Adverse Health Manifestations in the Hands of Vibration Exposed Carpenters - A Cross Sectional Study

Eva Tekavec (eva.tekavec@med.lu.se)  
Lunds Universitet  
https://orcid.org/0000-0003-1246-8471

Lotta Löfqvist  
Lund University: Lunds Universitet

Anna Larsson  
Lund University: Lunds Universitet

Karín Fisk  
Lund University

Jakob Riddar  
Lund University: Lunds Universitet

Tohr Nilsson  
Umeå Universitet Medicinska fakulteten: Umea Universitet Medicinska fakulteten

Catarina Nordander  
Lund University: Lunds Universitet

Research

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Abstract

Background
Despite EU regulatory standards, many workers suffer injury as a result of working with hand-held vibrating tools. Our aim of this study was to investigate whether carpenters, a highly exposed group, suffer more injuries to their hands than painters, a group assumed to be less exposed to vibration.

Methods
193 carpenters and 72 painters, all men, answered a questionnaire and underwent a clinical examination to identify manifestations of neural and vascular origin in hands. Neurosensory affection was defined as having at least one symptom in the fingers/hands (impaired perception of touch, warmth, or cold, impaired dexterity, increased sensation of cold, numbness or tingling, or pain in the fingers/hands when cold) and at least one clinical finding (impaired perception of touch, warmth, cold, vibration, or two-point discrimination). Logistic regression was used to calculate odds ratios (OR) and 95% confidence intervals (CI).

Results
Neurosensory affection was fulfilled for 31% of the carpenters and 17% of the painters, age-adjusted OR 3.3 (CI 1.6–7.0). Among carpenters with neurosensory affection 18% reported interference with daily life activities, the most common symptoms being increased sensation of cold, numbness and pain in the fingers/hands when cold, the most common clinical findings were impaired perception of touch and vibration. Neurosensory affection was found in 12% of young carpenters (≤30 years old). No difference was found in the prevalence of white fingers between carpenters and painters.

Conclusions
Carpenters showed more symptoms and clinical findings of neurosensory affection than painters, probably due to vibration exposure. Also young carpenters showed signs of neurosensory affection, which indicates that workers at today’s working conditions are not protected against injury. This underlines the importance of reducing exposure to vibration, and conducting regular medical check-ups to detect early signs of neural and vascular manifestations indicating hand-arm vibration injuries. Special attention should be given to symptoms of increased sensation of cold, pain in the fingers when cold, and numbness, as these were the most common initiating ones, and should be addressed as early as possible in the preventive sentinel process. It is also important to test clinically for small- and large-fibre neuropathy, as the individual may be unaware of any pathology.

Background
Despite EU regulations [1] many workers handling vibrating tools get injured. Vibration injury is in fact, the most common diagnosis among Swedish men receiving compensation for occupational injuries [2]. Approximately 400,000 workers, corresponding to 13% of all men and 3% of all women in the Swedish workforce, are exposed to hand-held vibrating tools for at least two hours a day. In the construction sector, as many as 70% report daily exposure to vibrating tools [3].

Vibration injury is characterised by adverse health manifestations in digital nerves and vessels. Neural symptoms include impaired perception of touch and temperature and numbness (negative manifestations), additive neurosensory sensations (positive manifestations); tingling and increased sensation of cold, and provocative manifestations; pain in the finger/hands when cold or when the nerves are compressed. Impaired dexterity, impaired grip strength, sweating and shaking of the hands are often co-reported [4–6]. Manual handling of vibrating tools is ergonomically demanding and vibration exposure in combination with forceful grips in non-neutral wrist positions makes the median nerve prone to entrapment in the carpal tunnel [7]. Pain in the upper extremity is often co-reported with symptoms from the hands [8, 9]. Taken together these symptoms are often referred to as hand-arm vibration syndrome (HAVS) with neural, vascular and musculoskeletal components [10, 11]. The condition leads to considerable negative health impact, and little or no improvement is expected even if vibration exposure ceases [11]. Many patients report effects on their daily life activities due to impaired upper extremity function [12–14].

Carpenters constitute a large group in the construction sector, and the frequency of HAVS in this group has been shown to be twice that in workers not exposed to vibration [15]. Carpenters use vibrating tools such as impact drills, impact power wrenches and grinders. Endeavour to decrease the ergonomic load has made tools lighter, but at the same time more vibrating than the old heavier ones. Furthermore, the number of workers in the construction sector using vibrating tools is increasing [2]. Although statistics are available concerning the number of workers claiming compensation for occupational injuries, it is not known how prevalent neurosensory or vascular manifestations are among carpenters. Few studies have been carried out to determine whether exposure to vibration is still hazardous, or whether working conditions have improved. Neither have the symptoms that appear first been documented. This information could be useful in making screening more efficient, and allowing measures to prevent further injury from vibration to be instigated.

The aim of the study was to assess the occurrence of adverse health manifestations in hands of neural and vascular origin among carpenters, who are heavily exposed to vibrating tools and to compare it with the occurrence among painters, who are believed to be much less exposed. Furthermore, we investigated which symptoms appeared first, and which were the most prevalent, and the extent to which symptoms and clinical findings occur in combination. In order to determine whether improvements have been made in working conditions, we also investigated manifestations of injury in the younger carpenters in the group.

Subjects And Methods
Study design

In this cross-sectional study we examined carpenters at their workplace, and painters at their workplace or at the Occupational and Environmental Medicine Clinic. Carpenters working for two medium-sized and two large construction companies were examined at 18 different workplaces between April 2016 and April 2018. All the carpenters at these work sites were invited to take part in the study. The painters were recruited from three medium-sized painting companies, and were invited to participate at staff meetings, as they worked at different, smaller work sites. They were examined between May 2018 and September 2019. The participants were instructed not to use nicotine or vibrating tools one hour prior to the clinical examination. Their finger temperature was measured on arrival, and if it was below 28 °C the hands were heated with warm pads. They then filled in a questionnaire on a laptop (30–45 minutes). The participants were able to go back and change an answer, but not to skip questions. Some answers generated follow-up questions. An examiner was present in the room to answer any queries. All participants then underwent a clinical examination.

To assess the generalisability of the results, a shortened questionnaire was sent by post to all the carpenters who worked at the same construction companies, but at other work sites, for three of the four companies included in this study. This questionnaire was also sent to male carpenters at other construction companies, randomly selected from a list provided from the relevant trade union. Two reminders were sent.

Study population

The study included all 193 invited male carpenters (response rate 100%; one female carpenter was examined but was excluded from the data analyses). There were 139 male painters at the companies included in the study, 108 of whom attended the staff meetings, and were invited to participate in the study. The others could not be contacted. Of these 108, 72 agreed to participate in the study (participation rate 67%). All eight female painters invited to take part in the study participated, but were not included in the data analyses. The shortened postal questionnaire was returned by 202 of the 410 male carpenters at the construction companies chosen for the study (response rate 49%), and by 297 of 708 at other companies (response rate 42%).

Job tasks and vibration exposure

Carpenters, in the International Standard Classification of Occupations (ISCO) 7124, perform different work tasks in the construction or repair of buildings. According to the results of the questionnaire, common work tasks with vibration exposure among carpenters were framework, formwork and demolition. Plastering was the most common work task, but with lower vibration exposure. Painters, ISCO 7141, usually did not use vibrating tools, however, oscillating grinders could cause some exposure to vibration.

Outcome assessments

Symptom questionnaire

The following questions were asked regarding neurosensory symptoms in the fingers/hands: "Do you experience: sensation of cold; impaired perception of touch; impaired perception of warmth; impaired perception of cold; numbness or tingling when not working with vibrating tools; pain when cold; a tendency to drop things; or difficulty buttoning clothes?" The possible responses were: "Not at all", "Insignificant", "Somewhat" or "Quite a lot". The alternatives "Somewhat" or "Quite a lot" were considered a positive response. If a positive response was given to any of these questions, the participant was asked which of these symptoms that appeared first and when. More than one symptom could be given.

To assess symptoms of Raynaud's phenomenon, we asked: "Do one or more of your fingers turn white when you are exposed to cold or dampness?" A colour photograph was shown to facilitate recognition of the condition. Possible responses were "No" or "Yes". Those who responded "Yes" were considered to have white fingers, and were asked to draw the extent of their worst occurrence on a diagram of a hand, and to report the frequency of this symptom: "Once a month or less", "Once a week", "Once a day", "Several times a day", "All the time". They were also asked when their symptoms of white fingers started.

Participants who reported neurosensory symptoms or white fingers were asked whether any of these conditions influenced the activities of their daily life, at work or during leisure time. Additional questions were asked concerning symptoms in the hands: reduced strength, shaking, sweating cramps, pain in the fingers/hands/forearms/elbows, and pain in the neck/shoulders, with possible responses: "Not at all", "Insignificant", "Somewhat" or "Quite a lot". The alternatives "Somewhat" or "Quite a lot" were considered a positive response. The shortened questionnaire included the same questions as the main questionnaire concerning neurosensory symptoms, white fingers and other symptoms in the upper limb.

Clinical examination

After completing the questionnaire, the participants underwent testing of finger perception of digit II and V bilaterally [16–20]. This was performed in a quiet room at room temperature. We recorded whether or not the participant could detect the stimulus. The participant was asked to place both hands on a table, with the palms facing upwards, and to close his eyes. Perception of touch was tested with a Semmes Weinstein Monofilament® (detection threshold 3.61, calibrated such that 0.271 grams of force is required to bend it when touched on the skin of the finger) [21]. The participant was asked to report when he felt the touch of the filament when it was applied to the finger pulps, once on each finger. For two-point discrimination (2PD) we performed a static 2PD test with a two-point discriminator (separation 5 mm); seven correct responses out of ten attempts was considered normal. The ability to distinguish between cold and warmth was tested with temperature rolls at 25 °C and 40 °C (RollTemp® instrument), randomly applied to the middle phalanges [22, 23]. Perception of vibration was tested with a VibroSense®* equipment. The participants were given information on the test procedure, and asked to wear earmuffs as high amplitudes at high frequencies generate a noise. Vibration perception thresholds (VPT) were recorded at 125 Hz and 250 Hz. Vibration thresholds exceeding one standard deviation (SD) above the mean value in the age-adjusted reference material were defined as impaired perception of vibration according to standards of the method [24]. When impaired perception of vibration was found in the digits, the lower extremity was examined, by applying vibrations of 128 Hz with a Vibratip® device at the base of the proximal phalanx of the big toe.
Specific nerve entrapment tests were also performed to diagnose nerve entrapment in the neck or upper extremities, including tests of neck mobility, the strength of selected muscles and provocation of the brachial plexus, as well as the median, radial and ulnar nerves.

**Individual characteristics**

The questionnaire also included questions on age, sex, nicotine use, medication, concurrent diseases, hearing impairment and doctor's diagnosis of carpal tunnel syndrome. Questions were also included to obtain information on previous injuries to the neck, arm or hand that required hospital care. The responses to this question were reviewed by one of the authors (ET), and if these injuries could have caused sensory impairment in the hands, they were noted as "injury relevant to hands". Questions were also included on previous and present work tasks, employment, vibration tools used, and the participants' views on the company's safety policy were also included. These results will be presented elsewhere.

**Data processing and statistics**

Symptoms reported in the questionnaire were combined with clinical findings to indicate neural manifestation. These were staged by applying the International Consensus Criteria (ICC) [25], with some modifications. Stage N1: numbness and/or tingling of fingers; stage N2: as in stage 1, and with loss in two of three sensory modalities; perception of touch, temperature and vibration; and stage N3: as in stage 2, and with symptoms of impaired dexterity (a tendency to drop things or difficulty buttoning clothes) and reduced 2PD. For comparison, we also graded symptoms and findings according to the Stockholm Workshop Scale (SWS) [26], with some modifications. Stage 1SN: implying numbness and/or tingling; stage 2SN: as in stage 1SN and reduced perception of touch; and stage 3SN: as in stage 1SN and impaired 2PD. In addition, we defined the clinical condition *neurosensorial affection* (a de novo definition), as the combination of at least one symptom in the fingers/hands (impaired perception of touch, warmth or cold, impaired dexterity, increased sensation of coldness, numbness or tingling, or pain when cold) and at least one clinical finding: impaired perception of touch, warmth, cold, or vibration, or impaired 2PD.

Vascular manifestation of HAVS was evaluated by calculating Griffin scores for participants who had reported white fingers and indicated this on a hand diagram [27]. The right and left hands were graded separately, and the result for the hand with the highest score (i.e. the highest number of blanching phalanges) was used. The severity of finger blanching was then graded according to the vascular component of ICC [25]. Stage V1: Griffin score 1–4; stage V2: Griffin score 5–12; and stage V3: Griffin score > 12 [25]. We also graded symptoms and findings according to SWS, as above. Stage 1V: occasional attacks affecting only distal phalanges; stage 2V: occasional attacks affecting distal/middle phalanges on one or more fingers; stage 3V: frequent attacks affecting all phalanges on most fingers.

Logistic regression, with calculations of odds ratios and 95% confidence intervals, was used to compare the point prevalences of the different outcomes in carpenters and painters. These were reported as crude and age-adjusted values. Finally, participants with conditions that could affect the outcomes (diabetes, cardiovascular, thyroid or rheumatic disease, impaired perception of vibration in the foot, or peripheral nerve entrapment in upper extremity/neck (except for carpal tunnel syndrome) were excluded to test whether the results were influenced by such conditions (a sensitivity analysis). Two participants (both painters) reported the debut of white fingers before the age of 18 (i.e. before working age) and were excluded from all analyses concerning white fingers.

Among carpenters who were found to have *neurosensorial affection* in the hands, the percentage of carpenters that indicated a specific symptom as the first occurring one, as well as the prevalence of influence on daily life activities, were calculated. Further, to investigate possible correlations between symptoms and clinical findings, the prevalence of different pairwise combinations of symptoms among these carpenters were calculated. To determine whether current exposure is associated with the same risks as previously, we also calculated the prevalence of symptoms, findings and clinical conditions in carpenters aged 30 years and younger.

Based on the responses to the shortened postal questionnaire we calculated the prevalence of adverse neurosensory and vascular health manifestations in the fingers/hands of carpenters at the same companies, that were not examined, as well as carpenters at other companies, to assess generalisability of our results.

SPSS Statistics for Windows, Version 24.0 (IBM Corp., released 2016, Armonk, NY, USA) was used for all statistical calculations.

Possible nerve entrapment were defined according to criteria modified from Nordander et al. 2009 and Ohlsson et al. 1994 [28, 29], see Table 1.
Table 1

The case criteria for nerve entrapments according to criteria modified from Nordander et al 2009 and Ohlsson et al 1994.

| Nerve entrapment                        | Criteria                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Radiating neck complaints               | Pain radiating from the neck to the upper extremity, and limited/restricted neck movement, and radiating pain provoked by neck movement, and muscle weakness of the upper limb.                                                                                                                                   |
| Thoracic outlet syndrome                 | Pain radiating to the upper extremity, in the distribution of the ulnar nerve, and paraesthesia in the distribution of the ulnar nerve, and positive Roos test (increase in subjective symptoms, not only fatigue), and intense tenderness over the brachial plexus; diagnosis only if cervical syndrome is not present. |
| Pronator teres syndrome                  | Pain in the medial/proximal part of the forearm, and local tenderness over the edge of the pronator teres, and decreased strength in pronation or flexion of the wrist or the distal phalanges of digit I-II.                                                                                                          |
| Radial tunnel syndrome                   | Pain in the elbow during rest, and tenderness about 2–3 inches distally of the lateral epicondyle, and pain in the proximal, lateral part of the forearm, and pain on resisted supination.                                                                                                                             |
| Ulnar nerve entrapment at the elbow      | Pain and paraesthesia or numbness in the distribution of the ulnar nerve, and positive Tinel’s sign over the cubital tunnel.                                                                                                                                                                                                 |
| Ulnar nerve entrapment in the wrist      | Pain and paraesthesia or numbness in the distribution of the ulnar nerve, and positive Tinel’s sign over Guyon’s tunnel (volar/ulnar at the wrist) or decreased strength in spreading the fingers.                                                                                                                                      |
| Carpal tunnel syndrome                   | Previous surgery for carpal tunnel syndrome, or numbness or tingling in digit I-III and a positive nerve entrapment test (Phalen’s test or Tinel’s sign).                                                                                                                                 |

**Results**

The individual characteristics of the participants are presented in Table 2. In mean, the painters were somewhat older than the carpenters. Injury relevant to hands was more common among the carpenters.

**Table 2**

|                          | Carpenters N = 193 | Painters N = 72 |
|--------------------------|--------------------|-----------------|
| Age, mean (range), (y)   | 40 (17–65)        | 46 (23–68)      |
| Seniority in the occupation mean (range) (y)* | 20 (0–50)    | 24 (3–54)       |
| Tobacco use, N (%)       | 86 (45)           | 32 (44)         |
| Diabetes, N (%)          | 5 (3)             | 1 (1)           |
| Cardiovascular disease, N (%) | 15 (8)         | 8 (11)          |
| Hypothyreosis, N (%)     | 2 (1)             | 1 (1)           |
| Rheumatic disease, N (%) | 3 (2)             | 2 (3)           |
| Injury relevant to hands, N (%) | 47 (24)     | 6 (8)           |
| Hearing impairment, N (%)| 56 (29)           | 9 (13)          |

*Data missing from 21 carpenters and 4 painters.

**Adverse health manifestations in hands – comparison of carpenters and painters**

**Symptoms**

Carpenters reported a higher occurrence of impaired perception of touch, impaired perception of warmth, increased sensation of cold, and pain in fingers when cold, than painters (Table 3). After excluding individuals with conditions that could affect the outcome, the ORs remained high, but only increased sensation of coldness remained statistically significant. Reports of white fingers did not differ significantly between the carpenters and painters. Pain in the neck/shoulders was less common among carpenters than painters, but after age adjustment this difference was not statistically significant.

**Clinical findings**

Carpenters exhibited twice the point prevalence of increased vibration perception thresholds at 250 Hz (Table 3), and three times the point prevalence of impaired 2PD, compared to painters, neither of which were statistically significant.
Table 3
Prevalence of adverse health manifestations among carpenters (N = 193) and painters (N = 72). Odds ratios (OR) and 95% confidence intervals (CI) calculated by logistic regression (Statistically significant differences are shown in bold face.)

| Symptoms                                      | Carpenters N (%) | Painters N (%) | Crude OR (CI)   | Age-adjusted OR (CI) | Sensitivity analyses (CI) |
|-----------------------------------------------|------------------|----------------|-----------------|----------------------|--------------------------|
| **Symptoms**                                 |                  |                |                 |                      |                          |
| **Negative neural manifestations**            |                  |                |                 |                      |                          |
| Impaired perception of touch                 | 28 (15)          | 3 (4)          | **3.9 (1.1–13.3)** | **4.4 (1.3–15.0)** | 4.2 (0.9–19.0)            |
| Impaired perception of cold                  | 19 (10)          | 3 (4)          | 2.5 (0.7–8.8)   | 2.7 (0.8–9.6)        | 2.6 (0.5–12.1)            |
| Impaired perception of warmth                | 23 (12)          | 2 (3)          | **4.7 (1.1–20.6)** | **5.7 (1.3–25.4)** | 4.1 (0.9–18.8)            |
| Tendency to drop things                      | 23 (12)          | 3 (4)          | 3.1 (0.9–10.7)  | 3.3 (0.9–11.5)       | 2.9 (0.6–13.3)            |
| Difficulty buttoning clothes                 | 13 (7)           | 2 (3)          | 2.5 (0.6–11.5)  | 3.0 (0.7–14.0)       | 1.7 (0.3–8.6)             |
| Impaired grip strength                       | 35 (18)          | 9 (13)         | 1.5 (0.7–3.4)   | 1.7 (0.8–3.9)        | 1.1 (0.4–2.7)             |
| **Positive neural manifestations**           |                  |                |                 |                      |                          |
| Increased sensation of cold                  | 67 (35)          | 14 (19)        | **2.2 (1.1–4.2)** | **2.5 (1.3–5.0)**    | **2.2 (1.1–4.7)**         |
| Numbness or tingling                         | 51 (26)          | 16 (22)        | 1.3 (0.7–2.4)   | 1.4 (0.7–2.6)        | 1.3 (0.6–2.8)             |
| Cramp                                         | 26 (14)          | 8 (11)         | 1.2 (0.5–2.9)   | 1.2 (0.5–2.9)        | 0.8 (0.3–2.1)             |
| Shaking                                       | 22 (11)          | 4 (6)          | 2.2 (0.7–6.5)   | 2.4 (0.8–7.2)        | 2.2 (0.6–8.2)             |
| Hand sweat                                   | 35 (18)          | 8 (11)         | 1.7 (0.8–4.0)   | 1.5 (0.7–3.6)        | 1.5 (0.6–3.8)             |
| **Provoked manifestations**                  |                  |                |                 |                      |                          |
| White fingers at cold or dampness            | 18 (9)           | 6 (8)          | 1.1 (0.4–2.9)   | 1.7 (0.6–4.6)        | 2.2 (0.6–7.8)             |
| Pain in fingers when cold                    | 47 (24)          | 6 (8)          | **3.5 (1.4–8.7)** | **3.6 (1.4–8.8)**    | **2.5 (1.0–6.5)**         |
| **Musculoskeletal symptoms**                 |                  |                |                 |                      |                          |
| Hand/elbow pain                              | 60 (31)          | 21 (29)        | 1.1 (0.6–1.9)   | 1.1 (0.6–2.1)        | 1.0 (0.5–2.0)             |
| Neck/shoulder pain                           | 67 (35)          | 36 (50)        | **0.5 (0.3–0.9)** | 0.6 (0.3–1.0)        | 0.6 (0.3–1.1)             |
| **Clinical findings**                        |                  |                |                 |                      |                          |
| Impaired perception of touch                 | 60 (31)          | 25 (35)        | 0.9 (0.5–1.5)   | 1.3 (0.7–2.6)        | 1.6 (0.7–3.3)             |
| Impaired perception of cold                  | 12 (6)           | 6 (8)          | 0.7 (0.3–2.0)   | 0.9 (0.3–2.5)        | 0.5 (0.2–1.6)             |
| Impaired perception of warmth                | 7 (4)            | 3 (4)          | 0.9 (0.2–3.4)   | 0.9 (0.2–3.6)        | 1.0 (0.2–5.4)             |
| Impaired 2PD                                  | 17 (9)           | 2 (3)          | 3.4 (0.8–15.1)  | 4.1 (0.9–18.4)       | 2.5 (0.5–12.0)            |
| Increased VPT at 125 Hz                      | 19 (10)          | 6 (8)          | 1.2 (0.5–3.1)   | 1.6 (0.6–4.6)        | 1.7 (0.5–5.4)             |
| Increased VPT at 250 Hz                      | 38 (20)          | 8 (11)         | 2.0 (0.9–4.4)   | 2.0 (0.9–4.6)        | 2.0 (0.8–5.2)             |
| Increased VPT at 125 and 250 Hz*             | 42 (22)          | 10 (14)        | 1.7 (0.8–3.7)   | 2.0 (0.9–4.5)        | 2.1 (0.9–5.2)             |

a Two painters excluded due to debut of white fingers before age 18.
b Excluding participants with diabetes, cardiovascular, thyroid or rheumatic disease, impaired perception of vibration in the foot, or peripheral nerve entrapment in upper extremity/neck (except for carpal tunnel syndrome).

**Neural and vascular manifestations**

No statically significant differences were found between carpenters and painters regarding manifestations when comparing the prevalence of ICC stage 2 or more, or SWS stage 2SN or more (Table 4). Instead, when combining symptoms and findings according to our definition of neurosensory affection, we found an age-adjusted OR of 3.3 (CI 1.6–7.0). The OR remained increased excluding individuals with conditions that could affect the outcome. Concerning vascular manifestations the ORs were high but there were few cases and the CIs were broad.

The prevalence of carpal tunnel syndrome was about 10% in both groups (Table 4). Other forms of nerve entrapment were rare.
### Table 4
Clinical conditions among 193 carpenters and 72 painters. Odds ratios (OR) and 95% confidence intervals (CI) calculated by logistic regression (Statistically significant differences are shown in bold face.)

|                           | Carpenters | Painters | Crude OR (CI) | Age-adjusted OR (CI) | Sensitivity analyses OR (CI) |
|---------------------------|------------|----------|---------------|----------------------|-----------------------------|
| **Neural manifestations** |            |          |               |                      |                             |
| ICC ≥ N2                  | 11 (6)     | 2 (3)    | 2.1 (0.5–9.8) | 2.8 (0.6–13.2)       | n.a.                        |
| SWS ≥ 2SN                 | 32 (17)    | 7 (10)   | 1.8 (0.8–4.4) | 2.3 (0.9–5.6)        | 3.2 (1.0–10.1)              |
| **Neurosensory affection**| 60 (31)    | 12 (17)  | 2.3 (1.1–4.5) | 3.3 (1.6–7.0)        | 3.5 (1.5–8.3)               |
| Nerve entrapment (all except carpal tunnel syndrome) | 25 (13) | 8 (11)   | 1.2 (0.5–2.8) | 1.3 (0.6–3.2)        | n.a.                        |
| Carpal tunnel syndrome    | 20 (10)    | 8 (11)   | 0.9 (0.4–2.2) | 1.1 (0.4–2.6)        | 1.6 (0.5–5.2)               |
| **Vascular manifestations** |        |          |               |                      |                             |
| ICC ≥ V2                  | 9 (5)      | 1 (1)    | 3.4 (0.4–27.1) | 5.6 (0.7–47.2)       | 6.1 (0.7–55.8)              |
| SWS ≥ V2                  | 10 (5)     | 2 (3)    | 1.9 (0.4–8.7) | 2.8 (0.6–13.5)       | 6.0 (0.7–52.5)              |

* Data missing from two carpenters due lack of hand diagram, and data excluded from two painters due to debut of white fingers before age 18

b Excluding participants with diabetes, cardiovascular, thyroid or rheumatic disease, impaired perception of vibration in the foot, or peripheral nerve entrapment in upper extremity/neck (except for carpal tunnel syndrome)

n.a. not applicable

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### The clinical picture

Among carpenters with neurosensory affection or white fingers, 74% fulfilled the criteria for neurosensory affection: 13% reported white fingers only, and 13% had a combination. Two carpenters reported white fingers as the earliest symptom, while all other carpenters reported that symptoms of impaired neurosensory function occurred first. Among the 60 carpenters who fulfilled our criteria for neurosensory affection, the most common symptoms were increased sensation of coldness (67%), numbness or tingling (55%) and pain when cold (45%) (Table 5). These symptoms were also the most common early symptoms (Table 6).
Table 5

Existing co-occurring neural and vascular manifestations among the 60 carpenters with neurosensory affection. Bold face denotes the prevalence of each symptom and finding.

| Symptoms                                      | IPT | IPC | IPW | TDT | DBC | IGS | ISC | N  | C  | S  | HS | WF | PWC | MF | TC | TW | 2PD | 125 | 250 | VIB |
|-----------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Impaired perception of touch (IPT)            | 30  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Impaired perception of cold (IPC)             | 15  | 20  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Impaired perception of warmth (IPW)           | 24  | 8   | 32  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Tendency to drop things (TDT)                 | 13  | 7   | 10  | 22  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Difficulty buttoning clothes (DBC)            | 7   | 2   | 4   | 10  | 12  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Impaired grip strength (IGS)                  | 13  | 4   | 11  | 15  | 7   | 30  |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Increased sensation of cold (ISC)             | 24  | 17  | 26  | 17  | 9   | 17  | 67  |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Numbness (N)                                  | 15  | 9   | 20  | 13  | 4   | 17  | 35  | 55  |     |     |     |     |     |     |     |     |     |     |     |     |
| Cramp (C)                                     | 11  | 4   | 11  | 10  | 2   | 7   | 11  | 15  | 20  |     |     |     |     |     |     |     |     |     |     |     |
| Shaking (S)                                   | 7   | 2   | 7   | 9   | 4   | 9   | 11  | 13  | 9   | 17  |     |     |     |     |     |     |     |     |     |     |
| Hand sweat (HS)                               | 11  | 7   | 13  | 12  | 4   | 7   | 20  | 15  | 7   | 9   | 25  |     |     |     |     |     |     |     |     |     |
| White fingers (WF)                            | 7   | 4   | 9   | 3   | 2   | 4   | 13  | 13  | 4   | 4   | 2   | 15  |     |     |     |     |     |     |     |     |
| Pain when cold (PWC)                          | 15  | 13  | 15  | 13  | 4   | 9   | 15  | 26  | 9   | 7   | 9   | 45  |     |     |     |     |     |     |     |     |

| Clinical findings                             |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Monofilament! (MF)                            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| RollTemp Cold (TC)                            | 11  | 7   | 9   | 10  | 2   | 4   | 11  | 7   | 7   | 0   | 2   | 2   | 7   | 9   | 17  |     |     |     |     |     |
| RollTemp Warm (TW)                            | 7   | 7   | 7   | 2   | 0   | 2   | 9   | 4   | 2   | 0   | 2   | 0   | 7   | 7   | 4   | 8   |     |     |     |     |
| Two-point discrimination (2PD)                | 11  | 4   | 9   | 7   | 4   | 11  | 15  | 13  | 4   | 4   | 4   | 7   | 11  | 15  | 2   | 4   | 25  |     |     |     |
| Vibration at 125 Hz (125)                     | 7   | 7   | 9   | 3   | 2   | 30  | 15  | 13  | 2   | 2   | 7   | 7   | 11  | 9   | 0   | 2   | 7   | 17  |     |     |
| Vibration at 250 Hz (250)                     | 17  | 13  | 17  | 7   | 2   | 11  | 30  | 26  | 9   | 7   | 13  | 9   | 17  | 17  | 4   | 4   | 7   | 13  | 37  |     |
| Vibration at 125 or 250 Hz (VIB)              | 17  | 13  | 20  | 7   | 2   | 11  | 33  | 30  | 9   | 7   | 15  | 11  | 20  | 20  | 4   | 4   | 9   | 17  | 37  | 40  |

The most common clinical findings among the carpenters with neurosensory affection were impaired perception of touch (72%), and increased VPT (40%), where an impairment at 250 Hz was more common than at 125 Hz (37% and 17%, respectively; Table 5). The most common pairwise combinations of symptoms were: increased sensation of coldness with numbness or tingling (35%), and increased sensation of coldness with impaired perception of warmth (26%). The most common pairwise combinations of findings with symptoms were: impaired perception of touch with increased sensation of coldness (52%), numbness or tingling (41%), and pain when cold (35%). Impaired perception of touch and increased VPT (20%) was the most frequent combination of
clinical findings. Combinations of white fingers with other symptoms or findings were rare. The majority of carpenters with neurosensory affection (54%), had these symptoms daily, and almost one fifth (18%) reported discomfort to such an extent that it influenced their daily life activities: work 13%, leisure time 15% (not in table).

| Symptom                                      | N (%) |
|----------------------------------------------|-------|
| Increased sensation of cold                  | 28 (47) |
| Numbness                                     | 24 (40) |
| Pain in fingers/hands when cold              | 14 (23) |
| Impaired perception of warmth                 | 7 (12)  |
| Impaired perception of touch                  | 5 (8)   |
| Impaired perception of cold                   | 4 (7)   |
| Impaired dexterity - tendency to drop things  | 4 (7)   |
| Impaired dexterity - difficulty buttoning clothes | 4 (7) |

Among the 18 carpenters that had white fingers, 2% reported having symptoms on a daily basis, 3% that these symptoms affected their work and 1% reported affection on leisure activities, and.

**Young carpenters**

Among the 60 carpenters aged 30 years or less, 28 (47%) reported at least one neurosensory symptom indicating HAVS, most commonly increased sensation of coldness (28%) or pain in the hands when cold (25%; Table 7). One fifth had increased VPT and 12% fulfilled our criteria for neurosensory affection. In addition, one third reported neck/shoulder pain.
Table 7
Prevalence of adverse health manifestations among 60 young carpenters (≤ 30 years old)

| Symptoms                        | N (%) |
|---------------------------------|-------|
| **Negative neural manifestations** |
| Impaired perception of touch    | 5 (8) |
| Impaired perception of cold     | 3 (5) |
| Impaired perception of warmth   | 3 (5) |
| Tendency to drop things         | 6 (10) |
| Difficulty buttoning clothes    | 2 (3) |
| **Positive neural manifestations** |
| Increased sensation of cold     | 17 (28) |
| Numbness or tingling            | 10 (17) |
| **Provoked manifestations**     |
| White fingers at cold or dampness | 1 (2) |
| Pain in hands when cold         | 15 (25) |
| **Musculoskeletal findings**    |
| Hand/elbow pain                 | 16 (27) |
| Neck/shoulder pain              | 18 (30) |
| **Clinical findings**           |
| Impaired perception of touch    | 5 (8) |
| Impaired perception of cold     | 3 (5) |
| Impaired perception of warmth   | 2 (3) |
| Increased 2PD                   | 3 (5) |
| Increased VPT at 125 Hz         | 5 (8) |
| Increased VPT at 250 Hz         | 11 (18) |
| Increased VPT at 125 & 250 Hz   | 12 (20) |
| **Clinical conditions**         |
| Carpal tunnel syndrome          | 2 (3) |
| Neurosensory affection          | 7 (12) |

Adverse health manifestations in carpenters’ hands in general

The carpenters that were not examined, but who answered the shortened questionnaire, reported a higher prevalence of almost all symptoms than the carpenters examined in this study (Table 8). No major differences were seen in symptoms between the two non-examined groups of carpenters (at the same companies as those examined and at other companies).
Table 8
Prevalence (%) of symptoms among the examined carpenters (N = 193), non-examined carpenters at the same companies, but working at other sites from the ones that were examined (N = 202), and at other companies (N = 297) (all men)

|                     | Carpenters - examined | Carpenters - not examined | Carpenters - not examined |
|---------------------|-----------------------|---------------------------|---------------------------|
|                     | N (%)                 | N (%)                     | N (%)                     |
| Age, mean (min.-max.) | 40 (17–65)            | 46 (23–67)a               | 45 (19–66)b               |
| Negative neural manifestations |                     |                           |                           |
| Impaired perception of touch | 15                   | 25                        | 25                        |
| Impaired perception of cold | 10                   | 17                        | 17                        |
| Impaired perception of warmth | 12                   | 23                        | 18                        |
| Tendency to drop things | 12                   | 18                        | 23                        |
| Difficulty buttoning clothes | 7                    | 14                        | 19                        |
| Impaired grip strength | 18                   | 28                        | 33                        |
| Positive neural manifestations |                     |                           |                           |
| Increased sensation of cold | 35                   | 49                        | 45                        |
| Numbness or tingling | 26                   | 46                        | 41                        |
| Cramp | 14                   | 33                        | 28                        |
| Shaking | 14                   | 21                        | 23                        |
| Hand sweat | 18                   | 18                        | 21                        |
| Provoked manifestations |                     |                           |                           |
| White fingers when cold or damp | 9                    | 32c                       | 30d                       |
| Pain when cold | 24                   | 44                        | 46                        |
| Musculoskeletal manifestations |                     |                           |                           |
| Hand/elbow pain | 31                   | 50                        | 53                        |
| Neck/shoulder pain | 35                   | 61                        | 57                        |
| ^aData missing from 14 subjects. |
| ^bData missing from 5 subjects. |
| ^cData missing from 68 subjects. |
| ^dData missing from 52 subjects. |

Discussion

Main findings

One third of all the carpenters examined in this study had neural manifestations, defined as neurosensory affection, with an age-adjusted OR of 3.3 (95% CI; 1.6–7.0), compared to painters. No statistically significant differences were found neither in the prevalence of white fingers, nor carpal tunnel syndrome, between carpenters and painters. Among carpenters that fulfilled the criteria for neurosensory affection, the most common, as well as the earliest symptoms, were increased sensation of cold, numbness and pain when cold. The most common clinical findings were impaired perception of touch and increased VPT. The majority of carpenters with neurosensory affection reported symptoms on a daily basis, 18% reported that symptoms interfered with their daily life activities. More than 10% of young carpenters (≤ 30 y) fulfilled the criteria for neurosensory affection, indicating that harmful exposure still occurs.

Limitations and strengths

We chose painters as a control group, as they belong to the same socioeconomic group as carpenters, and, like carpenters, have a physically demanding job with hand-intensive work, often above shoulder level. During the course of the study, we discovered that some painters used vibrating tools, although to a limited extent. Furthermore, the participation rate among painters was lower than that among carpenters, and there is a risk that painters without symptoms...
chose not to participate. Therefore, the ORs reported may be underestimated. On the other hand, carpenters may be more aware of symptoms in their hands as they are well aware of their exposure to vibration, resulting in some information bias. This would cause the ORs to be somewhat overestimated.

All the participating companies were well functioning, and it is possible that their management of the working environment was somewhat better than average. To account for this, we included carpenters from other companies. The response rate among the carpenters who answered the shortened questionnaire was only about 50%. This obviously renders a high risk of selection bias concerning symptoms of HAVS. If all the carpenters who did not participate were symptom-free, the true prevalence would have been about half that reported, and about as high as that among the carpenters in the examined group. Taken together, we believe that the carpenters examined in our study were somewhat less affected by vibration than carpenters as a whole.

An important strength of this study is that the clinical examination was performed with standardised methods by trained personnel. Since the neuropathy described in HAVS is often diffuse and difficult to distinguish from other neuropathies, a test battery of different neurosensory modalities is recommended in the clinical setting. However, the test methods rely on the alertness and willingness of the tested individuals to report somatosensory stimuli [30]. Previous studies report a fair to good accordance between neurosensory symptoms and clinical findings [30]. To minimise the examination time, we only tested the perception of touch (using monofilaments) once on each tested finger, although it is recommended that this should be done three times if no response is elicited [31]. The Purdue Pegboard and aesthesiometer are recommended for obtaining ICC scores [25]. Due to practical, economic and time limitations we used 2PD and the RollTemp® instrument. However, as the same strategy was used for all the examined workers we consider the results reliable for the purpose of this study. Both groups are manual workers, and therefore there should be no reason to suspect difference in epidermal thickness that could influence the results. Even so epidermal thickness does not seem to influence vibrotactile and thermal perception [32].

Self-reporting of white fingers has shown a predictive value of 80% when followed up by medical interview [33]. To allow the comparison of our results with those in other studies, we used both the ICC and the SWS criteria for staging HAVS.

**Carpenters versus painters**

**Neural manifestations**

The increased prevalence of neurosensory symptoms in fingers among carpenters is well in line with the results from a previous questionnaire survey in the UK in 1997 of over 1000 men of working age [15]. Neural symptoms were found to dominate over vascular symptoms, which is also in agreement with previous studies [11, 34, 35]. Increased sensation of cold, which may be an important indication of vibration injury [36], was more common among carpenters than among painters. As many as 35% of the carpenters reported increased sensation of cold. This symptom has also been associated with medical conditions such as diabetes mellitus and rheumatic disease, but the difference remained after the exclusion of participants with these diseases. Thus, the difference is probably due to the use of vibrating tools. Cold sensitivity/cold intolerance/cold hypersensitivity is defined as abnormal aversion to cold with pain, sensory alterations, stiffness and/or colour change, but with no observable vasospasm. Pain in the fingers/hands when cold was reported among 24% of the carpenters, while the prevalence among painters (8%) was in agreement with that in the general population (5–15%) [34]. Concerning the clinical findings, we found no statistically significant differences between carpenter and painters, although the ORs were high for impaired 2PD and VPT in the carpenters. The difference between groups was greater at 250 Hz than at 125 Hz.

The ability to perceive vibrations, i.e. vibrotactile sense, is dependent on the function of cutaneous receptors and large-diameter (Aβ) afferent nerves. Some studies indicate that that larger myelinated nerves (Aβ) seem to be more vulnerable to compression than smaller myelinated nerve fibres (Aδ) and the small, unmyelinated (C) nerve fibres seem to be the most resistant to external stress [18, 37, 38]. Animal studies on vibrated rat tail have shown structural changes in blood vessels, reduced nerve fibre density and demyelisation of myelinated nerve fibres [39–41]. Nerve biopsies from vibration-exposed workers (with neural symptoms) have revealed structural changes and low myelinated nerve-fibre density [37, 42–44]. Epidemiological studies have also revealed correlations between thermal sensory impairment and cumulative exposure to vibration [45], where the perception of cold seems to be more affected than the perception of warmth [46]. In fact, the threshold for the perception of cold has been suggested as the best indicator of early neurosensory impairment since it showed greater sensitivity and specificity than the warm threshold and VPT in fingers with numbness or tingling [47]. However, in another longitudinal study on vibration-exposed workers, a low cumulative vibration dose did not significantly affect thermal perception thresholds, whereas age did [20].

In our study, impaired perception of touch and increased VPT were the two most common clinical findings among carpenters with neurosensory affection. In a study by Rolke et al., VPT was found to be the best method to capture neurosensory impairment in vibration-exposed workers, compared to controls [18]. The experts behind ICC suggest examination at 32 Hz and 125 Hz, but other studies have shown a greater increase in the threshold at 150 Hz than at 20 Hz among patients with HAVS [24]. In our study, VPT was more affected at 250 Hz than at 125 Hz. We therefore suggest that examination at 250 Hz be included in screening.

We found no difference in thermal perception between the carpenters and the painters, but impaired perception of cold was twice as prevalent as impaired perception of warmth among carpenters with neurosensory affection, when tested with the RollTemp® instrument. However, this method has not been validated, and these results should be interpreted with caution. Furthermore, the conduction velocity is much slower in the thin unmyelinated C fibres (which detect warmth) than in the myelinated Aδ fibres (which detect cold), which could have affected our results, leading to under-reporting of the true impairment of warmth perception.

The validity of 2PD has been questioned [48], but in the present study the prevalence of impaired 2PD was three times higher among carpenters than among painters, (although the difference was not statistically significant, due to few individuals), indicating that it may provide valuable information.
About one third of the carpenters fulfilled our criteria for neurosensory affection, which is of the same magnitude as reported previously for forestry workers [9]. Neurosensory affection was much more common among carpenters than among painters, which we attribute to the exposure of the carpenters to vibration. This difference was neither detected by the SWC nor the ICC score, although SWS stage ≥ 2 was more prevalent than the corresponding ICC score. These scales are based solely on the symptom of numbness, but the dominating symptom among carpenters was increased sensation of cold (67%), followed by numbness (55%), and then pain in fingers/hands when cold (45%). Therefore we choose to set a clinical condition that we called neurosensory affection including impairment/sensation in Aδ, A6, and/or C fibres. We did not include symptoms of impaired grip strength or neuro-vegetative effects (shaking, tremors and sweating), since it has been suggested that nerve fibres other than the cutaneous afferents are involved in these conditions [26]. Only a few individuals exhibited ICC or SWS neurosensory scores indicating stage 2 or higher. Yet half of the carpenters with neurosensory affection reported symptoms on a daily basis, and one fifth that they interfered with daily life activities.

Both hand-intensive work and vibration exposure are risk factors for carpal tunnel syndrome [7, 49]. A prevalence of 7–35% has been reported among vibration-exposed workers in various epidemiological studies [11, 18, 50], with an elevated POR of 3.4 (1.4–8.3) among stoneworkers, compared to controls [51] [52]. In the clinical setting it is often difficult to distinguish neuropathy caused by compression in the carpal tunnel from more distally distributed neuropathy, as in vibration injury. Vibration perception thresholds have also been found to be increased in a group of subjects with carpal tunnel syndrome not exposed to vibration, compared to controls [53]. In our study, the prevalence of carpal tunnel syndrome was the same in both groups, and higher than expected for men in the general population [54, 55].

Vascular manifestations

The prevalence of white fingers among carpenters was 8%. As expected, it was higher than in among men in the general population [33]. This is in line with a nationwide study in UK, where 14% of carpenters reported white fingers [56], and with a Swedish cross sectional study, where 13% of construction workers reported white fingers [57]. In a cross sectional study on vibration-exposed stoneworkers the prevalence of white fingers was found to be 30%, compared to 4% in non-exposed controls [51]. We found no difference concerning white fingers between the carpenters and painters, which is surprising. We cannot rule out that some painters may have developed white fingers as a result of working with vibrating tools. There may also be some selection bias among the painters. To the best of our knowledge, the prevalence of white fingers among painters has not been studied previously.

Both carpenters and painters exhibited an elevated prevalence of carpal tunnel syndrome, which is risk factor for white fingers [58]. However, we found no correlation between fulfilling the criteria for carpal tunnel syndrome and reporting of white fingers.

One third of the carpenters and one tenth of the painters had noise-induced hearing loss. Other studies have shown an increased prevalence of white fingers among workers with hearing loss [59]. Although hearing loss was more common among the carpenters than the painters in the current study, we found no difference in the prevalence of white fingers between the groups.

Conclusions

The study confirmed that carpenters reported more symptoms, and exhibited a greater number of clinical findings corresponding with HAVS than painters. The OR for neurosensory affection was more than threefold. Also young carpenters (≤30 years of age) showed neurosensory affection, which indicates that workers are currently not sufficiently protected against this kind of injury. This underlines the importance of reducing exposure to vibration, and conducting regular medical check-ups to detect early signs of neural and vascular manifestations indicating HAV-injury. Special attention should be paid to the neurosensory symptoms of increased sensation of cold, pain in fingers when cold, and numbness, as these were the most common early symptoms in our study and should be addressed early in the preventive sentinel process. It is also important to test clinically for small- and large-fibre neuropathy, since the individual may be unaware of this kind of pathology.

Abbreviations

Hand Arm Vibration Syndrome (HAVS), International Consensus Criteria (ICC),

Stockholm Workshop scale (SWS), Vibration Perception Threshold (VPT)

Declarations

Availability of data and materials

The dataset supporting the conclusions of this article is available from the corresponding author on reasonable request.

Consent for publication

Written consent was obtained from all participants. The participants were informed that no individual results would be presented in the report.

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**Authors’ contributions**

All authors contributed to design of the study. ET, LL and AL collected the data. ET and CN performed the analyses. ET and CN were mainly responsible for writing the manuscript. All authors read, contributed to, and approved the final manuscript.

**Ethics declarations**

**Ethics approval and consent to participate**

Written informed consent to participate and for publication of the results was obtained from the participants in this study. The study was approved by the Regional Ethics Committee in Lund (No. 2015/875).

**Competing interests**

The authors declare that they have no competing interests.

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