

Work ability in vibration-exposed workers

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Background	Hand–arm vibration exposure may cause hand–arm vibration syndrome (HAVS) including sensorineural disturbances.
Aims	To investigate which factors had the strongest impact on work ability in vibration-exposed workers.
Methods	A cross-sectional study in which vibration-exposed workers referred to a department of occupational and environmental medicine were compared with a randomized sample of unexposed subjects from the general population of the city of Gothenburg. All participants underwent a structured interview, answered several questionnaires and had a physical examination including measurements of hand and finger muscle strength and vibrotactile and thermal perception thresholds.
Results	The vibration-exposed group (47 subjects) showed significantly reduced sensitivity to cold and warmth in digit 2 bilaterally ($P < 0.01$) and in digit 5 in the left hand ($P < 0.05$) and to warmth in digit 5 in the right hand ($P < 0.01$), compared with the 18 referents. Similarly, tactilometry showed significantly raised vibration perception thresholds among the workers ($P < 0.05$). A strong relationship was found for the following multiple regression model: estimated work ability = $11.4 - 0.1 \times \text{age} - 2.3 \times \text{current stress level} - 2.5 \times \text{current pain in hands/arms}$ (multiple $r = 0.68$; $P < 0.001$).
Conclusions	Vibration-exposed workers showed raised vibrotactile and thermal perception thresholds, compared with unexposed referents. Multiple regression analysis indicated that stress disorders and muscle pain in hands/arms must also be considered when evaluating work ability among subjects with HAVS.
Key words	Hand–arm vibration syndrome; pain and stress disorders; vibration exposure; work ability.

Introduction

Hand–arm vibration exposure may cause hand–arm vibration syndrome (HAVS), which is characterized by ‘vibration white finger’ (VWF), sensorineural symptoms and musculoskeletal disturbances [1]. The development of these symptoms depends on several factors, e.g. the intensity and duration of exposure, the type of processes involved and the tools used [2], as well as genetic and ergonomic factors. The neurological component of HAVS includes segmental degeneration, axonal atrophy and degeneration and disorders of the cell bodies [2]. Nerve conduction studies, regarded as the gold standard for assessing peripheral nerve damage, are, however, insensitive to abnormalities that may appear in the fingertips of vibration-exposed workers. In these areas, quantitative sensory testing (QST) has a greater potential to detect early signs of vibration-related injuries [3], but other factors such as age, gender and finger

temperature must also be considered. The use of several different QST tests instead of a single test increases the proportion of subjects with detected quantitative skin sensory disorders. Vibration exposure may affect large myelinated nerves ($A\beta$) that respond to touch, pressure and vibration exposure. Small sensory nerves (myelinated $A\delta$ -fibres and unmyelinated C-fibres) can also be affected, which will decrease the patient’s thermal (cold and warm) and pain perception. In some cases, the thenar muscles may undergo necrosis, fibrosis and fibre-type regrouping, indicating that vibrating tools may cause direct damage to the muscles as well as to the nerve supply [4]. The concept of work ability was defined in 1981 and is based on the stress–strain concept and balance model where human health resources correspond to work demands in a healthy and balanced way [5]. Later, a work ability index (WAI) was constructed and

validated [6,7]. In a study by Ilmarinen *et al.* [5] based on >8000 subjects, health, functional capacities and work factors each explained about one-third of changes in the WAI. In older workers (55–64 years), the same pattern was observed. The test–retest reliability for the WAI questionnaire has been found to be satisfactory [8].

In a previous investigation, the influence of psychological status on work ability in vibration-exposed workers was studied, using the Hospital Anxiety and Depression Scale [9]. This study of vibration-exposed workers with varying stages of vibration-induced neuropathy aimed to investigate the impact of factors that may affect work ability, e.g. age, gender, vibration exposure, duration of symptoms, medication, muscle pain and stress levels.

Methods

The study was approved by the ethical committee at the University of Gothenburg. The study sample consisted of vibration-exposed workers, referred to the department of Occupational and Environmental Medicine in Gothenburg from 1 January 2005 to 31 December 2007 for investigation of vibration-related symptoms and signs. They were compared with an unexposed reference group collected from an age- and gender-matched random sample of 400 subjects from the general population of the city of Gothenburg. Of these 400 subjects, ~1 out of 20 was willing to participate. The study was conducted from 1 January 2008 to 31 December 2010.

Those workers and referents who agreed to participate were contacted by mail and then by telephone and asked to provide signed written consent. Participants then visited the clinic where they spent ~3–4 h completing several questionnaires and undergoing a medical examination and several tests. They were asked to avoid vibration exposure on the day of the measurement and to refrain from using tobacco and coffee ≥ 1 h before the testing started. All neurophysiological tests were performed at room temperature, ~21–22°C, after an adjustment period at the department for ~1 h. During that period, the subjects completed the questionnaires. None of the participants had previously suffered from frost damage.

None of the participants had undergone any of the tests during the year before the study. The person who administered the tests had extensive experience in these testing procedures. The questionnaires included questions about work and medical history, use of tobacco and alcohol, use of vibrating tools (years), symptoms related to vibration exposure (VWF, numbness, tingling, vibration-induced neuropathy), general health status and work ability. Work ability was estimated using the WAI [6,7]. Pain in hands/arms was defined by the question ‘How severe would you rate your current pain in your hands and arms (11-grade scale from no pain to worst imaginable pain)?’. Stress was described as ‘a condition where you feel tense, restless and anxious and have difficulty

sleeping at night because you think about problems all the time’. The question asked was ‘Do you currently feel such stress (5-grade scale from not at all to very much)?’ A standardized medical examination was performed by an experienced physician. The neurophysiological tests included dynamometer grip measurements and determination of thermal (TPT) and vibration perception thresholds (VPT). Hand grip strength was determined by a Baseline® Hydraulic Hand Dynamometer (Fabrication Enterprises Incorporated, New York, NY, USA) through a standardized procedure. The mean of three measurements was calculated for both hands. For the measurement of finger muscle strength, a mechanical pinch gauge (PG-60; North Coast Medical, San José, CA, USA) was used [10]. The key grip strength (Pinch key) and the three-digit pinch (Pinch 3-Chuck) were measured using the mean of three measurements in each hand. Measurements of vibrotactile thresholds were performed by delivering sinusoidal vibrations at seven frequencies (8, 16, 32, 64, 128, 256 and 512 Hz) by a vibration probe (diameter 4 mm) to the pulp of digits 2 and 5 in both hands (the up-and-down method of limit; von Békésy method) and registering the subject’s response, using the VibroSense Meter® system (Vibrosense Dynamics, Malmö, Sweden). The forearm and the wrist of the participant were supported and the test did not start until the skin temperature of the subject’s forefinger exceeded +28°C. The magnitude of the vibration was increased until the patient depressed the response button. The vibration magnitude was then decreased until the patient released the response button. Thereafter, the amplitude of the stimulus began to rise again. The rate of change of the vibration amplitude was 3 dB/s and there were six reversals for each frequency. By connection to a computer, the individual results were compared with an age-corrected reference zone. Ear protective devices were used by all participants to mask the noise from outdoor and indoor sources. A sensibility index (SI) was calculated by dividing the area under the curve from the patient with the corresponding area for the reference population. An SI index < 0.8 indicates an abnormal response. Several studies have shown good reliability for measurements of vibrotactile thresholds. The day-to-day intraclass correlation coefficients exceeded 0.94 in studies of patients with diabetic neuropathy [11]. Quantitative testing of thermal sensibility was performed with a unidirectional stimulation technique using a commercially available test instrument with a Peltier element-based thermode of 25 × 50 mm (Termotest®; Somedic Sales AB). The forearm and the wrist of the participant were supported and the tests were performed on the pulps of digits 2 and 5 on both hands. The starting temperature was 32°C. The perception thresholds to non-painful cold and warmth, respectively, were obtained by delivering six cold stimuli, followed by six warm stimuli at a random pattern, at a rate of 1°C/s. The subject was

instructed to press a button of a handheld switch at the first sensation of cold and warmth. The average of the last four assessments for cold and warmth was calculated as the cold or warmth perception threshold.

Parametric statistics were used to compare elements that showed a normal distribution (checked by normal probability plots, Levene's test). Associations between the studied variables were tested by calculating Pearson correlation coefficients (r). P values <0.05 were regarded as statistically significant. Multiple linear regression analysis was performed with the subject's estimated current work ability as the dependent variable and with age and variables reflecting symptoms and signs with a high correlation to WAI as explanatory variables. Model fits were checked by means of residual analysis. All calculations were performed with the IBM SPSS Statistics for Windows, Version 22.0 [12].

Results

The study sample consisted of 47 (36 males and 11 females) of 71 vibration-exposed workers: 24 workers were unwilling to participate. The vibration-exposed group had a mean age of 50 ± 12 years (range 25–70 years) and a median vibration exposure time of 16 years. The reference group ($N = 18$) had a mean age of 38 ± 16 years (range 21–69 years). No significant differences between workers and referents were noted for the hand and finger muscle strength tests (Table 1). Determination of thermal thresholds showed significantly raised warmth thresholds and significantly impaired cold thresholds among the exposed workers (digit 2 bilaterally, $P < 0.01$; digit 5 left

hand, $P < 0.05$ and in digit 5 right hand, warmth threshold only, $P < 0.01$). Tactilometry showed significantly raised vibration perception thresholds in the exposed workers in digit 2 ($P < 0.05$) and digit 5 bilaterally ($P < 0.01$). None of the participants showed any signs (Phalen's and Tinel's tests) of carpal tunnel syndrome.

The estimated current work ability was considerably higher among the referents (mean 8.6 on a 0–10 scale) than among the exposed workers (mean 5.6). A multiple regression analysis was performed with estimated work ability as the dependent variable and with variables reflecting symptoms and signs with a high correlation to WAI as explanatory variables. The strongest multiple correlation coefficient was found for three explanatory variables (age, current stress level, dichotomized from a 5-grade scale; current pain in hands/arms, dichotomized from an 11-grade scale) associated with WAI. A strong relationship was found for this model with the following equation:

Estimated work ability = $11.4 - 0.07 \times \text{age} - 2.3 \times \text{current stress level} - 2.5 \times \text{current pain in hands/arms}$ (multiple $r = 0.68$; $P < 0.001$). Corresponding 95% confidence intervals were the following: age -0.11 to -0.03 ; current stress level -3.4 to -1.2 and current pain in hands/arms -3.8 to -1.3 . Of these three explanatory variables, current stress level (single item, Beta -0.40) and current pain in hands/arms (Single item, Beta -0.41) made the largest unique contributions to the model followed by age (Beta -0.33). The vibration exposure, estimated as the number of vibration-exposed years, was however not included in the model. Other variables, e.g. age, gender, the neurophysiological tests shown in Table 1, duration

Table 1. Median values and ranges of test results for hand grip, pinch grip, '3-Chuck grip', vibration perception threshold and temperature perception threshold in vibration-exposed workers and referents

Variables	Workers	Referents	P value
Hand grip, right hand (kg)	40 (8–74)	42 (23–64)	NS
Hand grip, left hand (kg)	43.2 (4–82)	39.3 (24–69)	NS
Pinch grip, right hand (kg)	9.9 (3–15)	8.8 (6–14)	NS
Pinch grip, left hand (kg)	10 (2–15)	8.8 (6–14)	NS
3-Chuck grip, right hand (kg)	8.6 (3–14)	8.2 (6–14)	NS
3-Chuck grip, left hand (kg)	8.3 (2–15)	7.9 (6–15)	NS
VPT, digit 2, right hand (SI index)	0.83 (0.26–1.23)	0.94 (0.55–1.24)	<0.05
VPT, digit 2, left hand (SI index)	0.80 (0.18–1.13)	1.08 (0.71–1.49)	<0.001
VPT, digit 5, right hand (SI index)	0.79 (0.09–1.14)	0.94 (0.47–1.42)	<0.01
VPT, digit 5, left hand (SI index)	0.79 (0.05–1.07)	0.99 (0.64–1.54)	<0.001
TPT cold, dig 2, right hand ($^{\circ}\text{C}$)	25.7 (10–30)	27.5 (16–31)	0.001
TPT warm, dig 2, right hand ($^{\circ}\text{C}$)	41.8 (34–50)	36.8 (34–48)	<0.01
TPT cold, dig 2, left hand ($^{\circ}\text{C}$)	25.7 (10–31)	28.9 (22–31)	<0.01
TPT warm, dig 2, left hand ($^{\circ}\text{C}$)	42.2 (34–50)	36.8 (34–47)	<0.01
TPT cold, dig 5, right hand ($^{\circ}\text{C}$)	20.9 (10–30)	24.4 (16–30)	NS
TPT warm, dig 5, right hand ($^{\circ}\text{C}$)	43 (34–50)	37.8 (34–48)	<0.01
TPT cold, dig 5, left hand ($^{\circ}\text{C}$)	21.4 (10–31)	27.3 (10–31)	<0.05
TPT warm, dig 5, left hand ($^{\circ}\text{C}$)	4 (34–50)	37.1 (34–48)	<0.01

NS, non-significant; TPT, temperature perception threshold; VPT, vibration perception threshold.

of symptoms and medication did not meet the inclusion criteria and did therefore not contribute to the model.

Discussion

In multiple regression analysis of the data from this study population, a strong association with work ability was noted for the explanatory variables current stress level and current pain in arms/hands, giving a high R^2 value around 0.47 ($P < 0.001$). The crude estimate of vibration exposure used (number of vibration-exposed years) was not included in the model, but it is possible that a more refined vibration exposure calculation, considering both vibration amplitude and duration of exposure for each vibrating tool used, could have given a higher R^2 value. Several other factors may also influence the work ability of vibration-exposed subjects, including common occupational exposures such as dust, noise, vibration, humidity, high temperature, ergonomic factors and the climate at work [7]. Stress at work has been shown to affect the mental health and well-being of government employees [13] and the risk of early retirement increases if workers experience poor work ability, frequent emotional exhaustion, low organizational commitment and low job control [14].

In our study, pain in the hands and stress had a strong impact on subjects' work ability. Similar results have been reported in a study of patients with systemic sclerosis [15]. In a study of 1100 subjects from the public sector several factors, e.g. gender, presence of musculoskeletal disorders, work pressure, monotonous work, social support from superiors, full-time work and unsatisfactory social contacts, were significantly associated with the need for recovery after work [16]. High levels of perceived work stress were a risk factor for decreased psychological health as shown by a poorer work ability index among Italian call centre workers [17]. Several workplace stressors, e.g. lack of support from colleagues and supervisors and a high workload, are statistically associated with a decreased work ability index [18]. In both men and women and for different types of work, work ability is influenced by a combination of high workload, high level of stress symptoms and the presence of a disease [19]. Other factors must also be considered however. In a previous study, we found that psychological status, assessed by the Hospital and Anxiety Depression Scale, had a considerable impact on work ability [9]. Thus a multidimensional approach, including psychological factors, is needed when studying work ability in vibration-exposed workers.

In a study by Sakakibara *et al.* [20], patients with HAVS displayed increased vibrotactile thresholds, decreased grip strength and reduced hand function. Contrary to these findings no significant differences between workers and referents were noted for hand grip and finger grip strength in our study. Long-term exposure to vibration

may, however, lead to muscular dysfunction, which may be due to sensory disturbances, vibration-induced changes in the muscles or vascular disturbances [21]. Hand muscles seem to be affected earlier than the forearm muscles, suggesting that grip strength tests may not be a sensitive tool for assessing muscular dysfunction in the early stages of HAVS [21].

The vibration-exposed workers in our study showed impaired cold and warmth thresholds in digits 2 and 5 bilaterally, indicating signs of thin fibre neuropathy. In the clinical setting the first sign of a distal neuropathy is often pathological cold and warmth thresholds, affecting the A δ and C-fibres. Nilsson *et al.* [3] found a low correlation and agreement between the modalities for cold and warmth, suggesting that separate tests for these modalities may be advantageous, instead of using a single measurement such as the neutral-zone gap. In their study, vibration-exposed workers with decreased sensitivity to cold could still have normal results for warmth thresholds. Thermal sensory impairment has also been found to be related to the cumulative exposure to vibration. However, the effect of age must also be considered as it can influence both thermal and vibrotactile perception thresholds. Thermal thresholds may be affected also after short-term exposure in young workers showing reduced thermal perception for digit 2 compared with digit 5 and for females compared with males [3]. If the vibration exposure continues, larger myelinated nerve fibres (A β) may also be affected. In our study, this is demonstrated by raised VPTs among exposed subjects. In a Finnish study, a dose-response relationship was reported between cumulative lifetime hand-arm vibration dose and the development of white fingers, sensorineural symptoms and symptoms of carpal tunnel syndrome [22]. A significant dose-response relationship between hand-arm vibration exposure and abnormal vibration perception thresholds has been found in several studies. Lundström *et al.* [23] found the most pronounced deterioration in the frequency range mediated by Pacinian corpuscles (63–500 Hz). Similar findings were observed in a cross-sectional study of 142 young male machine shop and construction workers who in spite of a fairly short hand-arm vibration exposure showed a tendency to raised VPTs (125 Hz; digit 2 bilaterally), compared with referents [24].

Short-term effects are also common. In an experimental study of the rat-tail model, decreased sensitivity of the A β fibres was noted after acute vibration exposure [25]. The temporary threshold shift of vibration sensation has been reported to increase significantly with increasing gripping force in a study of six healthy subjects gripping a handle with different forces (5–80 N) [26]. In an experimental study, the subjects grasped a handle vibrating at three different amplitudes and at three frequencies. After ~30 min of exposure, increased VPTs were observed and

paresthesia and numbness developed. The effects were greater for 125 Hz compared with 31.5 and 500 Hz, respectively [27].

In conclusion, work ability among vibration-exposed workers in this study was mainly influenced by current stress levels and current hand/arm pain, followed by age. The exposed workers showed significantly increased VPTs for frequencies from 8 to 500 Hz as well as reduced sensitivity to cold and warmth in digits 2 and 5 bilaterally, compared with the reference group. Conditions such as stress disorders and hand/arm pain should therefore be considered when evaluating the work ability of vibration-exposed workers.

Key points

- Vibration-exposed workers showed impaired temperature perception thresholds and vibration perception thresholds, compared with unexposed referents.
- The estimated current work ability was significantly lower among the vibration-exposed workers than among referents.
- Stress disorders and pain in the hand/arm had the strongest impact on the reduced work ability in vibration exposed workers. These factors must therefore be considered when studying work ability in such exposure groups.

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Conflicts of interest

The authors declare that they have no competing interests.

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Hunting canaries

As one of the surgical consultants at medical school warned, ‘Sparrows are commoner than canaries’. But the case I have in mind followed a series of canaries, so I was in full canary-spotting mode. The differential diagnosis of red eye does not usually include being stabbed in the eye by an unpeeled banana. Then there was the airman who was attacked by a screaming rabbit while he was cycling home from work. And the little girl who had to be freed when the cinema seat she had been sitting on flipped. At the time, one of my hospital roles was to head the Board deciding medical categories for RAF personnel in Germany. The particular patient that day had noticed a lump under his left arm 4 years before. Biopsy proved it to be an anaplastic secondary melanoma. He had a block dissection of the axilla. Intensive investigation, including whole body screening, failed to discover any primary. A year later, he had a lump under the other arm. Biopsy this time showed reactive hyperplasia.

Now, a further 3 years later and still well, he wanted to be able to return to his specialist role as a parachute jumping instructor. On taking his history, I noticed that his glasses were extremely clean, unlike my usually dusty and smeared lenses. He confirmed that they were new but said that they were not very good, particularly the right eye. On looking with the ophthalmoscope I could only see grey fuzz. I dropped the blinds and turned out the lights. Still only grey fuzz. The canaries started chirping. I knew about melanoma of the choroid, but could you have amelanotic melanoma of the choroid? Fortunately, we had a consultant ophthalmologist just down the corridor and, intrigued by the story, he saw him immediately. Within 5 minutes, I had my answer. The patient had a mature cataract. Which only goes to show that, as a late Texan colleague of mine put it: ‘The hoofbeats you hear outside your window are usually horses, not zebras’.

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