic workshops and personal research. Evidence was collated on the reliability of symptom histories and clinical signs, and papers on whole diagnostic schemes were scored for documentation, standardisation, and supporting evidence of reliability and/or validity.

Results
Search 1 identified 23 reports. All but two included symptom inquiries, but around 50% were classed as ‘poor’ by the review criteria. Only three fully met all of the quality criteria proposed. Nine reports included an examination and/or proposed specific rheumatological diagnoses relevant to the review. None fully met all of the proposed quality criteria, although several partially met them by specifying the elements of examination and/or case definition without explicit details of method or cut-points; and by making choices that, although not empirically evaluated, had reasonable face validity or consensus support.

Search 2 yielded 50 relevant accounts, including 12 reviews, many schemes directed at classifying ULDs, and 18 papers on the properties of specific physical signs, and/or test-retest reliability of symptom questionnaires. For the latter many researchers use the Standardised Nordic Questionnaire, which is well documented with acceptable face validity, and 4 reports indicate good within-subject repeatability (observed agreement >80% with kappa coefficients (κ) denoting excellent agreement). In terms of physical signs, most effort has been expended on assessing Phalen's and Tinel's tests. These have good-to-excellent inter- and intra-observer reliability in secondary care, but less good in the community (κ 0.20-0.43). A second focus is measurement of shoulder movements by goniometry, pleurimetry or visual estimation. Nine papers were identified, mostly showing adequate repeatability. Findings at the neck were similar, but less extensive. A few studies of other physical signs (e.g. elbow tenderness, pain on resisted wrist movement) also suggest adequate repeatability. The search also identified four classification schemes in wider use. Although developed in different settings, all rated well for face validity. The scheme of Waris [1], modified by Viikari-Juntura [2], arose from a systematic review; that of Harrington *et al* [3], as modified by Palmer *et al* (Southampton Schedule) [4], was based on Delphi consensus of a multi-disciplinary workshop; and that by Sluiter *et al* (the SALTSA criteria) [5] also derived from a consensual process. No single scheme was complete in documentation, but each provided the elements of examination and/or case definition; and the SALTSA criteria went further, being supported by a well illustrated publicly available procedures protocol. Only the Southampton Schedule had been evaluated, however, for repeatability and concurrent validity of diagnosis. In the outpatient setting, when performed by a pre-trained nurse, it had a specificity of 84-100% and a sensitivity of 58-100% vs. the specialist as reference standard [4]; while in the community these observers showed reasonable agreement over diagnosis (median κ =0.66) [6]. Infill work has explored how case definition can be refined/supported by differential associations with risk factors, and by capacity to distinguish groups on different treatments and with differing levels of disability (3 reports). Finally, the predictive validity of the Southampton Schedule is being assessed, the goal being to propose case definitions that imply practical utility in the management and/or prevention of ULDs.

Discussion

Most studies of ULDs in HTV-exposed populations have used custom-specified diagnostic methods, poorly documented, and non-stringent in terms of standardisation and supporting evidence of reliability and/or validity. The broader literature contains several protocols that improve upon this, and offer immediate scope in vibration-exposed populations to diagnose ULDs more systematically.

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Musculoskeletal symptoms and associations with exposure to hand-arm vibration and ergonomic stressors among young men

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Introduction
The scientific literature on the associations between vibration exposure and the hand-arm vibration syndrome (HAVS) is quite extensive regarding the vascular and neurological components, but there are few studies focussing on the association between exposure to hand-arm vibration and musculoskeletal symptoms and disorders in the neck and upper limbs. To our knowledge there are no longitudinal studies that have explored the associations between neck pain and hand-arm vibration exposure.

Objectives
The overall aim was to explore associations between musculoskeletal symptoms in the neck and upper limbs and exposure to hand-arm vibration and ergonomic stressors in young men.

Subjects and Methods
The study has a prospective design and data at baseline and follow-up was assessed by self-administered questionnaires. The study population consisted of students that graduated from vocational high schools in 2001, 2002 and 2003 in northern and western Sweden. The programs were construction, auto mechanics and restaurant. The baseline questionnaire was returned by 1868 young workers (response rate 57%) of which 1562 were men. A total of 1029 workers who answered the baseline questionnaire were given a follow-up questionnaire approximately one year after the baseline. The follow-up questionnaire was returned by 852 workers of which 658 were men. The mean age for the men was 21 years (range: 19-27). The women were excluded from the prospective analyses due to the relatively small number of women eligible (n=86), this was due to the initially small number of women (n=177) and the high prevalence of neck and arm pain at baseline, 52% and 41% respectively.

The exposure information included questions regarding hand-arm vibration, postural stress, computer work, mental stress and perception of muscular tension. Individual factors like age, sex, height, weight and smoking were also assessed.

Musculoskeletal symptoms in the neck and upper limbs were assessed at baseline and at follow-up, and subjects who reported pain at baseline were excluded from the prospective analyses.

In the prospective analyses hazard ratios (HR) with 95% confidence intervals (CI) were computed using proportional hazard models (Cox-regression).

Results
A total of 378 men were free from neck pain at baseline and at follow-up 36 (9.5%) reported neck pain the past 7 days and 112 (29.6%) reported neck pain at some occasion during the past year. At baseline 409 men were free from arm pain and at follow-up 60 (14.5%) reported arm pain the past 7 days and 120 (29.3%) reported arm pain at some occasion the past year.

Men with an 8-hours weighted vibration exposure level above 1.7 m/s^2 had an increased risk of developing neck pain, compared to the reference group (Figure 1).

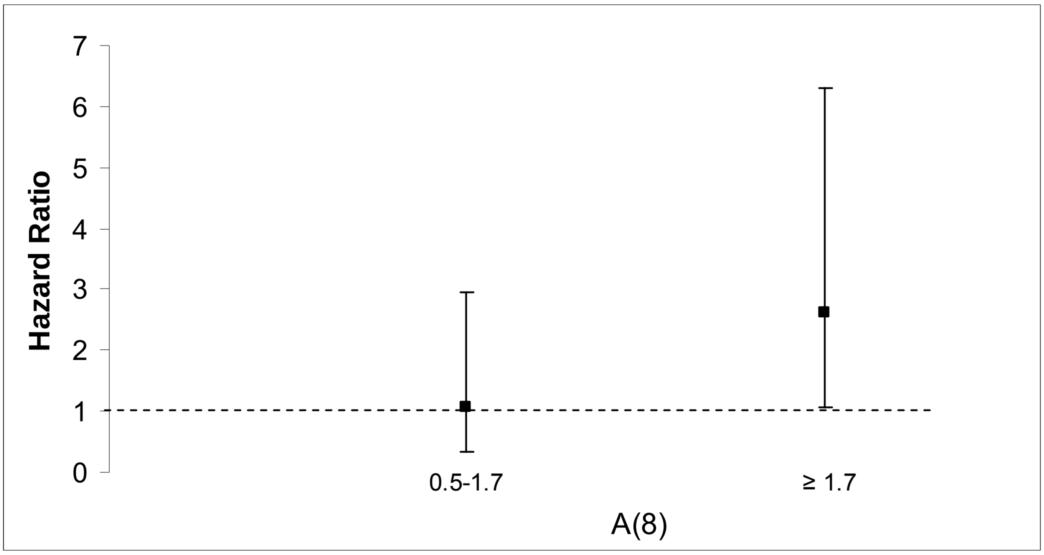

Figure 1. Subjects with high vibration exposure (≥ 1.7 m/s^2) compared to low exposure (< 0.5 m/s^2) and the risk for pain in the neck and arms (shoulders, elbows and wrists), presented as hazard ratios with 95% CI:s.

Discussion
Men with an 8-hours weighted vibration exposure level above 1.7 m/s^2 had an increased risk of developing neck pain compared to those with an exposure level below 0.5 m/s^2. This is, to our knowledge, the first time exposure to hand-arm vibration has been observed to increase the risk of neck pain in a study with a prospective approach. However, as has been pointed out by others [1-3], with the present study design it is impossible to conclude that the increase in risk is due to hand-arm vibration exposure *per se*, since the assessment of ergonomic stressors were incomplete.

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Grip strength in miners with Hand-Arm Vibration Syndrome

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Introduction

In 1996 British Coal was found to be in breach of duty of care in matters related to exposure to vibrating tools. On the 31st December 1998 the liabilities of British Coal were taken over by the United Kingdom Government. The Government, through the Department of Trade & Industry, set up a medical assessment process to evaluate disability in miners arising from Hand-Arm Vibration Syndrome and to compensate their loss [1]. This study reviews the grip strength measurements of miners assessed for compensation.

Methods

Over 100,000 miners and ex-miners were assessed for compensation for Hand-Arm Vibration Syndrome (HAVS). A standardised medical assessment process (MAP) was developed and applied in 18 centres in the United Kingdom. One hundred and ninety five doctors were trained to carry out the assessments. The doctors were inducted to the process and audited by the medical authors to ensure individual accuracy and consistency between centres. The examining doctors took a detailed history of symptoms of HAVS, including relevant previous medical history, medications and presence or absence of Carpal Tunnel Syndrome (which if considered to be caused by exposure to vibration attracted additional compensation). Hand dominance was identified on the basis of that used for writing. The years of exposure to vibration including all other employments were established. Clinical examinations included Purdue pegboard test for dexterity and an assessment of grip strength. Neurological staging was based on history and the results of the thermal aesthesiometry and vibrotactile thresholds.

Grip was measured using a Jamar Hand Grip Dynamometer (model 5030 J1) with strength assessed against normative data developed by Matthiowetz et al [2] and guidance from the Institute of Sound and Vibration Research, Southampton. The Jamar Dynamometer is considered the most reliable and valid method of measuring grip. The dial faces away from the subjects who are unable to access the reading during maximal grip. The second grip setting on the Jamar was used. The subject sat at a table 76 cm high with the shoulder in neutral rotation: the elbow was held at 90º with the forearm in neutral position. Instructions to the claimants were standardised requiring three maximal grips to the dominant hand and then three to the non-dominant hand. The mean of the three tests for each side was calculated and recorded as the average grip strength in Kg.

Weakness of grip was defined as two standard deviations below Matthiowetz’s normative data. The claimants were grouped into three age bands 20-54, 55-69 and 70-75+ years. Claimants aged 20-54 were considered to have weakness of grip if their dominant hand grip was less than 33 Kgs, and their non-dominant hand 30 Kgs. Claimants aged 55-69 were considered to be weak if their dominant hand-grip was less than 22 Kgs or the non-dominant 16 Kgs. Claimants aged 70 to 75 years of age were considered to have weakness of grip if their dominant hand-grip was less than 12 Kgs or in the non dominant 11 Kgs.

Results

The results of 97,581 miners' assessments available for analysis were reviewed. Grip strength in this cohort is noted to halve over the 50 years span from 25-75 starting with figures in the upper 30's Kgs and dropping to below 20 Kg in the over 75 year group. 65.7% of the claimants exhibited weak grip. Every year of age is associated with a decrease in grip strength of 0.43 Kgs (95% CI 0.44,0.42). Every year of additional exposure is associated with a decrease in grip strength of 0.02 Kgs (95% CI 0.03,0.01). The effect of age is much greater than the effect of exposure. This is illustrated in Figure 2 where the lines of best fit for claimants with five and 40 years exposure to vibration are shown. No significant association was found between grip strength and results of other sensorineural tests (thermal aesthesiometry and vibrotactile threshold measurements), neurological and vascular stagings (except 3SN). These miners are significantly weaker than normatives for all age bands.

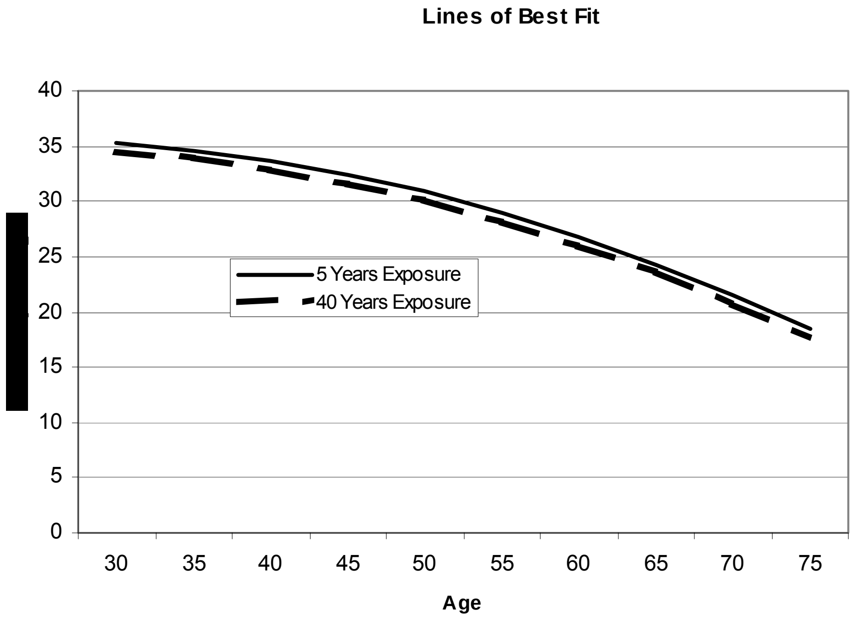

Figure 1. The effect of vibration exposure of five and 40 years on mean grip right hand by age band.

Discussion

The claimants low grip strength values in all age bands compared to normative data is not readily explained and an early vibration effect on grip, during the first five years, has not been identified.

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Diagnosis of vascular injuries caused by hand-transmitted vibration

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Introduction

Prolonged exposure to hand-transmitted vibration causes various disorders involving vascular, neural and musculo-skeletal systems, collectively called the hand-arm vibration syndrome (HAVS). For assessment of the vascular components of upper extremities in HAVS, cold provocation tests have been widely used, which were standardized by ISO/TC108/SC4 in 2005 [1]. We organized an international mini-workshop on standardization of vascular assessment methods in 2004 (Yamaguchi Workshop 2004) in Japan [2]. The standardized tests constitute of finger skin temperature measurement during hand(s) immersion in cold water (FST test) and finger systolic blood pressure measurement during local cold exposure (FSBP test).

Pathophysiology

Vibration-induced white finger (VWF) as well as persistent cold sensation of the upper extremities are common vascular symptoms of HAVS [3]. Regarding the pathophysiology of vascular disorders, organic and functional factors have been pointed out [4, 5]. The former includes narrowing of arterial lumen with medial smooth muscle hypertrophy enhancing vasoconstriction. The latter is described as increased sympathetic activity and vasoconstrictor response to cold, endothelin-1 release and increased α_2-adrenoreceptor reactivity, and decreased vasodilatation relating to less release of nitric oxide and calcitonin-gene-related peptide.

Diagnostic methods

At present for diagnosing VWF, medical interview is the best method [6]. Though it is not an objective method, careful interview by an experienced physician can judge with high reliability whether or not the patient has VWF. As objective methods for diagnosing vascular disorders including VWF, several tests including angiography, plethysmography, thermography, laser Doppler, nail press test have been investigated. The cold provocation tests are expected to be the most practical methods among them; the FST and FSBP tests are widely used. The ongoing criticisms are on the repeatability, correlation to the vascular stages by Stockholm workshop scale and sensitivity/specificity of these tests.

Diagnostic significance of cold provocation tests

The sensitivity and specificity of the FST test depend on the test condition, especially water temperature; sensitivity for VWF patients is not so high, 20% to 60% when specificity is around 95% [5]. Those of FSBP test are larger than FST test; the sensitivity is 40% to 90% when specificity is around 95% [7]. Although FSBP test is suggested to be highly specific for VWF [8], false negative rate should not be ignored. Also, these two tests are pointed out to have different significance for evaluating vascular disorder; FST test reflects the extent of vasodilatation and FSBP test, the extent of vasoconstriction [9]. It is also pointed out that VWF is induced by abnormal vasoconstriction and persistent cold sensation of the upper extremities is partly from insufficient vasodilatation [10].

Usefulness and limitation

No single test can assess the vascular disorder or the neurological disorder of HAVS [11]. The practical approach is comprehensive evaluation including test batteries together with medical interview and physical examination; both FST and FSBP tests can contribute in assessing vascular disorder as objective evaluation methods. In the field of occupational health, medical examinations have different purposes, such as evaluation of exposed population, follow up of affected workers, diagnosis of patients for medical treatment and compensation. For each purpose, the FST and FSBP tests have their own diagnostic significance; we have to utilize these tests with consideration of their limitations. There are not enough data for the standardized FST test except for a few reports [12]; it is necessary to investigate the test conditions further. Although, there are many reports regarding the diagnostic significance of the FSBP test, normative values need further discussions together with those of the FST test.

Conclusion

There are limitations in diagnostic significance of the FST and FSBP tests. However, there is no single test with satisfactory diagnostic performance; it is reasonable to use these tests as parts of comprehensive evaluation method, also comprising neurological tests together with medical interview and physical examination. For increasing the diagnostic significance, test conditions and proper normative values must be investigated further.

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A longitudinal study of finger systolic blood pressure and exposure to hand-transmitted vibration

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Introduction

Vibration-induced white finger (VWF) is as a secondary form of Raynaud's phenomenon characterised by episodes of finger blanching usually triggered by exposure to cold. Most of the epidemiological studies of VWF and vascular reactivity to cold provocation are of cross-sectional type [1]. There are very few longitudinal studies of the cold response of digital arteries in healthy vibration-exposed workers or patients affected with VWF.

Objectives

To investigate prospectively the relation between VWF, exposure to hand-trasmitted vibration (HTV) and the cold response of digital arteries in users of vibrating tools.

Subjects and methods

Two hundred and sixteen HTV workers and 133 control men of the same companies underwent initially a medical examination and a standardised cold test with measurement of the change in finger systolic blood pressure after finger cooling from 30° to 10°C ($FSBP\%_{10°}$). They were re-examined one year later. Tool vibration magnitudes were expressed as frequency-weighted and unweighted r.m.s. accelerations. Daily vibration exposure was assessed in terms of 8-hour energy-equivalent frequency-weighted or unweighted r.m.s. acceleration magnitude, $A(8)$ ($A_w(8)$ or $A_{uw}(8)$, respectively). From the vibration magnitudes and exposure durations, alternative measures of cumulative vibration dose were calculated for each HTV worker, according to the expression: dose = $\Sigma a_i^m t_i$, where a_i is the acceleration magnitude on tool i, t_i is the lifetime exposure duration for tool i, and m = 0, 1, 2 or 4 [2].

Results

Among the HTV workers, the initial prevalence and the 1-year incidence of VWF were 18.1% and 1.7%, respectively. At the first examination, the HTV workers with moderate or severe score for VWF showed a significantly increased cold reaction in the fingers when compared with the controls and the HTV workers with no vascular symptoms. At the follow up, the controls, the asymptomatic HTV workers, and the prevalent cases of VWF did not show significant changes in the cold response of digital arteries. A deterioration of cold-induced digital vasoconstriction was found in the incident cases of VWF. In the HTV workers, vibration doses with high powers of acceleration (i.e. $\Sigma a_i^m t_i$ with $m > 1$) were major predictors of the vasoconstrictor response to cold at the follow up examination (Table 1). Measures of vibration dose determined solely by lifetime exposure duration, such as years of exposure or total hours of tool use, were not associated with $FSBP\%_{10°}$ at the end of the follow up period. There were no significant associations over time between smoking and the changes in vascular symptoms and FSBP%$_{10°}$ in both the controls and the HTV workers.

Table 1. Linear regression models for the relation between FSBP%$_{10°}$ and alternative measures of vibration exposure. In each regression model, the regression coefficient (95% confidence interval) is an estimate of the decrease in FSBP%$_{10°}$ per unit (or ln(unit)) increase in vibration exposure over one-year follow up period. Regression coefficients are adjusted by age, body mass index, smoking, drinking, leisure activity with vibration tools, symptoms of finger whiteness, and FSBP%$_{10°}$ at baseline. The likelihood ratio (LR) test for the measures of vibration exposure and the Bayesan Information Criterion (BIC) for comparison between models are reported.

Measures of vibration exposure	FSBP%$_{10°}$	LR test (χ^2, 1*df*)	BIC
$A_w(8)$ (ms^{-2} r.m.s.)	-0.7 (-1.6 – 0.1)	3.36 (p=0.07)	-57.4
$A_{uw}(8)$ (ms^{-2} r.m.s. × 10^{-1})	-0.7 (-1.4 – -0.1)	4.67 (p=0.031)	-58.8
Exposure duration (yrs)	-0.2 (-0.6 – 0.2)	0.81 (p=0.37)	-54.9
Σt_i [ln(hours)]	-1.4 (-3.6 – 0.8)	1.59 (p=0.21)	-55.7
$\Sigma a_{vwi} t_i$ [ln(ms^{-2}h)]	-2.5 (-4.7 – -0.2)	4.89 (p=0.027)	-58.9
$\Sigma a_{vwi}^2 t_i$ [ln(m^{2}s^{-4}h)]	-2.9 (-12.1 – -0.9)	8.29 (p=0.004)	-63.4
$\Sigma a_{vwi}^4 t_i$ [ln(m^{4}s^{-8}h)]	-2.0 (-3.3 – -0.7)	9.81 (p=0.0017)	-63.9
$\Sigma a_{vuwi} t_i$ [ln(ms^{-2}h)]	-2.1 (-3.9 – -0.3)	5.29 (p=0.021)	-59.4
$\Sigma a_{vuwi}^2 t_i$ [ln(m^{2}s^{-4}h)]	-2.0 (-3.5 – -0.5)	7.09 (p=0.008)	-61.2
$\Sigma a_{vuwi}^4 t_i$ [ln(m^{4}s^{-8}h)]	-1.3 (-2.2 – -0.3)	7.30 (p=0.007)	-61.4

Discussion

The measurement of FSBP after local cooling may be a helpful objective test to monitor prospectively the change in vibration-induced vascular symptoms. The findings of this longitudinal study suggest a dose-effect relationship between cold-induced digital arterial hyperresponsiveness over time and measures of cumulative vibration exposure. In the controls, the cold response of the digital arteries was stable over one-year follow up period.

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Normal values for finger systolic blood pressures in males and females

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Introduction

The vascular component of the hand-arm vibration syndrome (HAVS) is vibration-induced white finger (VWF), which is characterised by episodic and clearly demarcated finger blanching. Vascular symptoms typically occur during or following exposure to cold.

Finger systolic blood pressures (FSBP) following cold provocation are used to detect dysfunction in the digits compared to normal values in healthy individuals [1]. Currently, the normal values are not adjusted for either age or gender.

Objectives

This study was undertaken to compare finger systolic blood pressures in males and females and in younger and older persons.

Method

Eighty healthy subjects participated in the study: 20 males and 20 females aged 20 to 30 years, and 20 males and 20 females aged 55 to 65 years.

Subjects were students or office workers with no history of regular use of hand-held vibrating tools. None reported cardiovascular or neurological disorders, connective tissue disease, injuries to the upper extremities, a history of cold hands, or were on medication likely to affect finger systolic blood pressures.

Measures of fingers systolic blood pressure

Finger systolic blood pressures were measured using strain-gauge plethysmography following local cooling in accord with International Standard 14835-2 [2].

The FSBPs were measured simultaneously in the thumb and the index, middle, ring, and little fingers of the dominant hand using a multi-channel plethysmograph (HV*Lab*, ISVR, University of Southampton).

Mercury-in-silastic strain gauges were placed around the distal phalanges at the base of the nail on all five digits. A cuff for air-inflation was fixed around the proximal phalanx of the thumb. Water-filled cuffs were fixed around the middle phalanges of the other four fingers. The FSBPs were measured at 30°C and 10°C with an initial cuff occlusion pressure of 200 mmHg and an occlusion duration of 5 minutes. Increases in finger volumes following pressure reduction were detected by means of the strain gauges according to the criteria given by Greenfield *et al.* [3].

The results of the cold test were expressed as the change of systolic blood pressure in the fingers (test fingers) 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 thumb (i.e. the reference finger) during the examination ($FSBP_{ref,30°} – FSBP_{ref,10°}$):

$$FSBP\%_{10°} = (FSBP_{t,10°} \times 100)/[FSBP_{t,30°} - (FSBP_{ref,30°} - FSBP_{ref,10°})]$$

Experimental procedure
In accord with ISO 14835-2 [2], measurements were performed in a laboratory with a median temperature of 21.6 °C (range 20.4 to 22.2°C) and smoking, drinking of alcohol, and caffeine consumption were restricted.

Each of the 80 subjects attended the laboratory on one occasion. Measurements were made while the subjects were supine with their dominant hand resting on a support alongside their body at the level of the heart. The non-dominant hand was also alongside the body. After acclimatisation for about 30 minutes, subjects lay supine for 10 minutes during which the fingers were instrumented. Finger systolic blood pressures were then measured at 30°C and then at 10°C.

Results
On all five digits and at both temperatures, the median FSBPs were lower for the group of younger females (aged 20 to 30 years) than for the group of younger males.

At 30°C, the reduction in FSBPs in females compared to males was highly significant on the middle finger ($p<0.001$) and marginally significant on some other fingers. At 10°C, the reduction in FSBPs in females compared to males was statistically significant on the middle finger ($p=0.035$).

On all five digits, the median %FSBPs were greater in females compared to males. The difference was statistically significant on the middle finger ($p=0.028$) but not on the other three fingers.

The measured values for both the younger and the older subjects are to be found in the paper.

Discussion
There may be a need to consider the influence of both gender and age when using measurements of finger systolic blood pressure following cold provocation to detect dysfunction in the digits arising from exposures to hand-transmitted vibration [4].

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Finger systolic blood pressure among young adults in relation to gender and hand-transmitted vibration

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Introduction
Measurement of finger systolic blood pressure can be a way to objectify vascular disorder caused by hand-transmitted vibration [1]. The pathogenic mechanism of VWF is not completely understood but digital artery vasospasm is a probable cause. Whether there is a dose-response relationship between exposure to hand-transmitted vibration and finger systolic blood pressure reaction to local cooling is still unclear. Furthermore whether gender or individual factors affect a probable dose-response relationship is not known.

Objectives
To study the association between finger systolic blood pressure and vibration exposure in addition to gender and individual factors.

Population and methods
A study group of 206 young persons were enlisted in a sub-cohort for physical examination and investigations. They were selected based on self reported exposure to hand-transmitted vibration (HTV) in the previous questionnaire, to ensure to have different exposure levels in the study group. The mean age of males was 21.7 years (range 20-25 years) and the mean age for females was 22.0 (range 20-23 years). Effect measurements included physical examination and testing. Exposure and health history was obtained by questionnaires and interviews according to the VIBBRISKS Protocol for Epidemiological Studies of Hand-transmitted vibration (www.vibrisks.soton.ac.uk).

FSP procedure
Finger systolic blood pressure (FSBP) was measured using in the 3rd finger (middle finger) on the right hand on 206 subjects. Measurements were performed according to the VIBBRISKS Protocol for Epidemiological Studies of Hand-transmitted vibration (www.vibrisks.soton.ac.uk). Percentage of finger systolic blood pressure (%FSBP) was calculated as FSBP at 10 degrees cooling divided by FSBP at 30 degrees thermal provocation times 100. Two instruments were used, a) a five channel plethysmograph (HV Lab, IVSR, Southampton, UK) b) a two channel plethysmograph developed by Department Clinical Physiology at Sahlgrenska University Hospital, Göteborg, Sweden. Room temperature was kept at 22 degrees (quartile 1 and 3: 21,4-22,4) using HV Lab instrument and at 18

degrees (quartile 1 and 3: 17.9-18.8) using Clinical Physiology instrument. The reason for the two different temperatures was that the two instruments have standards and reference values for the different room temperatures.

Statistics
Descriptive statistics and multiple linear regressions were computed using SAS 8.4 [2].

Results
For the 162 males with vibration exposure the mean FSBP 10 degrees was 93.5 mm Hg (95% CI 89.4-97.6) and for the 7 females with vibration exposure the FSBP was 74.4 mm Hg (95% CI 59.2-89.6). The mean maximal weighted acceleration for any tool used by the subjects was for the exposed females 3.1 and males 5.4. In a linear multiple regression using FSBP as the dependent variable vibration exposure dose, room temperature and gender were significant factors (Table 1). Vibration exposure dose calculated as maximal weighted any tool, or maximal weighted A(8) or current weighted were significant in the regressions. However, neither duration nor duration times vibration level as measures of vibration exposure dose were significant in the regressions.

Table 1. Multiple linear regressions of FSBP(%) digiti 3 right hand as dependent variable as a function of gender (male=0, female=1), age, room temperature (degrees Celsius) and vibration exposure dose defined in different ways. Parameter estimate given/ probability.

Vibration dose definition	Intercept	Gender	Age	Room temperature	Vibration dose	R-squared
Duration (hours)	29.4/0.07	-7.3/0.19	-0.9/0.35	2.66/0.0006	-0.0022/0.18	0.11/0.0002
Weighted acceleration x duration	30.0/0.06	-7.42/0.18	-0.10/0.34	2.63/0.0005	-0.0005/0.09	0.12/0.0002
Maximal weighted acceleration any tool	41.2/0.01	-12.6/0.03	-0.11/0.09	2.51/0.0005	-2.08/0.003	0.15/0.0001
Maximal weighted acceleration A(8) each tool	31.3/0.04	-8.5/0.11	-0.10/0.31	2.70/0.0002	-4.15/0.03	0.12/0.0001
Current weighted acceleration A(8)	31.4/0.03	-9.7/0.08	-0.11/0.10	2.70/0.0002	-3.72/0.007	0.14/0.0001

If only vibration exposed subjects were entered into the regression the significant relation between FSBP and maximal weighted acceleration persisted. We found no significant relations between FSBP and outside temperature and nicotine use.

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Use of color charts for the diagnosis of finger whiteness

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Introduction
Some authors have suggested that color charts, in addition to medical history, may be helpful for the diagnosis of Raynaud's phenomenon [1].

Objectives
To assess the usefulness of color charts for the diagnosis of finger whiteness in workers exposed to hand-transmitted vibration (HTV).

Subjects and methods
In this study we investigated a group of 146 HTV operators (forestry and stone workers) and 78 control workers, who were examined twice over one-year follow up period. The anamnestic diagnosis of finger whiteness was made on the basis of (i) individual clinician's assessment using a standardised questionnaire and (ii) the use color charts consisting of a series of photographs illustrating various degrees of blanching and cyanosis of the hands. Color charts were shown to the workers at the end of the medical interview. In the controls and the HTV workers, the cold response of digital arteries was assessed by measuring the change in finger systolic blood pressure (FSBP) after local cooling from 30° to 10°C ($FSBP\%_{10°}$).

Results
At the initial investigation, the prevalence of finger whiteness in the HTV workers was 15.8% when based on the medical history alone, and 11.6% when a positive medical history was combined with positive color charts. At the end of the follow-up period, the prevalence of finger whiteness in the HTV workers was 13.7% (medical history alone) and 12.3% (medical history & color charts). Assuming the color charts as the gold standard, the sensitivity and specificity of medical history alone to diagnose finger whiteness was 88.2% and 93.8%, respectively, at the initial cross sectional study, and 94.4% and 97.7% at the end of the follow-up. The positive and negative predictive values (PPV, NPV) of medical history was 65.2% (PPV) and 98.4% (NPV) at the cross-sectional survey, and 85.0% (PPV) and 99.2% (NPV) at the follow up. Random intercept linear regression analysis was used to assess the relation between $FSBP\%_{10°}$ and finger whiteness in both the controls and the vibration-exposed. Age, body mass index, smoking, drinking, systemic disorders, hand trauma or surgery, drugs, and cumulative vibration dose (a^2t) were included in the model as covariates. Data analysis (Tables 1 and 2) showed that the reduction in $FSBP\%_{10°}$ was significantly associated with finger whiteness assessed by either medical history alone ($p<0.005$) or medical history & color charts ($p<0.001$), in both the controls and the HTV workers. However, when the regression models were compared by means of the difference (Δ) in the Bayesan Information Criterion (BIC), there was very strong evidence that the model including finger whiteness assessed by color charts performed substantially better, at least from a statistical viewpoint, for the prediction of the

vasoconstrictor response to cold at the follow up than finger whiteness assessed by medical history alone, in both the controls (Δ BIC=20.8) and the HTV workers (Δ BIC=15.1). In the HTV workers, FSBP%$_{10°}$ was inversely related to the vibration dose accumulated over their working life (0.001<p<0.05).

Table 1. Random intercept linear regression of FSBP%$_{10°}$ on finger whiteness in the control workers (n=78), adjusted for several covariates.

Predictors	**FSBP%$_{10°}$ (%)**	
Finger whiteness (medical history alone)	-20.2(-33.4 to-6.9)†	–
Finger whiteness (medical history & color charts)	–	-49.1 (-65.5 to -32.8)‡
Follow-up time	4.7 (0.7 to 8.7)*	4.8 (1.1 to 8.6)*
Log likelihood	-640.9	-630.6
BIC	1342.6	1321.8

Likelihood ratio test (χ^2,1df):* p<0.05, †p<0.005, §p<0.001. Δ BIC= 20.8

Table 2. Random intercept linear regression of FSBP%$_{10°}$ on finger whiteness in the vibration-exposed workers (n=146), adjusted for several covariates

Predictors	**FSBP%$_{10°}$ (%)**	
Vibration dose (ln($m^2s^{-4}h$))	-4.6 (-7.1 to -2.1)‡	-3.1 (-5.6 to -0.7)*
Finger whiteness (medical history alone)	-17.8(-26.9 to-8.6)†	–
Finger whiteness (medical history & color charts)	–	-29.2 (-39.5 to -19.0)‡
Follow-up time	1.3 (-2.3 to 4.9)	1.8 (-1.8 to 5.5)
Log likelihood	-1296.8	-1289.7
BIC	2656.0	2641.9

Likelihood ratio test (χ^2,1df): *p<0.05, †p<0.005, ‡p<0.001). Δ BIC= 15.1

Discussion

In this study, the administration of color charts, in addition to the medical history, seems to reduce the proportion of false-positive responses for finger whiteness in a population of HTV workers. A learning effect at the follow up survey, however, cannot be ruled out. Random intercept linear regression of FSBP%$_{10°}$ on finger whiteness showed an improvement of the regression model when the assessment of finger whiteness was made by means of the color charts compared with the medical history alone. This finding suggests that the use of color charts in clinical and epidemiological studies may be of help to assist in the diagnosis of Raynaud's phenomenon in HTV workers.

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Diagnosis and prognosis of vascular injuries caused by hand transmitted vibrations in Japan

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Introduction
Peripheral circulatory disturbances are common problem among national forest workers. Patients receive treatments and annual examinations at hospitals. Measurement of finger skin temperature and cold water immersion test (10°C, 10 min) are employed to assess peripheral circulatory disturbances for medico-legal cases in Japan. Finger systolic blood pressure (FSBP) tests are conducted c1inically using the Digimatic 2000 units (Medimatic Co.) that are currently available at only six hospitals in Japan. Multicentric studies have been conducted since 2004 when the Japanese Ministry of Health, Labor and Welfare requested evaluation of the FSBP test for diagnosis of VWF.

Objective
This paper presents a follow-up study among national forest workers and a study about the effects of room temperature on the diagnostic values of FSBP% when testing for VWF.

Methods

(1) Follow-up study
Between 1975 and 1994, 99 men with vibration syndrome received the annual compulsory examination at San-in Rosai Hospital for more than 15 years. All of them were national forest workers. They were treated at their home town. The Stockholm vascular scale and FSBP% on the medical records were collected at every 5 years and used for analysis.

(2) Diagnosis for peripheral circulatory disturbances
A total of 289 subjects, 154 vibration-unexposed subjects (Group A) and 135 vibration-exposed subjects (Groups B, C, and D) participated in clinical examinations over six hospitals in Japan. The subjects in Group A were further subdivided according to age. The vibration-exposed subjects were divided into 3 groups according to the severity of VWF: 21 subjects without VWF (Group B), 31 subjects with no signs of VWF in the previous year (Group C), and 83 subjects with active VWF (Group D). Measurements of FSBP% were conducted in accordance with the International Standard (ISO/DIS 14835-2) using the Digimatic 2000. Cooling temperature and period were 10°C and 5 min, respectively. Measurements were made at two ranges of room temperature 21±1°C and 23±1ºC. Measurement interval was at least 30 min.

Results

(1) Follow-up study
After 15 years, 43.2% and 70.4% of patients who were initially diagnosed as stage 2 and 3, respectively, still suffered from VWF.

(2) Diagnosis for peripheral circulatory disturbances
In Group A, there was no significant difference in the mean value of FSBP% between the age groups within 20~59 years with the room temperature at 21±1°C. The groups with more than 60 years old showed significant lower values of FSBP% compared to the younger groups.

In the room at 21±1ºC, the mean FSBP% for Groups A, B, C and D were 91.1%, 78.1%, 56.1%, and 49.4%, respectively. Significant differences in FSBP% values were observed between Groups A and C, Groups A and D, and Groups B and D. An analysis of mean FSBP% for Groups A, B, C and D over 60 years old with room temperature of 21±1°C were 81.0%, 82.7%, 56.2% and 50.0%, respectively. The FSBP% in Group D showed lower values than those in Groups A and C. Similar results were obtained with 23±1°C.

The ROC curve for the diagnosis of active VWF showed that sensitivity was higher at a room temperature of 21±1°C than at 23±1ºC. Assuming a value of 75% as the normal lower limit for FSBP% at 21±1ºC, the sensitivity and specificity were 78.1% and 81.5%, respectively. The ROC curves obtained from the subjects aged 60 and over indicated that the sensitivity was higher at 21±1°C than 23±1°C. Assuming a value of 65% as the normal lower limit for FSBP% at 21±lºC, sensitivity and specificity were 71.2% and 85.7%, respectively.

Conclusion
Improvement of VWF at Stage 3 is not so expected after medical treatment for more than 15 years. Measurement of FSBP% for assessing VWF should be conducted in an environment with the temperature set at 21±1ºC.

Disorders of the finger's main artery and terminal arteriole measured in Raynaud's phenomena

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Introduction
Vibration-induced white finger is Raynaud's phenomenon (RP) caused by exposure to hand vibration. Chemotherapy-induced RP is a late-effect after treatment for germ-cell cancer with cisplatin, vinblastine and bleomycin. The autoregulation F% of blood flow in the skin of the finger was investigated in men with RP and in their exposed and non-exposed controls. F% was also measured after a short term exposure to hand vibration. The findings were related to the cold reaction of the digital arteries FSBP% and the subjective symptoms of RP.

Subjects and Methods
The following groups of subjects were investigated: Ten men with vibration-induced white finger (VWF); 9 men without RP after same vibration exposure as VWF (HAV); 16 men with chemotherapy-induced RP (CRP); 16 men without RP after same chemotherapy as CRP (CVB); 10 male controls (MC). The anamnestic diagnose of RP was obtained in a medical interview. The stage of RP judged by the Stockholm Workshop scale was 2 (2-3) for the investigated hand in VWF and CRP. None had ischemic or atrophic fingers. The finger systolic blood pressure was measured at 30^{o}C and 10^{o}C in a test using combined body and finger cooling [1]. FSBP% was the ratio between the two pressures, corrected for pressure changes in a reference finger.

The autoregulation of capillary blood flow rate in finger skin is assumed to be executed by the non-neurogenic terminal arterioles [2]. It was tested by raising the finger 20 cm. The reference body posture was lying supine with the finger at the midaxillary line. F% was measured by the local Xenon-133 washout technique at a room temperature of 24ºC [3]. A traumatic Xenon-133 skin labelling was performed on the dorsum of the distal interphalangeal joint. The disappearance of the radioactive depot was externally monitored with a scintillation detector. A two minutes' test period was proceeded and followed by a two minutes' reference period. Washout rate constants of the test period (k_2) and reference periods (k_1 and k_3) were estimated. The relative blood flow rate was defined as: $F\% = 100\ k_2 / 0.5(k_1 + k_3)\ \%$. F% of VWF, HAV and MC was also measured 3 minutes and 60 minutes after a 3 minutes' ipsilateral hand-arm vibration [$L_{h,w}$ = 130.0 dB (129.8-130.4)] by use of an impact drill on a flint stone. The theoretical F% for a completely abolished autoregulation was about 80%.

Results
All men had a normal systolic blood pressure gradient from upper arm to finger. FSBP% and F% are given in Table 1. FSBP% was significantly lower in VWF and CRP than in MC, HAV and CVB ($p<0.05$). F% of MC, HAV and VWF did not differ significantly from 100 before the short term exposure to vibration ($p>0.10$) and were significantly reduced three minutes after the vibration ($p<0.01$). F% of MC sixty minutes after vibration did not differ significantly from

its value before vibration ($p>0.10$). F% was significantly reduced in CRP and CVB compared to F% in MC before vibration ($p<0.05$).

Table1.The arterial reaction to cold, FSBP%, and the arteriolar autoregulation, F%, in the fingers of 5 subject groups. F% was also measured 3 and 60 minutes after a three minuts' vibration of the ipsilateral hand. Values are given as medians (ranges).

Group	No	FSBP%	F% before vibration	F% 3 min after vibration	F% 60 min after vibration
VWF	10	30 (0 - 75)*$	99 (96-101)	82 (73-100)*º	
HAV	9	78 (20- 96)	96 (92-109)	80 (67- 90)*º	
MC	10	85 (72- 88)	99 (97-111)	80 (71- 94)*º	100 (96-106)
CVB	16	78 (30-104)	82 (52-106)*		
CRP	16	0 (0 - 70)*$	75 (44-114)*		

*Significantly different from corresponding value of MC before hand vibration ($p<0.05$).

º Significantly different from its corresponding value before hand vibration ($p<0.01$).
$ Significantly different from corresponding value of HAV or CVB ($p<0.05$).

Discussion

The autoregulation of the capillary blood flow rate in the skin of the finger was normal in men who had used vibrating hand tools for 16 years (9-19). It was equally impaired in VWF, HAV and MC three minutes after the short term exposure to hand-arm vibration. The abolished autoregulation in MC was completely restored within sixty minutes. This indicates a rapid and complete reversibility of the vibration-induced disorder. An abolished autoregulation was detected in CRP and CVB. It indicates that the treatment with chemotherapy induces a prolonged toxic after-effect on the autoregulatory function. An impaired autoregulation indicates an impaired function of the smooth muscle cells of the non-neurogenic terminal arterioles [2].

The normal pressure gradient from upper arm to finger at 30ºC indicates that VWF and CRP are vasospastic types of RP. The exaggerated arterial contraction to cold in CRP may be induced through an exaggerated sympathetic stimulus acting on normal smooth muscle cells of the of the main finger arteries. An increased muscular reaction to a normal sympathetic stimulus seems less possible as the induced disorder of the terminal arteriole was an impaired function of the smooth muscle cells. The exaggerated arterial reaction to cold in VWF may have more biological causes including an exaggerated or normal sympathetic stimulus acting on normal or hyperreactive smooth muscle cells of the main arteries.

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Exploring whether or not hand transmitted vibration can cause ulnar artery damage (hypothenar hammer syndrome)

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A worker in the UK has been awarded damages for palmar arch disease in a claim for HAVS. Review of the published literature reveals a lack of epidemiological evidence regarding the role – if any – of exposure to hand transmitted vibration in the aetiology of HHS.

In 1993, Kaji et al [1] reported on 24 cases of HHS among a series of 330 vibration exposed workers, suggesting that HGHS accounted for 8% of cases. Of those 24, 12 were coal miners and rock drillers, 9 were forestry workers, 1 was a carpenter, 1 used an impact wrench and 1 used hand tools in an iron foundry. The later study by Ferris et al (2000) [2] reported on a series of 21 cases of HHS and noted that all had a history of occupational exposure to repetitive trauma. They concluded that the ulnar artery had to be intrinsically abnormal to be susceptible to such trauma, and therefore for the development of HHS. Exposure to hand transmitted vibration was not defined for those cases, although the job description of 19 suggested possible occupational exposure. Two cases of HHS have been reported in association with systemic sclerosis, of which one was in a silica worker [3,4].

Two important issues arise from the knowledge that HHS may occur in these occupational groups:

1. Does exposure to hand transmitted vibration cause or contribute to the development of HHS?

and

2. Is the diagnosis of HAVS correct in cases where there may be repetitive hypothenar trauma as well as exposure to hand transmitted vibration?

There are two potentially plausible causes of ulnar artery damage from vibratory tools, being either a diffuse effect of vibration, or repetitive trauma resulting from the vibration of the tool as it is held. As with many other health effects of vibration, the differentiation between the effects of that vibration and other inseparable aspects of the work may prevent clarification of the first question. It is suggested that those papers which refer to exposure to hand transmitted vibration as a cause of HHS have not made the distinction between these factors.

One group that figures highly among the reports of HHS is that of motor mechanic. There have been various reports of HAVS occurring following use of impact wrenches/ nut runners, which, in general, have not demonstrated consideration of the alternative diagnosis of HHS.

It has been accepted practice to undertake Allen's test as part of the assessment of HAVS, although the rationale for that has not always been clear. However it is undoubtedly a useful test for detecting ulnar artery input to the palmar arch circulation, although there have been suggestions of unreliability and poor reproducibility. Use of hand held Doppler is likely to be more reliable [5].

The potential causes of ulnar artery damage are either a diffuse effect of vibration, repetitive trauma resulting from the vibration of the tool as it is held against the hypothenar eminence or a combination of the two. While differentiation of these components may be helpful, reduction of duration of exposure is likely to address both of these issues irrespective of the vibration characteristics of the tool. In the absence of clear epidemiological evidence, a consensus medical opinion is needed as to whether or not HHS should be regarded as part of the hand arm Vibration Syndrome.

It is suggested that assessment of ulnar collateral flow should be routinely undertaken by Doppler when undertaking surveillance of vibration exposed workers, and that identification of ulnar artery input may be important in pre-placement assessments, as well as influencing decisions on clinical management of the symptomatic case.

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Hand-Arm Vibration, Biomechanical Load and Nerve Entrapment: a Diagnosis by Degree

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Introduction

Whether or not hand-arm vibration (HAV) exposure predisposes workers to carpal tunnel syndrome (CTS) remains controversial. There are at least four outstanding issues: 1) hand arm vibration syndrome (HAVS) appears to induce mechanoreceptor injuries in the fingertips that cause paresthesias; 2) HAV produces injury to myelinated nerve fibers distal to the carpal tunnel, mimicking nerve entrapment; 3) biomechanical risk factors co-exist with HAV, producing potential confounding and interactive effects; and 4) CTS is a protean disease with a poorly understood natural history and workplace exposure only add to its complexity.

The HAVIC (Hand-Arm Vibration International Consortium) is a multi-national research group, organized to better define exposure-response relationships from segmental vibration through application of longitudinal study design. Study populations included 217 North American shipyard workers, 94 dental hygienists using ultrasonics, an inception cohort of 56 Swedish truck cab workers and 34 controls, and 61 Finnish forest workers. Evaluations tools included, vibrometry to assess vibrotactile threshold (VTT) independently of nerve conduction. Fractionated nerve conduction was also performed providing comparisons of SNCV in the digits with cross-wrist and longer track measurements. Segmental SNCV followed established methods [1,2], vibrotactile thresholds (VTT) were ISO consistent [3]. In the follow-up studies, acclimatization and surface warming for NCV testing were replaced by whole body exercise-induced warming [4], because segmental SNCV seemed unacceptably unstable after surface warming [5]. Protocol alteration meant the potential loss of longitudinal, however, an opportunity to compare SNCV using two different warming techniques, albeit separated in time. The variety of assessment tools – questionnaire and hand diagrams, diagnosis by study physician, past treatment history, and electrophysiological studies – allows for comparative and contingent case definitions.

Table 1. Characteristics of HAVIC cohorts at Baseline				
Cohort	Baseline Test Year	Subjects Tested	+ Hand Paresthesias	CTS Cases Physician Dxed Dominant Hand
Shipyard Workers	2001	217	146 (69%)	74 (35%)
Dental Hygienists	2002	94	42 (45%)	14 (15%)
Forestry Workers	2003	61	17(29%)	3 (6%)
Truck Cab Workers	2002	54	7 (12%)	2 (4%)
Controls	2002	36	4 (11%)	0 (0%)

Results

As Table 1 shows, whereas hand paresthesias were common in shipyard workers, forest workers, and dental hygienists, CTS was sufficiently numerous for further analyses among shipyard workers and dental hygienists. Three different diagnostic criteria for CTS were used: diagnosis by the study physician, pre-existing diagnosis by an outside physician, and a combination of anatomic diagram and questionnaire responses. Among shipyard workers with follow-up data, the study physician diagnosed CTS in 36% of shipyard workers in 2001 and 24% at follow-up 21/2 years later, the comparable percentages were 28% and 40% for outside physician diagnosis, and 38% and 32% for self-report. There was a striking absence of overlap between diagnostic methods. Fifty-eight percent of shipyard workers were diagnosed as CTS cases by at least one of the diagnostic metrics, but only 11% were positive in all three metrics. Being diagnosed by more than one method did not generate a more specific case definition. SNCV, particularly in the transpalmar segment, could not be differentiated between single or multiple CTS case definitions. There were some differences between diagnostic methods: the study physician seemed to include more cases with a broader vibration-related neuropathy, and the outside physician diagnoses tended to be more in agreement with SNCV results. Following systemic warming, the marked difference between CTS cases and non-cases in the digital segments, that accompanied cutaneous warming, largely disappeared. SNCV in the transpalmar segment was slightly higher with systemic warming, despite the additional age and exposure.

The patterns in dental hygienists were quite different. Like the shipyard workers, there was an increase in digital SNCV with systemic warming compared with cutaneous warming. Unlike the shipyard workers, transpalmar SNCV declined by almost 10% in both CTS cases and controls.

In the shipyard workers, CTS proved to be a volatile diagnosis over time. Among study physician diagnosed cases, 53% were CTS negative in 2001 and 2004, 22% were CTS positive in both years, 14% became negative after being positive and 11% became positive after being negative. Sensorineural status based on the Stockholm Scale [6] was largely unchanged, and VTT showed a slight and uniform increase from 2001 and 2004, whereas there was considerably more volatility with CTS case definitions.

Discussion

The support other observations that CTS is a dynamic condition and that different case definitions have limited overlap because they capture different aspects of the disease cycle and content. HAV exposure confounds CTS diagnostics as a competing source for paresthesias, and because of an apparent influence on nerve conduction.

Conclusions are:

– CTS prevalence is reducible to near background levels when vibratory tool exposures and workplace biomechanical risks are reduced to conventional consensus standards. HAV alone, in the absence of other workplace factors, does not appear to be the primary concomitant of CTS risk.
– Clinical case definitions of CTS based on diagrams and self-assessment, clinical evaluation, and personal physician's prior diagnoses seem to have limited overlap.
– Combining clinical criteria to create a more narrow or specific case definition of CTS does not appear to predict nerve conduction findings.
– Warming method and perfusion appear to affect median nerve conduction velocity, most dramatically in CTS cases with HAV exposure.
– The natural history of CTS suggests a protean disorder with considerable flux in case status over time.
– Different CTS profile between occupations suggests a spectrum of disorders.

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Negligent exposures to hand-transmitted vibration

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Introduction

Employers who fail to take reasonable steps to minimise risks to their employees arising from exposures to hand-transmitted vibration may be considered negligent. This paper considers what is negligent and how to anticipate the consequences of negligent exposures.

Employers may not be negligent if they could not have known that a disorder would ensue, or if they were incapable of preventing the disorder without taking unreasonable precautions. Where an employer should have anticipated a risk and failed to take reasonable measures that would have reduced the risks, the employer is negligent. Employers may argue that they are only responsible for the difference between what did happen to an employee and what would have happened if they had taken all reasonable measures to minimise the risks.

Employers need to know the consequences of their actions and inactions in order to decide what actions they should take. In part, an employer needs to know the benefit likely to be achieved by reducing vibration exposure (both the magnitude of vibration and the duration of exposure to vibration). In addition, an employer needs to know whether society (e.g. the courts) will hold them fully responsible for any disease that develops while a worker is in their employment or whether they will only be considered responsible for that portion of the disease that arose from exposures they could have prevented by reasonable actions.

Objectives

This paper considers the implications of alternative procedures that allow for 'non-negligent exposures' to hand-transmitted vibration, so as to guide employers and others towards appropriate actions. Standards, guides and action levels offering relationships between vibration exposure and disease have not been developed to define negligence and are not sufficient for this purpose.

Methods

It is considered whether the consequences of negligence by an employer may be quantified on the basis of either: (a) the severity of the disease, (b) the daily vibration exposure, (c) the exposures required to produce a defined probability of persons with disease, (d) a combination of methods (b) and (c), (e) reasonably achievable vibration magnitudes and exposure durations, (f) the percentage of days on which a limiting daily exposure is exceeded, (g) the delay in the onset of the disorder that could have been achieved if the employer had taken reasonable measures to prevent disease, and (h) various other methods.

It is assumed that a fair apportionment of an employer's responsibilities can be based on a few simple principles:

(i) An employer is responsible for some or all of the consequent disability in a worker when, on the balance of probabilities, the worker would not have developed a significant disability if the employer had taken all reasonable preventative measures;

(ii) The employer's responsibility can be apportioned if the worker would probably have developed a disability even if the employer had taken all reasonable precautions. The extent of the apportionment should be based on the difference between the impact that the disease actually had on the worker and the impact that would have arisen if the employer had taken all reasonable preventative measures.

The negligence of an employer in controlling risks is considered in two parts:

(i) the extent to which exposures to hand-transmitted vibration were negligent and the effects of this negligence on the employee, both at present and in the future (this requires consideration of both negligent and non-negligent exposures, taking into account the vibration magnitudes and the exposure durations);

(ii) the extent to which the employer was negligent in respect of 'other preventative measures' (e.g. warning, education, training, health surveillance) and the effects of this negligence on the employee, both at present and in the future.

An apportionment between negligent and non-negligent exposures assumes that it is understood: (a) what did happen as a result of the employee's actual exposure to vibration, and (b) what would have happened if the employee had been exposed to the greatest 'non-negligent exposure'. A similar approach can be used when considering the impact of the 'other preventative measures' that employers can take in respect of warning, education, training, and health surveillance.

Discussion

The disability a worker would have suffered if the employer had taken all reasonable measures might be estimated from a 'non-negligent vibration exposure' – a threshold level of exposure (either a daily exposure or a lifetime dose) below which the employer is not responsible for the consequences [1]. However, there is no known 'safe exposure', the methods in current standards are not sufficiently accurate for this purpose, and they do to allow for individual susceptibility [2,3].

Alternatively, a 'non-negligent disability' (e.g., determined from a threshold level of disease above which an employer is wholly responsible for any disability) might be suggested. The negligence is then wholly a consequence of failing to provide sufficient health surveillance to prevent the development of significant disease. This assumes that some degree of disease is acceptable and that disease can predict disability. It may have undesirable consequences for the employment of those reaching the threshold level of disease.

Quantifying negligence from the estimated delay in the onset of disorder that would have been achieved with non-negligent exposures seems fair and reasonable for both employers and employees. The estimation of this delay takes account of individual susceptibility and requires fewer assumptions than the calculation of a 'non-negligent vibration exposure'. The method is illustrated by examples.

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