Risks of Occupational Vibration Exposures

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Title: Longitudinal epidemiological surveys in Italy of workers exposed to hand-transmitted vibration

Author: Massimo Bovenzi

Organisation: Institute of Occupational Medicine, University of Trieste, Italy

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Summary

In a prospective cohort study of the health effects of hand-transmitted vibration (HTV) in 191 user of vibratory tools and 107 control men, a greater occurrence of upper limb disorders was observed in HTV exposed workers than in the controls, at both the cross-sectional survey and over a two-year follow up period. The point and period prevalences and the cumulative incidence of peripheral sensorineural and vascular symptoms were found two to four times higher in the vibration-exposed group than in the control group. An increased risk for musculoskeletal symptoms of the upper extremities was also observed in the HTV exposed workers, even though to a lesser extent when compared to that found for neurovascular disorders. The findings of two laboratory tests, i.e. a standardised cold test with measurement of finger systolic blood pressure (FSBP) and the Purdue pegboard test for manual dexterity, showed that over the study period there was a deterioration of the vascular function and the manipulative precision in the HTV exposed workers compared with the controls. This study suggests that the measurement of FSBP after local cooling and the the Purdue pegboard test are helpful laboratory tool to monitor prospectively vascular and sensory disfunction, respectively, in vibration-exposed workers. This study investigated the relationships between alternative measures of daily and cumulative exposures to hand-transmitted vibration (taking account of vibration magnitude, exposure duration and frequency of vibration) and the development of neurovascular disorders. Multivariate analysis of health and exposure data showed that after adjustment for potential confounders, there was evidence for a dose-response relationship for sensorineural and vascular symptoms in the HTV exposed worker group. There was also evidence for a dose-effect relationship for cold-induced digital arterial hyperresponsiveness and for impairment to manual dexterity over time. Of the several measures of daily vibration exposure (A(8)) and lifetime cumulative vibration dose used in this longitudinal study, those derived from unweighted acceleration magnitude gave better predictions for symptoms and signs of vibration-induced disorders than measures derived from acceleration magnitude frequency-weighted according to current standards. In this study, measures of cumulative vibration dose estimated by combining vibration magnitude and duration of exposure provided better predictions of the occurrence of upper limb disorders

than doses determined solely by lifetime exposure duration (years of exposure or total hours of tool use). Moreover, some statistical measures of information showed that regression models including dose measures with high powers of acceleration provided better fits to data that those with other measures of lifetime cumulative vibration exposure. The findings of this prospective cohort study of vibration-exposed workers suggest that improvements are possible to both the frequency weighting and the time-dependency used in current standards to predict the development of vibration-induced disorders.

1. Introduction

According to the project manual for Risks of Occupational Vibration Exposures (VIBRISKS – EC FP5 Project No. QLK4-2001-02650), Work Package (WP) 2 is devoted to ***Epidemiological Studies of Upper Limb Disorders (Vascular, Neurological, Musculoskeletal) caused by Hand-transmitted Vibration***.

VIBRISKS WP2 involves coordinated longitudinal studies in workers exposed to hand-transmitted vibration (HTV).

The main objectives of VIBRISKS WP2 were:

- to improve knowledge of the dose-response relationship between vibration exposure of the upper limb and development of:
    - vascular disorders (vibration-induced white finger, VWF)
    - neurological disorders (e.g. numbness, tingling, reduction of manipulative dexterity);
- to improve understanding of factors causing, or predicting, progression (i.e. natural history) of vascular and neurological disorders.

The Clinical Unit of Occupational Medicine, Department of Public Health Sciences, University of Trieste (UTRS), has been involved in WP2 Task 2.1 dedicated to dose-response studies of HTV exposed workers in Italy.

This final Report provides information about the findings of cross-sectional and follow up studies of HTV exposed workers carried out by the Italian investigators over the calendar period 2003-2006.

All VIBRISKS working documents and deliverables mentioned in this Report are available at the following VIBRISKS Web site:

http://www.vibrisks.soton.ac.uk/members/index.html

2. Epidemiological studies of HTV exposed workers in Italy (2003 – 2006)

In the calendar period from April 2003 to October 2006, the UTRS research team conducted the initial (cross-sectional) survey and two follow up studies of an original sample of 257 HTV exposed workers and 139 control workers.

In the same calendar period, vibration measurements and evaluation and assessment of vibration exposure have been carried out in the field by the Physical Agents Laboratory of the Department of Prevention of the National Health Service (NHS) in Siena (a subcontractor of UTRS).

2.1 Subjects and Methods

At the cross-sectional survey, the study populations exposed to hand-transmitted vibration in Italy included two occupational groups:

(i) 221 lumberjacks using chain saws and brush saws, employed in several forestry companies in Tuscany Region (central Italy) and the Province of Trento (northern Italy);

(ii) 36 stone processing workers using grinders/cutters, polishers and inline hammers, employed in the Versilia district (Tuscany Region).

The control group included 139 workers unexposed to hand-transmitted vibration (supervisors, inspectors, maintenace operators), who have been recruited from various industrial and public utility activities. They were employed in either the same industrial sectors or the same geographical areas where the vibration exposed workers were enrolled.

At the initial investigation, the study populations showed a slight, positive, deviation compared to the original plan and this was due to the inclusion in the cohort of additional vibration-exposed workers (n=18) and controls (n=23).

Since the cohort was of dynamic type, new workers were enrolled and others were lost during the follow up investigations. Causes of drop-out were change of residence, retirement, refusal to participate in the follow up, and death.

Table 1 reports the number of subjects (HTV exposed workers and controls) who participated in one, two, or three investigations. The distribution of the study populations is given by job title, tools used, and place of investigation (Province).

As a whole, 299 HTV exposed workers were investigated over the follow up period (2003-2006): of these, 61 men underwent one investigation, 47 two investigations, and 191 three investigations, these latter having a complete follow up. In total, 141 control men were investigated: of these, 3 men underwent one investigation, 31 two investigations, and 107 three investigations, these latter having a complete follow up.

In this final Report, we illustrate the findings of the epidemiological studies of the HTV exposed workers and the controls who participated in all three surveys (191 and 107 men, respectively), so that a complete set of repeated clinical and laboratory measurements could be analysed.

2.1.1 Medical investigation

The vibration-exposed workers, as well as the control workers, have been investigated by physicians specialist in Occupational Medicine and Industrial Hygiene. They used the medical procedures included in the document WP1-N4 ("*HTV diagnostic procedures manual*") and the final VIBRISKS "*Protocol for epidemiological studies of hand-transmitted vibration*" (deliverable D3). The procedures included in two further documents, dedicated to (a) "*Use of colour charts for the diagnosis of Raynaud's phenomenon*" (document WP1-N3 and N6), and (b) "*Diagnostic criteria for suspected carpal tunnel syndrome*" (document: WP1-N2), were also used in the epidemiological surveys [40].

The vibration-exposed workers and the control subjects examined in Italy, have been investigated using the following diagnostic tools:

(a) clinically administered questionnaire;

(b) complete physical examination;

(c) cold test with measurement of finger systolic blood pressures at 30°C and 10°C, by means of a strain-gauge plethysmographic technique;

(d) manual dexterity by means of the Purdue pegboard test.

All subjects gave signed informed consent to the study, which was approved by the Local Health Authorities.

2.1.1.1 The questionnaire and the physical examination

The HTV exposed workers and the controls were interviewed by traineed occupational health physicians on their personal, work and health histories using a structured questionnaire developed within the European research project VIBRISKS (document WP1-N9 "*HTV clinical questionnaire – Italian translation*"), [40].

The HTV exposed workers and the controls were questioned about smoking, alcohol consumption, metabolic, cardiovascular, and neurological disorders, previous musculoskeletal injuries, and use of medicines. Ex-smokers were classified as no smokers if they had stopped smoking for at least two years. The same time period was applied for ex-drinkers to be classified as no drinkers.

Each subject underwent a physical examination focused on the vascular, neurological and musculoskeletal systems of the upper limbs, according to the procedures included in the VIBRISKS clinically administered questionnaire [40].

In the VIBRISKS questionnaire, a section is dedicated to symptoms in the fingers and hands. Sensorineural disturbances (tingling and numbness), vascular symptoms (finger whiteness, cyanosis, redness), and musculoskeletal complaints in the neck and upper limbs (pain, stiffness, numbness, limited function) were accurately investigated with reference to appearance, location, frequency, extent, severity, and change over time of symptoms and signs.

The anamnestic diagnosis of vibration-induced white finger (VWF) was based on the criteria established at the Stockhom Workshop '94 [60]: (i) positive history of cold provoked episodes of well demarcated blanching in one or more fingers after excluding primary Raynaud's phenomenon or other probable causes of secondary Raynaud's phenomenon; (ii) first appearance of finger blanching after the start of occupational exposure to hand-transmitted vibration and experience of VWF attacks during the last two years.

VWF symptoms were staged according to the Stockholm scale [31].

The extent of finger blanching attacks was assessed using a scoring system described by Griffin [32]. On digits II to V, a score of 1 is given for blanching on the distal phalanx, a score of 2 for blanching on the middle phalanx and a score of 3 for blanching on the proximal phalanx. On the thumbs the scores are 4 for the distal phalanx and 5 for the proximal phalanx. The blanching scores were added up over the two hands for each worker who reported finger blanching attacks.

The same score system was used to quantify the severity of sensorineural symptoms in the fingers (tingling and numbness). These latter were also staged according to the Stockholm scale [12].

The questionnaire was administered to and the physical examination was performed on 191 HTV workers and 107 control subjects.

2.1.1.2 Colour charts

The clinical diagnosis of finger whiteness was made on the basis of (i) a medical history alone using standardised questions included in the VIBRISKS questionnaire [40], and (ii) the administration of colour charts. These latter consisted of a series of photographs illustrating various degrees of blanching, cyanosis, or redness of the fingers and hands, according to the scheme proposed by Maricq and Weinrich, partially modified [47]. The colour charts were shown to the workers at the end of the medical interview. The subjects were asked three questions: (i) "*have you experienced any of these color changes in your fingers/hands?*"; (ii) "*if yes, please show the affected part(s) (finger, hand palm or both)*"; (iii) "*if yes, when do these colour changes occur?*". A diagnosis of finger whiteness was established when the subject indicated the photographs displaying well-demarcated blanching of the fingers. White patching of hand palm, cyanosis of fingers, or acrocyanosis alone were not considered to be sufficient for a diagnosis of Raynaud's phenomenon.

The colour charts for the diagnosis of Raynaud's phenomenon were tested on a selected sample of 146 vibration-exposed workers who were investigated twice over one-year follow up period.

2.1.1.3 Cold test

The cold test was performed with the subject in a supine position after a rest period of 20-30 min in a laboratory room with an ambient temperature of 20-22°C. The cold test consisted of strain-gauge plethysmographic measurement of finger systolic blood pressure (FSBP) during local cooling according to the technique proposed by Nielsen and Lassen [51] and the procedure recommended by the international standard ISO 14835-2 [42]. A double inlet plastic cuff (3 × 9.5 cm) for both air filling and water perfusion was placed on the middle phalanx of the third right finger. In the subjects with subjective symptoms of VWF, the most affected finger was cooled. The test finger was warmed and cooled with water circulating at 30°C and 10°C with a digit cooling system. Two air filled cuffs were applied, one to the proximal phalanx of the test finger (for ischaemia during cooling), and one to the proximal phalanx of the thumb of the same hand (reference finger). The cold test was performed by pressurising the air cuffs to a suprasystolic level (210 mmHg) and perfusing the water cuff with water initially at 30°C and then at 10°C. After five minutes of ischaemic cooling, FSBP was measured by a strain gauge in the distal phalanx of the test and reference finger.

The following FSBP indices were calculated:

1. The change of systolic blood pressure in the test finger at 10°C ($FSBP_{t,10°}$) as a percentage of the pressure at 30°C ($FSBP_{t,30°}$), corrected for the change of pressure in the reference finger during the examination ($FSBP_{ref,30°} – FSBP_{ref,10°}$):

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

2. The reduction in finger systolic blood pressure ($R\text{-}FSBP_{10°}$) by cooling the test finger from 30°C to 10°C:

$$R\text{-}FSBP_{10°} = (FSBP_{t,30°} – FSBP_{t,10°}) – (FSBP_{ref,30°} – FSBP_{ref,10°}) \quad (mmHg)$$

3. The digitall pressure index at 10°C:

$$DPI_{10°} = (FSBP_{t,10°} \times 100)/ASP_{10°} \quad (\%)$$

where $ASP_{10°}$ is the arm systolic pressure measured by an ausculatory technique.

To avoid nicotine induced vasoconstrictive effects on the digital vessels, tobacco users refrained from smoking for at least two hours before testing.

The cold test at the cross-sectional and follow up investigations was performed by the same health personnel who used the same method and apparatus. FSBPs were measured in the same test and reference fingers at all examinations.

The cold test was performed on 191 HTV workers and 107 control subjects.

2.1.1.4 Purdue pegboard test

Manipulative dexterity was investigated by means of the Purdue pegboard testing method [70]. The test was administered according to a standardised test procedure [44]. Prior to performing the test, the occupational health physician explained how to perform it, using standardised verbal instructions and a quick demonstration. The subject had the possibility to practice before the beginning of test. Starting with the preferred hand, the subject had to pick up pins from a cup on the corresponding side of the board and place as many pins in the holes as possible within 30 seconds. The subject completed the test once for each hand and once for both hands together. Manipulative dexterity was scored on the basis on the number of pegs placed in the holes with the dominant and non-dominant hand and both hands. The hand scores from the previous three subtests were then summed. The assembly subtest consisted of a standardised sequence of assembly of pins, collars and washers in one minute and the score resulted in the number of pins, collars and washers correctly assembled.

The Purdue pegboard test was administered to 115 HTV workers and 64 controls.

2.1.2 MEASUREMENT AND ASSESSMENT OF VIBRATION EXPOSURE

Current and past exposures to hand-transmitted vibration were investigated by means of the VIBRISKS questionnaire which includes a section dedicated to workplace assessment in terms of exposures to mechanical factors (types of vibrating tools, daily and cumulative exposure duration for each tool), ergonomic risk factors (e.g. repetitiveness, force, awkward postures) and environmental factors (e.g. exposure to cold).

The measurement and assessment of vibration exposure in both forestry workers and stone workers have been carried out by the Physical Agents Laboratory of the Department of Prevention of NHS in Siena (a subcontractor of UTRS). The techniques and methods to measure hand-transmitted vibration (HTV) from hand-held powered tools and to assess vibration exposure are those established in the VIBRISKS manual for HTV epidemiological studies.

Vibration was measured on the brush saws (n=7), chain saws (n=29), and breakers (n=16) used by the forestry workers, and on the grinders (n=5), polishers (n=2) and inline hammers (n=3) used by the stone workers. Vibration measurements were made in the field during real operating conditions performed by skilled workers. Vibration was measured in three orthogonal directions according to the ISO 5349-1 procedure [41]. The vibration time histories were stored in a digital recorder (DAT HEIM DATa Rec-A80) and then analysed in the laboratory by a signal analyser (IMC FAMOS).

From the one third octave band frequency spectra (6.3-1250 Hz), the root-mean-square (r.m.s.) of the frequency-weighted (a_w) and unweighted (a_{uw}) accelerations were obtained. The root-sum-of-squares of the frequency-weighted (a_{vw}) and unweighted (a_{vuw}) r.m.s. acceleration values for the *x*-, *y*- and *z*-axes (also called the vibration total value) was calculated according to the following formula:

$$a_v = (a_x^2+a_y^2+a_z^2)^{½} \qquad (\text{ms}^{-2} \text{ r.m.s.})$$

Questionnaire data, information obtained by interviewing employees and employers, and company records were used to estimate daily exposure duration and total years of tool use. Moreover, to assess daily exposure duration to vibration, direct observation of exposure patterns at the workplace was made by supervisors over an entire week period. They used a stopwatch method and recorded the contact time the hands of the operator were actually exposed to the vibration from the tools.

A report on the findings of direct observations of daily exposure duration in the field is available at the VIBRISKS Web site (document WP2-N2 entitled "*Measured and reported HTV exposure durations*"), [40].

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), according to the European Directive on mechanical vibration [25]:

$$A(8)=a_v(T_e/T_0)^{½} \quad (\text{ms}^{-2} \text{ r.m.s.})$$

where T_e is the daily duration of exposure to vibration a_v (a_{vw} or a_{vuw}) in hours and T_0 is the reference duration of 8 h.

Using the vibration magnitudes and exposure durations, various alternative measures of cumulative vibration doses were constructed for each subject, according to the following general form [34]:

$$dose = \sum_i [a_i^m t_i] \qquad \text{[Eq. 1]}$$

where a_i and t_i are the acceleration magnitude (a_{vw} or a_{vuw} in ms^{-2} r.m.s.) and the total exposure duration (hours) respectively, for tool i.

In these doses, the relative importance of the acceleration, a, (weighted (i.e. a_{vwi}) or unweighted (i.e. a_{vuwi})) and the total exposure duration, t, depends on the value of m. If m has the value 2, the relationship between a and t is that assumed in root-mean-square averaging as suggested by the international standard ISO 5349-1 to evaluate vibration exposure over a working day [41]. Assigning values of 1 or 4 to m decreases or increases, respectively, the 'importance' of the vibration magnitude, a, relative to that of exposure duration, t. With m = 0, the dose takes no account of vibration magnitude. Doses with m = 0, 1, 2, and 4 were computed for each worker, with both frequency-weighted acceleration and unweighted acceleration [34].

The methods for the calculation of daily vibration exposure and cumulative vibration doses are described in the document WP1-N15 ("*Calculation of doses for HTV*"), [40].

2.1.3 Ergonomic risk factors

Ergonomic stressors at the workplace were investigated by means of the VIBRISKS questionnaire which includes a section dedicated to repetitiveness, force, and awkward postures exerted by the neck, upper arms and back during a typical working day [40].

Physical load was graded by rating the frequency of manual activities on a 4-point response scale (e.g. lifting loads > 25 kg: "never", "1-4 times", "5-20 times", "more than 20 times").

Scores for neck-upper arm posture, hand-intensive work, and total ergonomic load were calculated for each subject.

In the total sample, the three measures of physical load was divided into four categories which were assumed to correspond to four grades of increasing physical load.

For neck-upper arm posture: score 0 – 3 = no or very low exposure to physical load; score 4 – 6 = low load grade; score 7 – 9 = medium load grade; score 10 – 12 = hard load grade.

For hand-intensive work: score 0 – 3 = no or very low exposure to physical load; score 4 – 6 = low load grade; score 7 – 10 = medium load grade; score 11 – 15 = hard load grade.

For total ergonomic score: score 0 – 12 = no or very low exposure to physical load; score 13 – 23 = low load grade; score 24 – 35 = medium load grade; score 36 – 60 = hard load grade.

2.1.4 STATISTICAL METHODS

Data analysis was performed with the statistical software Stata 9.2 SE (Stata Corporation, 2006). Continuous variables were summarised using means or medians as measures of central tendency and standard deviations (SD) or range as measures of dispersion.

Point estimates and 95% confidence intervals for point prevalence, period prevalence, and cumulative incidence of disorders over the follow up period were calculated using traditional statistical techniques.

The Mann-Whitney rank sum test or the unpaired *t* test were used to compare two independent groups, when appropriate. The Kruskal-Wallis test were used to compare more than two independent groups.

Repeated measures analysis of variance (ANOVA) was used to test the hypothesis of no difference in the outcome within subjects over time, when the data were normally distributed. When the compound symmetry assumption (that is, the measures have the same variance and the correlations between each pair of repeated measures are equal) was violated, a conservative test of the repeated measures factor was used by reducing the degrees of freedom of the *F* ratio (Greenhouse-Geisser method). The 95% Bonferroni confidence intervals for pairwise mean comparisons of the response by time were used when the probability value for the *F* test of repeated measures ANOVA was $p<0.05$ (two-sided).

The χ^2 statistic was applied to dichotomous or categorical independent data tabulated in 2×2 or $2 \times k$ contingency tables.

The Cochran's Q test was used to test for the equality of proportions in matched samples.

The relation between dependent outcome variables and independent variables with repeated measures over time was assessed by means of either the generalised estimating equations (GEE) or the random-intercept modelling approach to repeated measures data sets [72]. Either linear or logistic regression models were fitted to continuous or dichotomous outcome variables, respectively.

For instance, the longitudinal relationship between a continuos outcome variable Y and a set of predictor variables X was assessed according to the following general model form (standard model), [72]:

$$Y_{it} = \beta_0 + \sum_{j=1}^{J} \beta_{1j} X_{itj} + \varepsilon_{it} \qquad \text{[Eq. 2]}$$

where Y_{it} are observations for subject *i* at time *t*, β_0 is the intercept, X_{ijt} is the independent variable *j* for subject *i* at time *t*, β_{1j} is the regression coefficient for independent variable *j*, *J* is the number of independent variables, and ε_{it} is the “error” for subject *i* at time *t*.

Both time-dependent covariates and time-independent covariates were included in the regression models as predictor variables.

For a dichotomous outcome variable, the logit of the dependent variable was included in the left side of [Eq. 2], i.e. ln [(Pr (Y_{it} = 1))/(1 – Pr (Y_{it} = 1))], where Pr (Y_{it} = 1) is the probability that the observations at t_1 to t_n of subject *i* equal 1. In a longitudinal logistic regression analysis, the coefficient (β_1) can be transformed into an odds ratio (exp(β_1)).

In addition to standard modelling, a transition model for repeated measures data set (also called Markov model or autoregressive model) was used to test the hypothesis of no difference in the outcome over the follow up time, according to the following general model form [72]:

$$Y_{it} = \beta_0 + \sum_{j=1}^{J} \beta_{1j} X_{ijt} + \beta_2 Y_{it-1} + \ldots.. \qquad \text{[Eq. 3]}$$

where Y_{it} is observations for subject *i* at time *t*, β_0 is the intercept, X_{ijt} is the independent variable *j* for subject *i* at time *t*, β_{1j} is the regression coefficient for independent variable *j*, *J* is the number of independent variables, Y_{it-1} is the observation for subject *i* at time *t* – 1, and β_2 is the autoregression coefficient.

The assumption underlying a transition model is that the value of an outcome variable at each time-point is primarily influenced by the value of this variable one measurement earlier.

The contribution of covariates to the fit of regression models was assessed by the either the Wald test (for GEE) or the likelihood ratio (LR) statistic (for random-intercept models). The Quasi-likelihood under the Independence model Criterion (QIC) for GEE models [62] and the Bayesan Information Criterion (BIC) for random-intercept models [64] were used as measures of overall fit and a means to compare non-nested regression models including different measures of cumulative vibration dose.

To compare the fit of non-nested regression models by means of the difference in BIC, the following guidelines suggested by Raftery were adopted [64]:

Absolute difference between models	Evidence for preferring one model over another one
0 – 2	Weak
2 – 6	Positive
6 – 10	Strong
> 10	Very strong

For the QIC statistic, the criterion for the selection of one model over another one is that, all else being equal, the model with the smaller QIC is considered the better fitting model [62].

2.2 Results

2.2.1 Characteristics of the study populations

Table 2 reports the characteristics of the control and HTV exposed workers at the cross-sectional survey and the follow up investigations. There were significant differences between the two groups for body mass index (BMI) and smoking (Table 1). BMI values tended to increase significanty over time in both the controls and the HTV exposed workers ($p<0.001$). Even though smoking was more frequent in the HTV exposed workers than in the controls, there was a significant decrease over time in the occurrence of smoking among the HTV exposed workers ($p<0.001$). No differences between the two groups were found for alcohol consumption, physical activity, marital status, prevalence of systemic disorders and use of medicines (results not shown). Previous jobs with HTV exposure and leisure activity with vibratory tools were more frequently reported by the HTV exposed workers than the controls.

2.2.2 VIBRATION MEASUREMENTS AND VIBRATION EXPOSURE

Table 3 reports the results of vibration measurements on the hand-held vibratory tools used by the forestry workers and the stone workers. The vibration total value of the frequency-weighted or unweighted r.m.s. acceleration magnitude averaged, respectively, 5.7 ms^{-2} (a_{vw}) and 38.6 ms^{-2} (a_{vuw}) for the brush saws, 5.2 to 5.5 ms^{-2} (a_{vw}) and 36.8 to 38.1 ms^{-2} (a_{vuw}) for the chain saws, 4.6 ms^{-2} (a_{vw}) and 82.1 ms^{-2} (a_{vuw}) for the grinders, 1.6 ms^{-2} (a_{vw}) and 18.3 ms^{-2} (a_{vuw}) for the polishers, and 19.5 ms^{-2} (a_{vw}) and 229 ms^{-2} (a_{vuw}) for the inline hammers.

Daily vibration exposure, in terms of $A_w(8)$, $A_{uw}(8)$ and daily exposure time, were significantly greater in the stone workers than in the forestry operators ($p<0.001$). In the two HTV exposed groups, however, there was a significant reduction in daily vibration exposure over the follow up period, mainly in the forestry workers. When $A_w(8)$ was averaged over time, daily vibration exposure exceeded the EU action value of 2.5 ms^{-2} r.m.s. for the forestry workers (3.8 ms^{-2} r.m.s.), and the EU exposure limit value of 5 ms^{-2} r.m.s. for the stone workers (9.4 ms^{-2} r.m.s.), [25].

Job seniority expressed as years of employment was not different between the forestry workers and the stone workers, 15.5 *vs* 17.5 years on average at the cross-sectional survey, respectively (Table 5). Cumulative vibration exposure, in terms of total operating time (hours) and alternative measures of vibration dose, was significantly greater in the stone workers when compared with the forestry workers.

2.2.3 PREVALENCE AND INCIDENCE OF VIBRATION-INDUCED DISORDERS IN THE UPPER LIMBS

Tables 6 to 8 reports in detail the prevalence of vascular, sensorineural and musculoskeletal symptoms in the upper limbs of the controls and the HTV exposed workers over the study period (2003 – 2006).

In general, the stone workers reported neurovascular symptoms, musculoskeletal disturbances, and clinically suspected carpal tunnel syndrome more frequently than the controls and the forestry workers, and these latter more than the controls ($0.05<p<0.001$).

Peripheral sensorineural symptoms (tingling and numbness) tended to increase significantly over time in both the controls and the HTV exposed workers ($0.05<p<0.001$). The same finding was observed for cold fingers/hands, but only in the forestry and stone workers ($0.05<p<0.001$).

At the initial cross-sectional survey, a positive history of VWF was reported by 36.4% of the stone workers and 13.3% of the forestry workers ($p<0.01$). Raynaud's phenomenon was complained by four control subjects (3.7%).

Limited work performance in the last 12 months due to disorders in the upper limbs was significantly higher in the stone workers than in the controls and the forestry workers ($p<0.001$).

Tables 9 and 10 report the point prevalence, period prevalence and cumulative incidence of disorders in the upper limbs of the controls and the HTV exposed workers. In general, the prevalence ratios for vascular, sensorineural and musculoskeletal symptoms were significantly greater in the HTV exposed workers than in the controls at both the cross-sectional survey (point prevalence) and over the study period (period prevalence).

Over the calendar period 2004 – 2006, the cumulative incidence of finger tingling was 19.2 *vs* 30.8% in the controls and HTV exposed workers, respectively; 5.1 *vs* 12.9% for finger numbness, 0 *vs* 5.7% for suspected carpal tunnel syndrome, 4.4 *vs* 11.4% for cold fingers/hands, 1.9 *vs* 4.4% for VWF assessed by medical history alone, and 0 *vs* 1.7% for VWF assessed by colour charts. As a result, increased risk ratios (RR) for the cumulative incidence of disorders over the follow up time were observed in the HTV exposed workers compared with the controls, even though the 95% confidence intervals show that the increased RRs were not statistically significant (Table 10).

Table 11 reports the distribution of sensorineural and vascular symptoms in the forestry workers, stone workers, and total HTV exposed sample over the calendar period 2003-2006, according to the Stockholm workshop scales. In both HTV exposed groups, there was a significant increase in the severity of peripheral sensorineural symptoms over time ($0.01<p<0.001$). An increase in the severity of VWF stages was observed only in the stone workers, even though not significant.

The absolute change and the percent change in sensorineural and vascular disorders in the HTV exposed workers during the study period (2003-2006) are reported in Tables 12 and 13, respectively. The estimated proportions of change show that significant deterioration in sensorineural disturbances occurred in the HTV exposed workers during the follow up period ($p<0.05$). Significant changes in both directions (i.e. improvement and deterioration) were observed for clinically suspected carpal tunnel syndrome.

There were seven new cases with a positive history of VWF during the follow up period, giving rise to a percent change of 6.3% (95% CI: 2.9 to 9.7%). Applying the Stockholm criteria for the reversibility of VWF (i.e. no episodes of finger whiteness during the last two years), there were five cases who recovered from VWF, the percent change being 2.6% (95% CI: 0.3 to 4.9%). During the follow up, the severity of VWF, staged according to the Stockholm scale, did not change in 16 men (8.4%), improved in 9 men (4.7%), and deteriorated in 15 men (7.9%).

There were no new cases of Raynaud's phenomenon among the controls during the follow up period.

When VWF was assessed by means of colour charts, there were three new cases of VWF during the follow up period (percent change: 2.3% (95% CI: -0.3 to 4.9)). Fourteen subjects have stationary VWF and none improved.

Table 14 reports the results of logistic regression analysis for the association between vascular and sensorineural disorders and individual and occupational covariates in the study population over the follow up period. Assuming the controls as the reference category, after adjustment for potential confounders both the forestry workers and the stone workers showed a significant increased risk for VWF (assessed by either medical history alone or colour charts), tingling, numbness, and suspected carpal tunnel syndrome. When the outcome variable at time-point $t - 1$ was included in the logistic model (transition model), there was, as expected, a reduction of the odds ratios for vascular and sensorineural disorders in the HTV exposed workers compared with the controls (Table 15). Nevertheless, a significant risk excess for all outcomes was observed in the HTV exposed workers, although the increase in the odds ratios was significant only for the stone workers.

2.2.4 Dose-response relationships for vibration-induced disorders in the upper limbs

To assess possible exposure-response relationship between alternative measures of vibration dose and health disorders in the upper limbs of the HTV exposed workers, several longitudinal logistic regression models were explored. To avoid spurious findings, the controls were excluded from data analysis. Tables 16a and 16b report the findings of standard GEE models according to (Eq. 2), and Tables 17a and 17b those of transition GEE models according to (Eq. 3).

After adjustment for potential confounders, significant associations were found between VWF assessed by either medical history alone or colour charts and various alternative measures of daily and cumulative vibration dose.

The Wald test for the odds ratio estimates and the QIC statistic for the comparison between non-nested models suggest that models including daily vibration exposure expressed in terms of $A_{uw}(8)$ fit the data better than those which include $A_{w}(8)$ as a measure of daily vibration exposure, (Tables 16a and 17a).

Significant associations were found between VWF and alternative measures of cumulation vibration exposure. In general, the measures of vibration dose estimated by combining vibration magnitude and duration of exposure were significant predictors of VWF over the follow up period. Measures of vibration dose determined solely by lifetime exposure duration were either not associated with VWF (years of exposure) or performed worse (total hours of tool use) for the prediction of the vascular outcome (Tables 16b and 17b). Moreover, transition models, which tend to capture more efficiently the longitudinal part of the relationship, seem to suggest that dose measures with high powers of acceleration (i.e. $\Sigma a_i^m t_i$ with $m > 1$) performed substantially better, at least from a statistical viewpoint, for the prediction of VWF over the follow up period than other measures of lifetime cumulative vibration exposure (Table 17b). Minor differences between doses derived from unweighted acceleration or frequency-weighted acceleration were observed when the data were modelled according to transition models (Table 17b). A preference for vibration doses derived from unweighted acceleration may be noted when standard models were applied to data (Table 17a).

The relations between sensorineural disorders (tingling, numbness, suspected carpal tunnel syndrome) and measures of daily and cumulative vibration doses were less evident than those observed for vascular symptoms (VWF). The pattern of the odds ratios and the information measures of overall model fitting do not suggest a clear preference for a particular measure of either daily vibration exposure ($A_w(8)$ or $A_{uw}(8)$) or cumulative vibration dose with different powers of acceleration magnitude, even though a better fit may be observed for dose measures with high powers of acceleration. Similarly to the findings for vascular symptoms, no or weak associations were found between sensorineural disorders and lifetime exposure duration (years of exposure or total operating time with vibrating tools).

After adjustment for personal characteristics, vibration exposure, and survey, multivariate regression analysis showed no significant effects of ergonomic risk factors (neck-upper arm posture, hand-intensive work, and total ergonomic score) on the occurrence of vascular, sensorineural, and suspected CTS in the HTV exposed workers.

2.2.5 Colour charts

One of the aims of VIBRISKS HTV epidemiological studies was to assess the usefulness of colour charts for the diagnosis of VWF. A further aim was to investigate the relation between the response of digital arteries to cold provocation and the anamnestic outcome of finger whiteness assessed by either medical history alone or the administration of colour charts.

For these purposes, the occurrence of finger whiteness and the cold response of digital arteries were investigated in a sample of 146 active HTV exposed workers (113 forestry workers and 33 stone workers), to whom colour charts were administered twice over one-year follow up period.

At the initial survey, in the selected sample 23 HTV workers (15.8%) reported VWF at the medical interview alone. Of these, 15 (10.3%) were positive and 8 (5.5%) were negative at the presentation of the colour charts. Two workers (1.4%), who did not report VWF at the medical interview, recognised finger blanching when the colour charts were administered.

Assuming the colour 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 (Table 18). 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 of longitudinal data showed that the reduction of FSBP%$_{10°}$ over time was significantly associated with the presence of finger whiteness assessed by either medical history alone ($p<0.005$) or the colour charts ($p<0.001$), (Table 19). However, when the two 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 colour charts performed substantially better, at least from a statistical viewpoint, for the prediction of the vasoconstrictor response to cold at the follow up than when finger whiteness was investigated by medical interview alone (Δ BIC=15.1), [64]. FSBP%$_{10°}$ was inversely related to cumulative vibration dose ($0.001<p<0.05$), while no association was found for age and other individual personal characteristics.

These findings were confirmed by the results of random-intercept linear regression analysis of the cold response of digital arteries in a sample of 131 HTV exposed workers to whom colour charts were administered three times over the entire follow up period (2003-2006), (Table 20). Using a marginal regression model for repeated measures of $FSBP\%_{10^\circ}$ over time, the difference in BIC suggests a very strong support for the model which includes finger whiteness investigated with colour charts compared with that in which finger whiteness was assessed by medical interview alone (Δ BIC=22). On the contrary, when the outcome variable measured at one time-point earlier (i.e. $FSBP\%_{10^\circ}$ at *t*–1) was included as a covariate in the regression model (transition model), there was no clear evidence for preferring one model over the other one (i.e. models which include finger whiteness assessed by either medical history alone or colour charts), (Δ BIC=1).

2.2.6 FINGER SYSTOLIC BLOOD PRESSURE INDICES DURING LOCAL COOLING

Table 21 reports in detail the results of cold provocation test in the controls and the HTV exposed workers over the study period (2003-2006). On average, the stone workers showed an increased cold response of digital arteries compared with the controls and the forestry workers at both the cross-sectional survey and the two follow up investigations.

In the controls, the lower normal limits for the cold response of digital arteries in terms of $FSBP\%_{10^\circ}$ (calculated as mean – 2 SD) was 58.9% at the cross-sectional survey, 61.5% at the 1st follow up, and 64.9% at the 2nd follow up. Averaging over the entire study period, a lower normal limit of 61.7% was estimated. These figures were 60.3, 50.0, 52.1, and 53.9%, respectively, in the HTV exposed workers who never experienced finger blanching attacks during the follow up period.

When the HTV exposed workers were divided into two groups according to VWF status (negative or positive), there was significant evidence for cold-induced digital arterial hyperresponsiveness in the subjects with VWF compared with the controls and the HTV workers without VWF, at both the cross-sectional survey and the two follow up investigations. Similar findings were observed when VWF was assessed by either medical history alone (Table 22) or colour charts (Table 23).

In general, a trend for an increasing cold response of the digital arteries with the increase in the severity of VWF symptoms assessed by Griffin's score method was observed at both the cross-sectional survey and the two follow up investigations (Table 24). The vibration-exposed workers with moderate VWF (blanching score 13 – 24) and severe VWF (blanching score > 24) showed an increased cold-induced hyperreactivity in the digital arteries when compared with the controls and the HTV exposed workers with no vascular symptoms ($p<0.001$). A multiple comparison test showed no significant differences in the FSBP indices at 10°C between the controls, the asymptomatic HTV exposed workers and those with mild VWF (blanching score 1 – 12), even though these latter exhibited a greater responsiveness to cold than the other two groups.

When the crude findings of the cold provocation test were analysed according to the change in VWF symptoms during the follow up period (improvement, no change, deterioration), there was poor evidence for an association between the changes in FSBP indices during local cooling and the changes in VWF symptoms assessed by either medical interview alone (Table 25) or colour charts (Table 26). More interesting findings became apparent from a multivariate analysis of the follow up data (Table 27). Compared with the HTV exposed workers with never VWF, those with stationary VWF symptoms during the follow up showed a significant deterioration of the cold response of digital arteries. An increase in cold-induced digital arterial responsiveness, although not significant, was also found in the subjects who reported a worsening of white finger symptoms detected by colour charts. Using both standard and transition regression models, the difference in BIC between models tends to confirm that finger whiteness assessed by colour charts gives rise to better model fits than finger whiteness investigated with a medical interview alone.

2.2.7 Dose-effect relationship for cold provocation of the digital arteries

Tables 28a and 28b report the results of regression analysis aimed at investigating possible dose-effect relationships for the cold response of digital arteries in the HTV workers. To avoid spurious findings, the control subjects were excluded from data analysis.

After adjustment for several covariates, cold-induced digital vasoconstriction during the follow up period was related to some measures of vibration exposure. The information measure QIC tends to suggest that both standard and transition models which include $A_{uw}(8)$ as a predictor variable are associated with better model fitting than models in which daily vibration exposure is expressed as $A_w(8)$. The measures of cumulative vibration dose estimated by combining vibration magnitude and duration of exposure were significant predictors of the increased vasoconstrictor response to cold (i.e. reduction of $FSBP\%_{10°}$) in the HTV exposed workers. Measures of vibration dose determined solely by lifetime exposure duration, such as years of exposure or total hours of tool use, were less strongly associated with $FSBP\%_{10°}$ over the follow up period, mainly when transition models were fitted to data. Dose measures with high powers of acceleration (i.e. $\Sigma a_i^m t_i$ with $m > 1$) performed better for the prediction of the vasoconstrictor response to cold during follow up than other measures of lifetime cumulative vibration exposure.

These findings are remarkably similar to those observed when logistic regression analysis was conducted using VWF symptoms as an outcome variable (see Tables 16a to 17b). In the case of the cold response of digital arteries, there is some, although not strong, evidence for preferring models which include vibration doses derived from unweighted acceleration over models with doses derived from acceleration magnitude frequency weighted according to current standards [14, 41].

There was no evidence of significant interactions between individual characteristics and alternative measures of vibration dose when product terms involving these variables were added to the regression models.

2.2.8 MANIPULATIVE DEXTERITY

In the VIBRISKS project (Work Package 2), manipulative dexterity was assessed by means of the Purdue pegboard test in a group of 64 control men and a group of 115 HTV exposed workers (82 forestry workers and 33 stone workers), who were examined twice over one-year follow up study. Moreover, the relation between manipulative dexterity and vibration exposure, ergonomic risk factors, and upper limb disorders (sensorineural, vascular, and muscoloskeletal) was investigated.

At the cross sectional survey, Purdue pegboard scores (dominant hand, non-dominant hand, both hands, sum of hand scores, and assembly) were significantly lower in the HTV exposed workers than in the controls ($0.001<p<0.05$), (Table 29). No difference was found between the stone workers and the forestry operators.

Over one-year follow up period, Purdue pegboard scores were found to be inversely related to age ($p<0.001$), use of vibratory tools ($0.001<p<0.05$), and smoking habit ($p<0.05$ for the dominant hand), (Table 30). In the total sample, Purdue pegboard scores tended to improve over the follow up time ($0.001<p<0.05$).

Deterioration of some measures of manipulative dexterity was significantly associated with peripheral neurosensorial symptoms (tingling, numbness) and vascular disturbances (white finger), expressed as either dichotomous variables or symptom scores (Table 31). No association was found between manipulative dexterity and neck or upper limb musculoskeletal disorders.

After adjusting for individual characteristics and follow up time, random-intercept linear regression analysis showed that Purdue pegboard scores for the dominant hand, non-dominant hand and both hands decreased with the increase of cumulative vibration dose (Table 32). 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 cumulative vibration dose and ergonomic stress (neck-upper arm posture, hand-intensive work, total ergonomic score). There was no significant interaction between vibration exposure and ergonomic risk factors.

2.3 Discussion

The findings of this prospective cohort study of forestry and stone workers using hand-held vibratory tools confirm that occupational exposure to hand-transmitted vibration is associated with the onset and development of several health disorders of the upper limbs [2, 3, 4, 9].

Compared with control men unexposed to hand-transmitted vibration, an increased risk for peripheral sensorineural and vascular disorders in the fingers and hands was observed in the HTV exposed workers at both the initial cross-sectional survey and two consecutive annual follow up investigations.

These findings are consistent with previous epidemiological studies of several occupational groups exposed to hand-transmitted vibration [2, 3, 4, 9]. The strength of the present study of HTV exposed workers may be ascribed to the study design, i.e. a closed cohort of subjects who underwent repeated measures of subjective symptoms and objective signs over time performed by the same occupational health physicians who used the same clinical and laboratory methods at each investigation.

2.3.1 Vascular disorders

2.3.1.1 Prevalence and incidence of VWF

In this cohort study, the point and period prevalences of Raynaud's phenomenon was about four times higher in the HTV exposed workers than in the controls. These latter showed a prevalence of finger whiteness around 4%, a figure similar to those reported in previous epidemiological surveys of the general population in the mediterranean countries. During the follow up, a twofold increase in the risk ratio for the cumulative incidence of finger whiteness was observed in the HTV exposed workers compared with the controls. These findings strengthen an observation firstly reported by Giovanni Loriga in 1911 and Alice Hamilton in 1918 and then supported by hundred clinical and epidemiological studies, that is finger whiteness in users of vibratory tools is a secondary form of Raynaud's phenomenon caused by intense and prolonged exposure to a specific physical agent represented by hand-transmitted vibration. This notion has been accepted by the European Commission which has included vibration-induced white finger in the European schedule of recognised occupational diseases (2003/670/EC, item 505.02 "*angioneurotic diseases caused by mechanical vibration*"), [21].

2.3.1.2 Colour charts as a diagnostic tool

Patients affected with a severe form of Raynaud's phenomenon are usually able to report their symptoms very accurately. In the field of occupational exposure to hand-transmitted vibration, the exposed workers may be confused in differentiating sensorineural disorders in the fingers and hands (tingling, numbness) from vascular symptoms such as VWF, since sensory disturbances are associated with digital colour changes during finger blanching attacks. Proper questions by the physician and an accurate description of the symptoms by the patient are essential for an anamnestic diagnosis of Raynaud's phenomenon. According to the report of a working group at the Stockholm Workshop '94 [60], a medical interview is still the best available method of diagnosing Raynaud's phenomenon in vibration-exposed workers.

In clinical work, some authors have reported that the presentation of colour charts, in addition to a medical interview, is a useful tool for the diagnosis of Raynaud's phenomenon [47, 57]. It has been suggested that the administration of colour charts can lessen the proportion of false positive cases and this may be of help for standardising the diagnosis of Raynaud's phenomenon in epidemiological studies [47]. On the contrary, comparing three different assessment methods for the classification of Raynaud's phenomenon, Brennan *et al.* [13] concluded that color chart assessment was too insensitive to detect Raynaud's phenomenon, while individual clinician's assessement based on consensus opinion of a group of clinicians was more reliable for diagnosing Raynaud's phenomenon.

The findings of this longitudinal study of VWF in vibration-exposed workers seem to suggest that the administration of colour charts, in addition to a medical history, may reduce the frequency of false positive responses for finger whiteness. It should be noted, however, that when compared with the colour chart method, the performance of the medical history alone to detect finger whiteness (in terms of sensitivity, specificity, and predictive values) was greater at the follow up than at the initial cross-sectional survey. Therefore, a learning effect over time for the recognition of finger whiteness symptoms cannot be ruled out.

In this study, an objective measure of digital vasoconstrictor response to cold ($FSBP\%_{10°}$) was found to be related to finger whiteness assessed by the colour chart method more significantly than when the same symptom was investigated by a medical history alone. This finding seems to suggest that the use of colour charts in clinical and epidemiological studies may be of additional help to assist in the diagnosis of Raynaud's phenomenon in HTV exposde workers.

In conclusion, our experience with the colour chart method in the context of the European epidemiological project VIBRISKS suggests that the use of colour charts may improve the quality of information obtained by workers who report finger blanching attacks at the medical interview. The method is easy to implement and to use by workers and occupational health personnel.

2.3.1.3 Effect of smoking

In this study, there were no significant associations over the follow up period between smoking and the changes in finger blanching symptoms or cold test results in both the controls and the HTV exposed workers. A lack of association was observed when smoking was treated as a dichotomous variable (smoking/no smoking), a categorical variable (no smoker, ex-smoker, current smoker).

The role of tobacco consumption on the course of VWF and the cold response of digital arteries is still a controversial matter. The findings of some follow up studies suggest that smokers exposed to hand-transmitted vibration have a poorer prognosis for VWF and cold-induced digital arterial hyperresponsiveness than non-smokers [20, 26, 63]. Consistently, these studies reported that the improvement in the cold response of digital arteries was more evident in non-smokers or ex-smokers than in current smokers, even though the beneficial effect on digital vascular function was not accompanied by improvement in subjective experience of finger blanching attacks [20, 63]. On the contrary, other longitudinal and case-control studies have found no influence of smoking on either the progression of VWF in current users of vibratory tools or the reversibility of VWF in ex-users [30, 56]. Similar results have been reported in a prospective study of the cold response of digital arteries in chain saw operators [9]. Even though it is known that long-term cigarette smoking is associated with adverse effects on arterial function, possibly through impairment to endothelium-dependent arterial vasodilating mechanisms, nevertheless its contribution to the aggravation of VWF symptoms and the deterioration of the vasoconstrictor response to cold is not yet established.

2.3.1.4 Dose-response relationship for VWF

This prospective cohort study investigated the possible dose-response relationship between the occurrence of VWF and alternative measures of daily and cumulative vibration exposure.

In 2001, an annex to International Standard 5349-1 included a dose-response relationship between the occurrence of finger blanching (i.e. VWF) and three measures of exposure to hand-transmitted vibration: vibration magnitude, daily exposure duration, and years of exposure [41]. The vibration acceleration was frequency-weighted, on the assumption that the effects of different vibration frequencies varied according to an experimental study of the sensations produced by hand-transmitted vibration [48]. The ISO dose-response relationship gives the values of the daily vibration exposure *A*(8) which may be expected to produce episodes of finger blanching in 10% of workers exposed for a given number of years *D*y. It is said that the ISO dose-response relation is derived from studies of groups of workers exposed to tool vibration magnitudes up to 30 ms^{-2} r.m.s. in their occupations for up to 25 years. Almost all studies involved groups of workers who performed, near-daily, work involving one type of power tool or industrial process in which vibration was coupled to the hands. The acceleration values are derived from studies in which the dominant, single-axis, frequency-weighted component acceleration was reported.

The dose-response model included in the standard has allowed the severity of occupational exposures to hand-transmitted vibration to be assessed. Some subsequent epidemiological studies have reported results consistent with the predictions in the standard, while others studies have reported wide differences [7, 8, 23, 33, 34, 68]. One of the limitations of the ISO dose-response relationship is that it was derived from epidemiological studies of cross-sectional type, which may be liable to several sources of bias such as selection bias, information bias, and difficulty of determining the temporal relation of exposure to disease.

The present longitudinal study investigated the relationships between the onset of finger whiteness and the characteristics of exposures to hand-transmitted vibration, specifically the vibration magnitude and the daily and lifetime exposure duration. The effects of vibration frequency were investigated by comparing dose-response models constructed with and without the current frequency weighting.

In this study, for all alternative measures of daily and lifetime cumulative vibration doses, an increase in dose was associated with a significant increase in the occurrence of VWF, after adjustment for several potential confounders. However, measures of daily vibration exposure calculated from acceleration magnitude frequency weighted according to ISO 5349 (i.e. $A_w(8)$, current or maximum values) faired less well than measures derived from unweighted acceleration magnitude (i.e. $A_{uw}(8)$, current or maximum values). The W_h frequency weighting in International Standard 5349 assumes that vibration has an effect that depends on vibration velocity, between 16 and 1000 Hz (i.e. the acceleration weighting decreases in inverse proportion to frequency). Finding that the unweighted acceleration provides a better prediction of blanching suggests that the effect depends more closely on acceleration. It should be noted that there is not an epidemiological, pathological or physiological basis for the selection of the W_h characteristic for predicting VWF in ISO 5349 [41]; unweighted acceleration has been previously suggested for evaluating the severity of hand-transmitted vibration [49]. While the present results indicate that the use of frequency weighting W_h is not optimum for the prediction of VWF, it should be recognised that finger blanching is not the only adverse effect of hand-transmitted vibration and that the various disorders may have different frequency dependence: some may be better predicted by using weighting W_h than unweighted acceleration. Furthermore, the frequency range over which unweighted acceleration may be used to predict finger blanching is not known.

In this study, measures of vibration dose estimated by combining vibration magnitude and duration of exposure provided better predictions of the occurrence of VWF than doses determined solely by lifetime exposure duration (years of exposure or total hours of tool use). Moreover, regression models including dose measures with high powers of acceleration (i.e. $\Sigma a_i^m t_i$ with $m > 1$) were associated with better fits that those with other measures of lifetime cumulative vibration exposure. Consistently with the findings for the measures of daily vibration exposure and those for the cold response of digital arteries (see below), a small preference for cumulative vibration doses derived from unweighted acceleration magnitude seems to emerge from data analysis.

There are some limitations or potential biases in this study. Although the seven dose models used four different time dependencies (dose = $\Sigma a_i^m t_i$, where m = 0, 1, 2 or 4) the vibration magnitudes for all tools were represented by root-mean-square acceleration: the second-power relationship was assumed so as to obtain average measures of tool vibration magnitudes (i.e. root-mean-square acceleration was measured). Different averaging procedures during vibration measurement might have changed the relative severity of vibration on different tools, depending on the impulsiveness of the vibration. For example, fourth power (or root-mean-quad) averaging would have increased the magnitudes on percussive tools, such as stone-working hammers, relative to the rotary tools, such as grinders and polishing machines. This might have affected the relative performance of the seven dose models, and so the current findings are restricted to situations where the vibration magnitude is expressed in terms of r.m.s. acceleration.

The doses were primarily calculated from acceleration magnitudes (weighted or unweighted) and lifetime exposure durations, in hours. Both quantities have several sources of uncertainty that may contribute to uncertainty in the calculated doses, such as the accuracy of the measurements, the representativeness of the exposures, the possible intermittency of the exposure, the goodness of the information about daily and lifetime exposure duration obtained from employers and employees [34, 61]. In this study, some of these potential biases were, at least partially, controlled by measuring the vibration magnitudes from vibratory tools currently and previously used by the forestry and stone workers, and by consulting employment records, when available, in order to estimate past exposures. Moreover, daily exposure durations were directly observed and recorded during actual operating conditions over typical workshifts for one week.

In the present study, no distinction was made between the accumulation of exposure duration during the working day and the accumulation of exposure over days, months and years (i.e. lifetime exposure). However, the total duration of exposure expressed in hours was found to be a better predictor of finger whiteness than years of exposure (i.e. years in the job), suggesting that the study distinguished between individuals with low and high daily exposure durations.

International Standard 5349-1 [41] assumes a second-power time dependency during the day, and daily exposure to hand-transmitted vibration is represented by an ‘energy-equivalent’ vibration magnitude, the r.m.s. acceleration normalised to a reference period of 8 hours. In an informative annex, ISO 5349 suggests an almost linear relationship between this daily ‘energy-equivalent’ acceleration and the number of years of exposure for equal probability of developing vibration-induced white finger (e.g. $A_w(8)$/years = constant). The pattern of dose-response relationships for VWF emerging from the present study of vibration-exposed workers are partially discordant from that suggested by the international standard ISO 5349. Differences in the study design, the statistical treatment of data, the methods for the evaluation and assessment of vibration exposures, and the way simptoms and signs of upper limb disorders were collected, may account for the discrepancy between the ISO proposal and the findings of the present study. Hence, the results of this prospective cohort study should be considered a contribution for the improvement of both the frequency weighting and the time-dependency used in current standards to predict the development of vibration-induced white finger.

2.3.1.5 Cold response of the digital arteries

The findings of this study suggest that the measurement of FSBP after local cooling may be a helpful laboratory tool to monitor prospectively the change in vibration-induced vascular symptoms [5, 27, 37, 58, 59, 63]. The cold test could differentiate between subjects with and without peripheral vasospastic symptoms. Within the VWF group, however, the cold test could not discriminate patients with different stages of VWF, even though a decreasing trend for FSBP indices after cooling with the increase of the severity of vascular symptoms was observed.

In the literature, there is a small number of longitudinal studies of the cold response of digital arteries in HTV exposed workers and VWF patients [9, 20, 26, 58, 63]. Almost all studies reported an impairment of FSBP indices during local cooling in active HTV exposed workers who developed VWF during a follow up period. A beneficial effect of a reduction in or cessation of vibration exposure on finger blanching symptoms and vascular reactivity to cold has been observed in two cohort surveys of Danish and Italian forestry workers [9, 58]. Nevertheless, the relation between the cold response of digital arteries and subjective vascular symptoms is not fully clear. Some studies reported that amelioration of VWF symptoms was not associated with an improvement in the vasoconstrictor response to cold, while others found that subjective symptoms were less likely to recover than the finger reaction to cold provocation [20, 63]. These findings suggest that the cold test with measurement of FSBP may have limitations as a laboratory tool for the prognosis of

VWF. These limitations may be attributed to the study design because most of the currently available prospective studies included high-risk worker groups, series of VWF cases, or VWF claimants, so that self-selection or health-based selection cannot be ruled out. On the other hand, the poor prognostic performance of the cold test reported in some follow up studies may reflect our incomplete knowledge of the pathophysiological mechanisms underlying the adverse effect of hand-transmitted vibration on finger circulation.

To our knowledge, this is the first study which investigated the cold response of digital arteries over time in a group of control subjects. Previous studies of cold provocation in normal men were of cross-sectional type [5, 27, 59]. In these studies, the reproducibility or repeatability of FSBP indices after cooling varied from 5 to 13% in either normal individuals or HTV exposed workers [16, 59]. This range of values is consistent with the results of our previous investigation on the repeatability of FSBP measurements in which the coefficient of variation for repeated measures of $FSBP\%_{10^\circ}$ in five healthy men average 6% (range 3.8 – 9.2%), [5]. In the present study, the vasoconstrictor response to cold in the controls was stable over a two-year follow up period with no significant difference between the three examinations. The finger reaction to local cooling in the controls was not associated to either personal or health covariates. On the basis of the results of the cold test in the control subjects of this study, the lower normal limits for $FSBP\%_{10^\circ}$ (mean – 2 SD) were estimated to range between 59% (at baseline) and 65% (at the 2nd follow up). These discriminating thresholds between normal and pathological responses of the digital arteries to cold provocation are broadly consistent with those suggested by other authors who reported lower normal limits of 58% to 66% at 6° or 10°C in smaller samples of male controls [5, 27, 37, 52, 59].

2.3.1.6 Dose-effect relationship for cold provocation of the digital arteries

In this longitudinal study of HTV exposed workers, the reduction of $FSBP\%_{10^\circ}$ during the follow up period was significantly associated with the increase of dose measures with powers of acceleration greater than or equal to unity (i.e. $m \geq 1$), suggesting a dose-effect relationship between the cold response of digital arteries and cumulative vibration exposure. Dose determined solely by the lifetime exposure duration (without consideration of the vibration magnitude) faired less well than measures in which the weighted or unweighted acceleration, *a*, and lifetime exposure duration, *t*, were combined. Measures of daily and cumulative vibration exposure which included unweighted acceleration magnitude gave better predictions for the cold response of digital arteries than dose measures derived from acceleration magnitude frequency-weighted according to current standard.

These findings are broadly similar to those observed when VWF symptoms were used as an outcome variable (see above). It might be argued that vascular disorders caused by hand-transmitted vibration (either VWF or cold-induced vascular hyperreactivity) are more sensitive to the magnitude of tool vibration than to the duration of vibration exposure. These findings, however, should be interpreted with caution because selecting a model which maximise the value of a statistical measure of fit does not mean that the selected model is the best one for the interpretation of the pathophysiological mechanisms underlying a disorder. Nevertheless, there is experimental evidence that the magnitude of vibratory stimulus is associated with the haemodynamic changes occurring in the fingers of the exposed subjects. A study of finger blood flow and magnitude of acute exposures to hand-transmitted vibration showed that the higher the vibration magnitude in the range 5.5 to 62 ms^{-2} r.m.s. at a frequency of 125 Hz, the stronger the digital vasoconstriction in the exposed and unexposed fingers of 10 healthy men during both vibration exposure and the recovery period after vibration ceased [10]. Similar findings have been reported in other experimental investigations [11, 73]. Biomechanical studies have also shown that the higher the acceleration magnitude of vibration, the higher the absorption of mechanical energy in the fingers and hands [15]. According to some investigators, the energy absorbed and dissipated in the human hand may contribute to injury in the soft tissues of the fingers and hands of the exposed worker [22]. Moreover, it has been suggested that high vibration magnitudes can provoke an extremely high enhancement of arterial wall shear stress and this may be related to vibration-induced vascular disorders through either damage to the endothelial cells or impairment to endothelium-dependent vasoregulatory mechanisms [50].

2.3.2 Sensorineural disorders

2.3.2.1 Prevalence and incidence od sensorineural symptoms

In previous epidemiologic surveys of vibration-exposed workers, the prevalence of peripheral sensorineural disorders was found to vary from a few percent to more than 80% [28]. In this study, tingling and numbness in the fingers and hands were reported by both the controls and the HTV exposed workers at the initial cross-sectional investigation and during the follow up. However, the estimates of the period prevalence ratio and the risk ratios for cumulative incidence suggest that the occurrence of sensorineural disturbances over the study period was greater in the HTV exposed workers than in the controls. Similar findings were observed for clinically suspected carpal tunnel syndrome.

Neurophysiological studies have suggested that sensory disturbances in the hands of vibration-exposed workers are likely due to vibration-induced impairment to various skin mechanoreceptors (Meissner's corpuscles, Pacinian corpuscles, Merkel cell neurite complexes, Ruffini endings) and their afferent nerve fibres [46,]. Electron microscopic studies of human finger biopsy specimens suggest that hand-transmitted vibration can provoke perineural fibrosis, demyelination, axonal degeneration and nerve fibre loss [19, 39, 69].

In this longitudinal study, in addition to an increased incidence of sensory disorders in the HTV exposed workers compared with the controls, a significant deterioration of sensorineural symptoms, staged according to the Stockholm scale, was observed in the HTV exposed workers. These findings are consistent with those reported by other researchers and support the clinical and epidemiological evidence for a greater risk for peripheral sensory disorders in occupational groups using vibrating tools than in control groups not exposed to hand-transmitted vibration [28, 32].

2.3.2.2 Manipulative skill

To investigate some aspects of the function of the peripheral nervous system, manual dexterity was studied in the controls and the HTV exposed workers. Overall, this study showed a deterioration of manipulative dexterity in workers operating vibratory tools when compared with control men unexposed to hand-transmitted vibration. This finding is consistent with those reported by others researchers who found impairment to manual dexterity in groups of HTV exposed workers [1, 17, 29, 67, 71]. Banister and Smith [1] found a significant loss in manipulative skill (tested by Purdue pegboard as number of items correctly placed on board using the dominant hand) in a group of 22 saw operators when compared with 46 non-saw users. Sakakibara *et al.* [67] observed an impaired manual dexterity (tested by measuring the performance time in a bean-transferring task) in a group of 29 patients affected with the hand-arm vibration syndrome (HAVS) compared with 30 male controls. Toibana *et al.* [71] reported significantly prolonged performance times of buttoning-unbuttoning a work jacket and transferring beans from a plate to another one in 30 patients with HAVS compared with 50 controls (30 office workers and 20 manual laborers). In a cross-sectional study of 111 vibration-exposed workers, Cederlund *et al.* [18] observed a moderate agreement between Purdue pegboard scores and neurological and vascular symptoms staged according to the Stockholm Workshop scales.

The findings of this prospective study confirm a significant association between impairment to manipulative dexterity and neurovascular disorders in the fingers of HTV workers. Moreover, manipulative skill was inversely related to vibration exposure and ergonomic stress factors over one-year follow up period.

In this study, the measures of manipulative dexterity were positively related to the follow up time in both the controls and the HTV exposed workers, suggesting a possible learning effect over time. Previous studies observed that Purdue pegboard scores tended to increase when the test was repeated after few days [24] or after few weeks [65]. Haward and Griffin [38] found no significant age or gender effects on Purdue pegboard test results in a total sample of 72 office workers, even though there was some evidence of practice effect. However, the authors concluded for a sufficient repeatability of the Purdue pegboard test, at least for the purposes of health surveillance at the workplace. Further investigations are needed to confirm the possible learning effect associated with the clinical use of Purdue pegboard.

It has been shown that sensory perception and manipulative dexterity depend upon the integrity and/or functional capacity of various skin mechanoreceptors and their afferent nerve fibres which are located in the (epi)dermal and subcutaneous tissues of the glabrous skin of the fingers and hands [46]. In particular, the Meissner afferents seem to play an important role in providing a neural image of motion signals from the whole hand which are essential to control grip force and to hold objects securely [43]. It has been suggested that vibration can induce changes in skin microcirculation and biomechanical properties of the skin and these adverse effects might contribute to the impairment of manual dexterity observed in users of vibratory tools [46]. The findings of histological studies of both experimental animals and human finger skin biopsies have provided biological plausibility to the symptoms and signs of peripheral sensory neuropathy in vibration-exposed workers [19, 39, 69]. In acutely exposed animals, vibration can induce perineurial oedema, followed by fibrous thickening of the perineurium [19, 39, 45]. Prolonged exposure to intense vibration was found to provoke a variety of lesions in the peripheral nerves of rabbits and rats such as disruption of the myelin sheaths, constriction of the axons, and disappearance of microtubules and microfilaments in the axons [19, 39]. Noteworthy was that the major morphological changes observed in the experimental animals occurred in the nerve fibres with diameter from 2 to 12 μm, that is afferent fibres from Pacinian and Meissner corpuscles. These findings are consistent with the results of finger skin biopsy studies performed by Takeuchi *et al.* [69] who found severe loss of myelin sheath, perineural fibrosis and a decreased number of myelinated nerve fibres in the fingers of 30 patients exposed to hand-transmitted vibration. These findings may explain the symptoms of digital paraesthesias and numbness reported by professional users of vibratory tools as well as the signs of impaired tactile sensation and loss of precise manipulation exhibited by these patients at the neurological examination.

In summary, the findings of this prospective study tend to confirm and to extend those of previous investigations which suggest an association between deterioration of manipulative dexterity, exposure to hand-transmitted vibration, and peripheral neurovascular symptoms in users of vibratory tools. The Purdue pegboard may be considered a useful laboratory testing method for the clinical assessment of hand function in workers exposed to hand-transmitted vibration.

2.3.2.3 Dose-response relationship for sensorineural disorders

Clinical and epidemiologic surveys have revealed an increase in sensorineural disorders with the increase of daily vibration exposure, duration of exposure, or lifetime cumulative vibration dose [2, 3, 4, 28, 32].

In this longitudinal study, there was some evidence for a dose-response relationship between peripheral sensorineural symptoms and measures of daily and cumulative vibration exposure in the HTV workers. Moreover, multivariate data analysis indicated a dose-effect relationship between loss of precise manipulation and vibration exposure. In addition, impairment to some tests of manipulative dexterity was significantly associated with ergonomic risk factors (neck-upper arm posture, hand-intensive work, total ergonomic score).

As for VWF symptoms, model fitting to sensorineural data suggested better predictions for measures with high powers of unweighted acceleration magnitude compared with measures of lifetime exposure duration (either years of exposure or total hours of tool use). Nevertheless, there was not strong evidence for a preference between alternative measures of daily vibration exposure (i.e. between dose measures derived from either unweighted acceleration or frequency-weighted acceleration).

Some cross-sectional and case-control studies have shown an increased occurrence of symptoms and signs of entrapment neuropathies, mainly carpal tunnel syndrome (CTS), in occupations involving the usage of vibrating tools [3, 4, 32, 36]. CTS is also common in job categories whose work tasks involve high-force and repetitive hand wrist movements [35]. The independent contribution of vibration exposure and physical work load (forceful gripping, heavy manual labour, wrist flexion and extension), as well as their interaction, in the etiopathogenesis of CTS have not yet been established in epidemiologic studies of workers who handle vibratory tools.

In this study, clinically suspected CTS was related to several measures of daily and cumulative vibration doses, while no associations were found for ergonomic risk factors over time. This latter finding may be due to difference in the definition of the outcome, since in the present study CTS diagnosis was based on clinical findings solely, while in other investigations CTS was diagnosed on the basis of clinical and electrophysiological findings [3, 4, 32, 36, 66]

In summary, this longitudinal study confirms that there are a significant associations between exposure to hand-transmitted vibration, sensorineural disorders and clinically suspected CTS. However, to date the currently available epidemiological data are insufficient to outline the form of a possible dose-response relationship for vibration-induced neuropathies.

2.4 Conclusions

In this prospective cohort study of the health effects of hand-transmitted vibration, a greater occurrence of upper limb disorders was observed in HTV exposed workers than in control men, at both the cross-sectional survey and over a two-year follow up period. The point and period prevalences and the cumulative incidence of peripheral sensorineural and vascular symptoms were found to be from about two to four times higher in the vibration-exposed group than in the control group. An increased risk for musculoskeletal symptoms of the upper extremities was also observed in the HTV exposed workers, even though to a lesser extent when compared to that found for neurovascular disorders.

Colour chart method for the diagnosis of finger whiteness was found to be a useful and pragmatic diagnostic tool for improving the quality of information obtained by workers who reported finger blanching attacks at the medical interview.

The findings of two laboratory tests, i.e. a standardised cold test with measurement of finger systolic blood pressure and the Purdue pegboard test, showed that over the study period there was a deterioration of the vascular function and the manipulative dexterity in the HTV exposed workers compared with the controls. This study suggests that the measurement of FSBP after local cooling and the the Purdue pegboard test are helpful laboratory tool to monitor prospectively sensory and vascular disfunction, respectively, in vibration-exposed workers.

In this study, the relationships between alternative measures of daily and cumulative exposures to hand-transmitted vibration (taking account of vibration magnitude, exposure duration and frequency of vibration) and the development of neurovascular disorders were investigated.

Multivariate analysis of health and exposure data showed that after adjustement for potential confounders there was evidence for a dose-response relationship for sensorineural and vascular symptoms in the HTV exposed worker group. There was also evidence for a dose-effect relationship for cold-induced digital arterial hyperresponsiveness and for impairment to manual dexterity over time.

Of the several measures of daily vibration exposure (*A*(8)) and lifetime cumulative vibration dose ($\Sigma a_i^m t_i$) used in this longitudinal study, those derived from unweighted acceleration magnitude gave better predictions for symptoms and signs of vibration-induced disorders than measures derived from acceleration magnitude frequency-weighted according to current standards [14, 41].

In this study, measures of cumulative vibration dose estimated by combining vibration magnitude and duration of exposure provided better predictions of the occurrence of upper limb disorders than doses determined solely by lifetime exposure duration (years of exposure or total hours of tool use). Moreover, some statistical measures of information showed that regression models including dose measures with high powers of acceleration (i.e. $\Sigma a_i^m t_i$ with $m > 1$) provided better fits to data that those with other measures of lifetime cumulative vibration exposure.

The findings of this prospective cohort study of vibration-exposed workers, in addition to those reported in other papers [34, 53, 54], suggest that improvements are possible to both the frequency weighting and the time-dependency used in current standards to predict the development of vibration-induced white finger. Our findings should be considered a scientific contribution to the understanding of the complex relationship between the main characteristics of vibration exposure (magnitude, frequency, duration) and the adverse health effects associated with vibration exposure. This can be of help for the national and international bodies and institutions involved in the issue of guidelines, directives, and standards for the protection of safety and health of workers exposed to hand-transmitted vibration from powered tools.

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Table 1. Distribution of the controls and the workers exposed to hand-transmitted vibration who participated in the VIBRISKS prospective cohort study in Italy (2003-2006), according to the number of clinical and epidemiological investigations attended. Data are given as numbers.

Job title	Tools	Province	One Investigation	Two investigations	Three investigations
Forestry workers	Chain & brush saw	Siena	29	16	22
Forestry workers	Chain & brush saw	Arezzo	4	4	42
Forestry workers	Chain & brush saw	Arezzo	15	11	6
Forestry workers	Chain & brush saw	Grosseto	4	7	14
Forestry workers	Chain & brush saw	Trento	7	8	74
Stone workers	Grinders, Hammers	Viareggio	2	1	33
Total			**61**	**47**	**191**
Controls	-	Siena	-	20	-
Controls	-	Arezzo	-	-	10
Controls	-	Arezzo	1	4	8
Controls	-	Grosseto	1	3	2
Controls	-	Trento	-	2	54
Controls	-	Viareggio	1	2	33
Total			**3**	**31**	**107**

Table 2. Characteristics of controls (n=107) and the HTV exposed workers (n=191) over the follow up period (2003-2006) in Italy. Data are given as means (standard deviations) or numbers (%). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

	Study	Control workers (n=107)	HTV workers (n=191)
Age (yrs)	CS	39.8 (8.5)	41.0 (8.3)
	F1	40.9 (8.5)	42.0 (8.3)
	F2	41.9 (8.4)	43.2 (8.3)
BMI (kg/m^2)	CS	25.0 (2.8)	25.9 (3.3)*
	F1	25.2 (2.6)	25.9 (3.2)*
	F2	25.4 (2.9)‡	26.2 (3.0)*‡
Current smokers (n)	CS	22 (20.6)	83 (43.5)†
	F1	22 (20.6)	78 (40.8)†
	F2	23 (21.5)	72 (37.7)†§
Drinkers (n)	CS	81 (75.7)	154 (80.6)
	F1	84 (78.5)	152 (79.6)
	F2	81 (75.7)	155 (81.2)
> 1 yr HTV exposure prior to current job (n)	CS	0 (0)	75 (39.3)†
	F1	0 (0)	75 (39.3)†
	F2	0 (0)	75 (39.3)†
Leisure activities with vibrating tools (n)	CS	13 (12.2)	120 (62.8)†
	F1	13 (12.2)	120 (62.8)†
	F2	13 (12.2)	120 (62.8)†

Unpaired *t* test: *$p<0.05$
χ^2 test: †$p<0.001$
Repeated measures ANOVA within group: ‡$p<0.001$
Cochran's Q test for equality of proportion in matched samples: §$p<0.001$

Table 3. Results of vibration measurements on the hand-held vibratory tools used by the forestry workers and the stone workers in Italy. Data are given as means (standard deviations), [range]. a_{hwx}, a_{hwy}, a_{hwz} are the acceleration magnitudes of vibration (ms^{-2} r.m.s.) in the *x*, *y* , and *z* directions, respectively, frequency-weighted according to the international standard ISO 5349-1. a_{hwv} is the vibration total value (ms^{-2} r.m.s.), calculated according to ISO 5349-1 [$a_{hwv} = (a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2)^{½}$].

Tool	a_{hwx} (ms^{-2} r.m.s.)	a_{hwy} (ms^{-2} r.m.s.)	a_{hwz} (ms^{-2} r.m.s.)	a_{hwv} (ms^{-2} r.m.s.)
Chain saw (sample A, n=22)	3.20 (0.98) [1.88 - 5.77]	2.65 (0.77) [1.59 - 4.89]	3.43 (1.08) [1.94 - 6.20]	5.47 [3.36 - 9.12]
Chain saw (sample B, n=7)	3.05 (1.18) [1.35 - 6.75]	2.50 (0.85) [1.25 - 5.70]	3.26 (1.23) [1.45 - 7.10]	5.16 [2.57 - 10.1]
Brush saw (n=7)	3.77 (1.69) [2.36 - 6.66]	2.48 (0.50) [2.01 - 3.25]	3.13 (1.30) [1.77 - 5.03]	5.69 [3.91 - 9.02]
Grinder/cutter (n=5)	2.63 (0.25) [1.96 - 2.86]	2.31 (0.23) [1.96 - 2.81]	2.76 (0.37) [2.44 - 2.92]	4.57 [4.04 - 5.14]
Polisher (n=2)	0.72 (0.12) [0.62 - 0.86]	0.78 (0.11) [0.62 - 1.00]	1.21 (0.11) [0.82 - 1.34]	1.63 [1.42 - 1.89]
Inline hammer (n=3)	6.48 (1.44) [5.02 - 8.68]	16.0 (2.70) [13.9 - 18.9]	8.02 (1.02) [7.11 - 9.20]	19.5 [16.9 - 23.1]

Table 4. Daily vibration exposure in the forestry workers (n=158), stone workers (n=33), and total sample (n=191) over the calendar period 2003-2006 in Italy. Data are given as means (standard deviations). $A_w(8)$ and $A_{uw}(8)$ are 8-hr energy-equivalent frequency-weighted and unweighted acceleration magnitudes, respectively.

	Worker group	Cross-sectional study (2003-2004)	1st follow up study (2004-2005)	2nd follow up study (2005-2006)
Daily vibration exposure (mins)	Forestry workers	118 (88.5)	117 (97.9)	75.8 (57.1)‡
	Stone workers	343 (128)	336 (125)	329 (133)
	All workers	157 (128)	155 (132)	120 (122)‡
$A_w(8)$ (average, ms^{-2} r.m.s)	Forestry workers	4.0 (2.3)	3.9 (2.2)	3.8 (2.1)‡
	Stone workers	9.4 (5.5)	9.5 (5.4)	9.4 (5.5)
	All workers	4.9 (3.7)	4.9 (3.7)	4.8 (3.6)‡
$A_{uw}(8)$ (average, ms^{-2} r.m.s.)	Forestry workers	22.9 (19.5)	22.8 (18.7)	22.4 (18.1)‡
	Stone workers	122 (60.7)	122 (60.4)	121 (60.7)
	All workers	40.0 (48.5)	40.1 (48.2)	39.5 (47.9)‡
$A_w(8)$ (max, ms^{-2} r.m.s.)	Forestry workers	4.6 (3.4)	4.7 (3.3)	3.9 (3.0)‡
	Stone workers	9.0 (5.7)	10.5 (5.8)	9.0 (6.4)*
	All workers	5.3 (4.2)	5.7 (4.4)	4.8 (4.3)‡
$A_{uw}(8)$ (max, ms^{-2} r.m.s.)	Forestry workers	27.0 (27.0)	29.3 (26.5)	23.4 (22.1)‡
	Stone workers	115 (64.1)	130 (63.3)	110 (71.9)*
	All workers	42.2 (49.2)	46.6 (52.0)	38.4 (48.6)‡
$A_w(8)$ (current, ms^{-2} r.m.s.)	Forestry workers	3.5 (1.9)	2.6 (1.2)	2.4 (1.3)‡
	Stone workers	8.8 (5.4)	9.3 (6.3)	7.8 (6.2)*
	All workers	4.4 (3.5)	3.8 (3.8)	3.3 (3.5)‡
$A_{uw}(8)$ (current, ms^{-2} r.m.s.)	Forestry workers	18.2 (10.8)	17.6 (9.7)	13.2 (8.0)‡
	Stone workers	114 (61.3)	115 (70.8)	99.0 (70.0)*
	All workers	34.8 (45.3)	34.4 (47.8)	28.0 (44.0)‡

Repeated measures ANOVA: *$p<0.05$; ‡$p<0.001$

Table 5. Duration of exposure and cumulative vibration doses in the forestry workers (n=158), stone workers (n=33), and total sample (n=191) over the calendar period 2003-2006 in Italy. Data are given as means (standard deviations). See text for the definition of vibration doses.

	Worker group	Cross-sectional study (2003-2004)	1st follow up study (2004-2005)	2nd follow up study (2005-2006)
Duration of exposure (yrs)	Forestry workers	15.5 (8.3)	16.5 (8.3)	17.4 (8.3)
	Stone workers	17.5 (9.7)	18.5 (9.7)	19.5 (9.7)
	All workers	15.8 (8.6)	16.8 (8.6)	17.8 (8.6)
Dose1 (Σt_i, hours$\cdot 10^3$)	Forestry workers	6.3 (5.9)	6.8 (6.2)	7.1 (6.2)
	Stone workers	24.7 (13.3)	26.2 (13.3)	27.6 (13.4)
	All workers	9.5 (10.3)	10.2 (10.7)	10.6 (11.1)
Dose2 ($\Sigma a_{hwvi} t_i$, $ms^{-2}h \cdot 10^4$)	Forestry workers	4.8 (4.8)	5.0 (4.8)	5.2 (4.8)
	Stone workers	22.9 (18.8)	24.1 (19.3)	25.1 (19.8)
	All workers	7.9 (11.2)	8.3 (11.6)	8.6 (11.9)
Dose3 ($\Sigma a_{hwvi}^2 t_i$, $m^2s^{-4}h \cdot 10^5$)	Forestry workers	5.1 (7.7)	5.2 (7.8)	5.4 (7.9)
	Stone workers	30.5 (38.4)	32.5 (39.6)	34.1 (41.0)
	All workers	9.5 (19.7)	9.9 (20.5)	10.3 (21.3)
Dose4 ($\Sigma a_{hwvi}^4 t_i$, $m^4s^{-8}h \cdot 10^8$)	Forestry workers	1.6 (4.3)	1.6 (4.4)	1.7 (4.4)
	Stone workers	9.2 (14.5)	10.0 (15.0)	10.5 (15.5)
	All workers	2.9 (7.7)	3.1 (7.9)	3.2 (8.2)
Dose5 ($\Sigma a_{huwvi} t_i$, $ms^{-2}h \cdot 10^4$)	Forestry workers	29.7 (43.9)	31.2 (44.2)	32.0 (44.5)
	Stone workers	302 (225)	317 (230)	331 (235)
	All workers	76.8 (144)	80.6 (149)	83.6 (154)
Dose6 ($\Sigma a_{huwvi}^2 t_i$, $m^2s^{-4}h \cdot 10^5$)	Forestry workers	224 (637)	231 (637)	234 (643)
	Stone workers	4821 (5473)	5110 (5643)	5343 (5821)
	All workers	1018 (2900)	1074 (3020)	1117 (3130)
Dose7 ($\Sigma a_{huwvi}^4 t_i$, $m^4s^{-8}h \cdot 10^8$)	Forestry workers	4413 (28924)	4433 (28927)	4455 (29046)
	Stone workers	200000 (300000)	210000 (310000)	230000 (330000)
	All workers	38223 (150000)	40687 (150000)	42589 (160000)

Table 6. Prevalence of sensorineural and vascular disorders in the controls (n=107), forestry workers (n=158), and stone workers (n=33) over the calendar period 2003-2006 in Italy. Data are given as numbers (%). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006). CTS is carpal tunnel syndrome. VWF is vibration-induced white finger.

Disorder	Study	Control workers (n=107)	Forestry workers (n=158)	Stone workers (n=33)
Tingling (all subjects)	CS	13 (12.2)	69 (43.7)	18 (54.6)‡
	F1	21 (19.6)	79 (50.0)	21 (63.6)‡
	F2	30 (28.0)[c]	95 (60.1)[c]	24 (72.7)‡[a]
Tingling (CTS excluded)[1]	CS	11 (10.5)	55 (38.2)	16 (51.6)‡
	F1	21 (19.6)	69 (46.6)	17 (58.6)‡
	F2	30 (28.0)[c]	92 (59.4)[c]	17 (65.4)‡
Numbness (all subjects)	CS	8 (7.5)	41 (26.0)	11 (33.3)‡
	F1	9 (8.4)	49 (31.0)	11 (33.3)‡
	F2	13 (12.2)[a]	53 (33.5)[b]	15 (45.5)‡[a]
Numbness (CTS excluded)[1]	CS	7 (6.7)	30 (20.8)	10 (32.3)‡
	F1	9 (8.4)	39 (26.4)	11 (37.9)‡
	F2	13 (12.2)[a]	50 (32.3)[b]	10 (38.5)‡
Suspected CTS	CS	2 (1.9)	14 (8.9)	2 (6.1)
	F1	0 (0)	10 (6.3)	4 (12.1)†
	F2	0 (0)	3 (1.9)[b]	7 (21.2)‡
Cold fingers/hands	CS	15 (14.0)	21 (13.3)	12 (36.4)†
	F1	17 (15.9)	33 (20.9)	12 (36.4)*
	F2	17 (15.9)	35 (22.2)[c]	15 (45.5)†[a]
VWF (medical history)	CS	4 (3.7)	21 (13.3)	12 (36.4)‡
	F1	4 (3.7)	19 (12.0)	12 (36.4)‡
	F2	4 (3.7)	21 (13.3)	14 (42.4)‡
VWF (colour charts)[2]	CS	2 (2.7)	2 (2.0)	12 (36.4)‡
	F1	2 (2.7)	3 (3.1)	12 (36.4)‡
	F2	1 (1.4)	3 (3.1)	14 (42.4)‡

[1]denominators differ according to the number of subjects with suspected CTS
[2]based on 74 controls, 98 forestry workers, and 33 stone workers
χ^2 test: *p<0.05; †p<0.01; ‡p<0.001.
Cochran's Q test for equality of proportions in matched samples: [a]p<0.05; [b]p<0.01; [c]p<0.001

Table 7. One-year prevalence of musculoskeletal disorders in the upper limbs of the controls (n=107), forestry workers (n=158), and stone workers (n=33) over the calendar period 2003-2006 in Italy. Data are given as numbers (%). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Musculoskeletal disorders	Study	Control workers (n=107)	Forestry workers (n=158)	Stone workers (n=33)
Neck	CS F1 F2	43 (40.2) 39 (36.5) 46 (43.0)[a]	65 (41.1) 60 (38.0) 67 (42.2)	15 (45.5) 11 (33.3) 13 (39.4)
Shoulder	CS F1 F2	13 (12.2) 13 (12.2) 20 (18.7)[a]	54 (34.2) 30 (19.0) 38 (24.1)[b]	4 (12.1)‡ 4 (12.1) 6 (18.2)
Elbow	CS F1 F2	6 (5.6) 12 (11.2) 14 (13.1)[a]	36 (22.8) 30 (19.0) 37 (23.4)	5 (15.2)† 4 (12.1) 5 (15.2)
Wrist	CS F1 F2	6 (5.6) 2 (1.9) 4 (3.7)	11 (7.0) 12 (7.6) 12 (7.6)	1 (3.0) 1 (3.0) 3 (9.1)
Hand	CS F1 F2	5 (4.7) 6 (5.6) 6 (5.6)	13 (8.2) 20 (12.7) 22 (13.9)[a]	2 (6.1) 3 (9.1) 9 (27.3)†[b]
Hand-wrist	CS F1 F2	10 (9.4) 8 (7.5) 9 (8.4)	24 (15.2) 28 (17.7) 31 (19.6)	3 (9.1) 4 (12.1) 10(30.3)[b]†
Any upper-limb disorder	CS F1 F2	16 (15.0) 20 (18.7) 16 (15.0)	50 (31.7) 49 (31.0) 55 (34.8)	9 (27.3)† 10 (30.3) 13 (39.5)‡
Limited work performance in the last 12 months	CS F1 F2	3 (2.8) 2 (1.9) 1 (0.9)	11 (7.0) 12 (7.6) 6 (3.8)	8 (24.2)‡ 8 (24.2)‡ 3 (9.1)[b]
Reduced work output In the last 12 months	CS F1 F2	1 (0.9) 0 (0) 1 (0.9)	4 (2.5) 5 (3.2) 2 (1.3)	2 (6.1) 1 (3.0) 2 (6.1)

χ^2 test: †p<0.01; ‡p<0.001
Cochran' Q test for equality of proportions in matched samples: [a]p<0.05; [b]p<0.01

Table 8. One-year prevalence of pain in the upper limbs of the controls (n=107), forestry workers (n=158), and stone workers (n=33) over the calendar period 2003-2006 in Italy. Data are given as numbers (%). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pain in the last 12 months	Study	Control workers (n=107)	Forestry workers (n=158)	Stone workers (n=33)
Neck	CS	34 (31.8)	60 (38.0)	13 (39.4)
	F1	36 (33.6)	54 (34.2)	9 (27.3)
	F2	45 (42.1)[a]	66 (41.8)	12 (36.4)
Shoulder	CS	12 (11.2)	52 (32.9)	4 (12.1)‡
	F1	12 (11.2)	30 (19.0)	4 (12.1)
	F2	19 (17.8)[a]	38 (24.1)[b]	6 (18.2)
Elbow	CS	6 (5.6)	32 (20.3)	5 (15.2)†
	F1	11 (10.3)	29 (18.4)	4 (12.1)
	F2	13 (12.2)[a]	35 (22.2)	5 (15.2)
Wrist	CS	6 (5.6)	11 (7.0)	1 (3.0)
	F1	1 (0.9)	12 (7.6)	1 (3.0)*
	F2	3 (2.8)	10 (6.3)	3 (9.1)
Hand	CS	3 (2.8)	10 (6.3)	1 (3.0)
	F1	4 (3.7)	10 (6.3)	0 (0)
	F2	4 (3.7)	4 (2.5)	3 (9.1)
Hand-wrist	CS	8 (7.5)	21 (13.3)	2 (6.1)
	F1	5 (4.7)	19 (12.0)	1 (3.0)
	F2	6 (5.6)	13 (8.2)	4 (12.1)

χ^2 test: *$p<0.05$; †$p<0.01$; ‡$p<0.001$
Cochran' Q test for equality of proportions in matched samples: [a]$p<0.05$; [b]$p<0.001$

Table 9. Prevalence and incidence of peripheral sensorineural and vascular disorders disorders in the controls (n=107) and the HTV exposed workers (n=191) over the follow up period (2003-2006) in Italy. Data are given as numbers (%). Crude prevalence ratio (PR), risk ratio (RR) and 95% confidence intervals are shown.

Disorder		Prevalence at cross-sectional (2003-04) (%)	Period prevalence (2003-2006) (%)	Cumulative incidence (2004-2006) (%)
Finger tingling (all subjects)	Controls	12.2	29.0	19.2
	HTV workers	45.6	62.3	30.8
		PR 3.75 (2.20-6.39)	PR 2.15 (1.57-2.95)	RR 1.61 (0.97-2.66)
Finger tingling (without CTS cases)[1]	Controls	10.5	27.6	19.2
	HTV workers	38.9	56.4	28.7
		PR 2.68 (1.50-4.78)	PR 2.04 (1.46-2.86)	RR 1.50 (0.89-2.51)
Finger numbness (all subjects)	Controls	7.5	12.2	5.1
	HTV workers	27.2	36.7	12.9
		PR 3.64 (1.80-7.37)	PR 3.02 (1.75 -5.19)	RR 2.56 (0.98-6.67)
Finger numbness (without CTS cases)[1]	Controls	6.7	11.4	5.1
	HTV workers	21.2	30.3	11.5
		PR 3.18 (1.47-6.90)	PR 2.65 (1.48-4.74)	RR 2.26 (0.85-6.01)
Suspected CTS	Controls	1.9	1.9	0
	HTV workers	8.4	13.6	5.7
		PR 4.48 (1.05-19.1)	PR 7.28 (1.76-30.1)	RR +Inf. (1.47 - +Inf.)*
Cold fingers/hands	Controls	14.0	17.8	4.4
	HTV workers	17.3	26.7	11.4
		PR 1.23 (0.70-2.16)	PR 1.50 (0.94-2.41)	RR 2.62 (0.91-7.51)
VWF (medical history)	Controls	3.7	5.6	1.9
	HTV workers	17.3	20.9	4.4
		PR 4.62 (1.68-12.7)	PR 3.74 (1.64-8.52)	RR 2.28 (0.48-10.8)
VWF (colour charts)[2]	Controls	2.6	2.6	0
	HTV workers	10.7	12.2	1.7
		PR 4.06 (0.95-17.4)	PR 4.52 (1.07-19.1)	RR +Inf. (0.36 - +Inf.)*

[1]based on 105 controls and 165 HTV workers; [2]based on 74 controls and 131 HTV workers
*exact 95% confidence interval

Table 10. Prevalence and incidence of pain in the upper limbs in the controls (n=107) and the HTV exposed workers (n=191) over the follow up period (2003-2006) in Italy. Data are given as numbers (%). Crude prevalence ratio (PR), risk ratio (RR) and 95% confidence intervals are shown.

Pain in the last 12 months		Prevalence at cross-sectional (2003-04) (%)	Period prevalence (2003-2006) (%)	Cumulative incidence (2004-2006) (%)
Neck	Controls	31.8	50.5	27.4
	HTV workers	38.2	53.9	25.4
		PR 1.20 (0.86-1.67)	PR 1.07 (0.85-1.34)	RR 0.93 (0.57-1.51)
Shoulder	Controls	11.2	21.5	11.6
	HTV workers	29.3	37.7	11.9
		PR 2.61 (1.47-4.65)	PR 1.75 (1.17-2.63)	RR 1.02 (0.50-2.11)
Elbow	Controls	5.6	15.0	9.9
	HTV workers	19.4	30.9	14.3
		PR 3.46 (1.51-7.92)	PR 2.07 (1.25-3.40)	RR 1.44 (0.71-2.92)
Wrist	Controls	5.6	7.5	2.0
	HTV workers	6.3	12.6	6.7
		PR 1.12 (0.43-2.90)	PR 1.68 (0.78-3.61)	RR 3.39 (0.77-14.8)
Hand	Controls	2.8	7.5	4.8
	HTV workers	5.8	11.0	5.6
		PR 2.05 (0.59-7.20)	PR 1.47 (0.67-3.21)	RR 1.16 (0.41-3.29)
Hand-wrist	Controls	7.5	13.1	6.1
	HTV workers	12.0	20.4	9.5
		PR 1.61 (0.75-3.47)	PR 1.56 (0.89-2.74)	RR 1.57 (0.64-3.88)

Table 11. Distribution of sensorineural and vascular symptoms in the forestry workers (n=158), stone workers (n=33), and total sample over the calendar period 2003-2006 in Italy, according to the Stockholm workshop scales. Data are given as numbers (%). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

HTV group	Study	Sensorineural (SN) stages				Vibration-induced white finger (VWF) stages			
		SN0	SN1	SN2	SN3	VWF0	VWF1	VWF2	VWF3
Forestry workers (n=158)	CS	84 (53.2)	67 (42.4)	7 (4.4)	-	137 (86.7)	14 (8.9)	6 (3.8)	1 (0.6)
	F1	75 (47.5)	81 (51.3)	2 (1.3)	-	139 (88.0)	13 (8.2)	6 (3.8)	-
	F2	58 (36.7)	99 (62.7)	1 (0.6)[b]	-	137 (86.7)	15 (9.5)	6 (3.8)	-
Stone workers (n=33)	CS	14 (42.4)	18 (54.6)	1 (3.0)	-	21 (63.6)	4 (12.1)	7 (21.2)	1 (3.0)
	F1	11 (33.3)	21 (63.6)	1 (3.0)	-	21 (63.6)	3 (9.1)	6 (18.2)	3 (9.1)
	F2	7 (21.2)	25 (75.8)	1 (3.0)[a]	-	19 (57.6)	2 (6.1)	9 (27.3)	3 (9.1)
Total sample (n=191)	CS	98 (51.3)	85 (44.5)	8 (4.2)	-	158 (82.7)	18 (9.4)	13 (6.8)	2 (1.1)
	F1	86 (45.0)	102 (53.4)	3 (1.6)	-	160 (83.8)	16 (8.4)	12 (6.3)	3 (1.6)
	F2	65 (34.0)	124 (64.9)	2 (1.1)[b]	-	156 (81.7)	17 (8.9)	15 (7.9)	3 (1.6)

Cochran' Q test for equality of proportions in matched samples: [a]$p<0.01$; [b]$p<0.001$

Table 12. Change in sensorineural and vascular disorders during the study period (2003-2006) in the HTV exposed workers with complete follow up (n=191). VWF is vibration-induced white finger. Sensorineural and VWF stages are according to the Stockholm scales. CTS is carpal tunnel syndrome. Values are given as numbers.

Symptoms/signs	No symptoms/signs	Change in symptoms/signs		
		Improved	Stationary	Deteriorated
Finger tingling (all subjects)	72	-	87	32
Finger numbness (all subjects)	121	2	50	18
Sensorineural stages	65	7	85	34
CTS symptoms	169	12	4	6
Cold fingers/hands	140	1	32	18
VWF (medical history)	151	5	28	7
VWF stages (medical history)	151	9	16	15
VWF (colour charts)[1]	114	-	14	3
VWF stages (colour charts)[1]	114	-	11	6
Abnormal cold response ($FSBP\%_{10^{\circ}}$ <70%)	144	17	15	15
Abnormal cold response ($FSBP\%_{10^{\circ}}$ <60%)	163	9	9	10

[1]based on 131 subjects

Table 13. Percentage of change (95% confidence intervals) in sensorineural and vascular disorders during the follow up (2003-2006) in the HTV exposed workers (n=191). VWF is vibration-induced white finger. Sensorineural and VWF stages are according to the Stockholm scales. CTS is carpal tunnel syndrome.

Symptoms/signs	Percentage of change in symptoms/signs (%)		
	Improved	Deteriorated	Total
Finger tingling (all subjects)	-	16.7 (11.4 – 22.1)*	16.7 (11.4 – 22.1)*
Finger numbness (all subjects)	1.0 (-0.04 – 2.4)	9.4 (5.3 – 13.5)*	10.5 (6.2 – 14.8)*
Sensorineural stages	3.7 (-1.0 – 6.3)	17.8 (1.2 – 23.2)*	21.5 (15.7 – 27.3)*
CTS symptoms	6.3 (2.9 – 9.7)*	3.1 (0.6 – 5.6)*	9.4 (5.3 – 13.5)*
Cold fingers/hands	0.5 (-0.02 – 1.0)	9.4 (5.3 – 13.5)*	9.9 (5.7 – 14.1)*
VWF (medical history)	2.6 (0.3 – 4.9)*	3.7 (1.0 – 6.4)*	6.3 (2.9 – 9.7)*
VWF stages (medical history)	4.7 (1.7 – 7.7)*	7.9 (4.1 – 11.7)*	12.6 (7.9 – 17.3)*
VWF (colour charts)[1]	-	2.3 (-0.3 – 4.9)	2.3 (-0.3 – 4.9)
VWF stages (colour charts)[1]	-	4.6 (1.0 – 8.2)*	4.6 (1.0 – 8.2)*
Abnormal cold response ($FSBP\%_{10°}$ <70%)	8.9 (4.9 – 12.9)*	7.9 (4.1 – 11.7)*	16.7 (11.4 – 22.0)*
Abnormal cold response ($FSBP\%_{10°}$ <60%)	4.7 (1.7 – 7.7)*	5.2 (2.0 – 8.4)*	9.9 (5.7 – 14.1)*

[1]based on 131 subjects
*p<0.05

Table 14. Odds ratios (95% confidence intervals) for the association between vascular and sensorineural disorders and individual and occupational covariates in the study population over the follow up period (2003-2006). The generalised estimating equations (GEE) method (standard model) was used to account for correlation between repeated measures within subject during the follow up period. The controls and the cross-sectional survey (2003-04) were assumed as the reference categories for the variables occupation and survey.

Predictors		Health outcomes				
		Finger whiteness (medical history)	Finger whiteness (colour charts)	Tingling	Numbness	Suspected CTS
Age (yrs × 10^{-1})		1.49 (0.91 – 2.43)	1.40 (0.85 – 2.29)	1.71 (1.29 – 2.27)	1.25 (0.94 – 1.68)	1.62 (1.09 – 2.42)
Smoking (no/yes)		0.98 (0.54 – 1.79)	1.41 (0.80 – 2.51)	0.79 (0.50 – 1.24)	0.91 (0.53 – 1.56)	0.91 (0.37 – 2.22)
Drinking (no/yes)		3.98 (1.99 – 7.95)	5.38 (2.98 – 9.70)	1.14 (0.72 – 1.82)	1.12 (0.89 – 1.42)	1.33 (0.54 – 3.27)
Occupation:	Forestry workers	3.86 (1.41 – 10.5)	3.09 (1.04 – 25.0)	4.09 (2.39 – 6.98)	3.92 (2.00 – 7.70)	8.42 (1.89 – 37.5)
	Stone workers	19.3 (6.17 – 60.1)	51.1 (9.81 – 265)	8.93 (3.82 – 20.9)	5.91 (2.36 – 14.8)	22.2 (4.37 – 113)
Survey:	(2004-05)	0.90 (0.72 – 1.13)	1.05 (0.87 – 1.26)	1.34 (1.14 – 1.57)	1.18 (1.03 – 1.36)	0.72 (0.42 – 1.24)
	(2005-06)	0.99 (0.74 - 1.32)	1.29 (0.94 – 1.77)	1.97 (1.60 – 2.44)	1.44 (1.18 – 1.76)	0.47 (0.23 – 0.98)

Table 15. Odds ratios (95% confidence intervals) for the association between vascular and sensorineural disorders and individual and occupational covariates in the study population over the follow up period (2003-2006). The generalised estimating equations (GEE) method (transition model) was used to account for correlation between repeated measures within subject during the follow up period. The controls and the 1st follow up survey (2004-2005) were assumed as the reference category for the variables occupation and survey.

Predictors		Health outcomes				
		Finger whiteness (medical history)	Finger whiteness (colour charts)	Tingling	Numbness	Suspected CTS
Age (yrs × 10^{-1})		1.21 (0.66 – 2.23)	1.13 (0.72 – 1.78)	1.30 (0.91 – 1.87)	0.92 (0.54 – 1.56)	1.00 (0.99 – 1.02)
Smoking (no/yes)		1.16 (0.43 – 3.15)	2.48 (0.88 – 6.98)	0.96 (0.50 – 1.83)	1.31 (0.53 – 3.27)	1.00 (0.97 – 1.03)
Drinking (no/yes)		3.13 (0.45 – 21.9)	4.54 (0.80 – 25.6)	1.87 (0.80 – 4.35)	1.38 (0.44 – 4.34)	-
Occupation:	Forestry workers	2.05 (0.45 – 9.33)	2.32 (0.38 – 14.3)	1.84 (0.98 – 3.46)	2.09 (0.87 – 5.00)	1.02 (1.00 – 1.25)
	Stone workers	9.11 (1.99 – 41.7)	24.2 (3.89 – 151)	3.00 (1.02 – 8.78)	3.31 (1.04 – 10.5)	1.15 (1.06 – 1.25)
Survey	(2005-2006)	2.15 (0.73 – 6.38)	0.58 (0.32 – 1.94)	1.56 (0.86 – 2.81)	1.37 (0.63 – 2.99)	-
Outcome at time-point *t*-1		463 (158 -1357)	65.1 (19.6 – 216)	588 (142 – 2444)	731 (213 – 2514)	1.45 (1.23 – 1.72)

Table 16a. Odds ratios (robust 95% confidence intervals), adjusted by age, smoking, drinking, and survey, for the association between vibration induced disorders, daily vibration exposure and exposure duration in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The generalised estimating equations (GEE) method (standard model) was used to account for correlation between repeated measures within subject during the follow up period. The increase in the odds ratio (OR) for each one unit of increase in vibration dose is shown. The Wald test (p-value) for the OR estimates and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested logistic regression models are also reported. VWF is vibration-induced white finger. CTS is carpal tunnel syndrome. See text for the definition of *A*(8).

Vibration exposure	Health outcomes				
	VWF (medical history)	VWF§ (colour charts)	Tingling	Numbness	Suspected CTS
$A_w(8)$ current (ms^{-2})	**1.15 (1.09 – 1.22)** 24.9 (p<0.0001) QIC=452.9	**1.17 (1.09 – 1.25)** 19.1 (p<0.0001) QIC=211.2	1.03 (0.97 – 1.10) 1.1 (p=0.28) QIC=760.1	1.05 (0.99 – 1.12) 2.7 (p=0.10) QIC=705.8	**1.15 (1.05 – 1.27)** 8.6 (p=0.003) QIC=296.2
$A_{uw}(8)$ current ($ms^{-2}\times 10^{-1}$)	**1.15 (1.09 -1.22)** 29.1 (p<0.0001) QIC=442.3*	**1.16 (1.09 – 1.24)** 25.1 (p<0.0001) QIC=195.9*	**1.07 (1.01 – 1.13)** 4.7 (p=0.03) QIC=752.9*	**1.06 (1.00 – 1.13)** 4.2 (p=0.042) QIC=704.2	**1.11 (1.03 – 1.19)** 7.7 (p=0.006) QIC=296.9
$A_w(8)$ max (ms^{-2})	**1.12 (1.07 – 1.18)** 20.9 (p<0.0001) QIC=471.5	**1.12 (1.07 – 1.18)** 24.0 (p<0.0001) QIC=226.4	1.06 (0.99 – 1.13) 3.5 (p=0.06) QIC=758.7	**1.06 (1.02 – 1.11)** 7.7 (p=0.006) QIC=702.3*	**1.08 (1.00 – 1.17)** 4.0 (p=0.046) QIC=295.6*
$A_{uw}(8)$ max ($ms^{-2} \times 10^{-1}$)	**1.14 (1.08 – 1.19)** 28.2 (p<0.0001) QIC=454.3	**1.14 (1.09 – 1.20)** 35.2 (p<0.0001) QIC=197.7	1.05 (0.98 – 1.12) 1.8 (p=0.19) QIC=758.4	**1.05 (1.00 – 1.10)** 4.2 (p=0.039) QIC=706.1	1.05 (0.99 – 1.11) 2.6 (p=0.10) QIC=297.8
Exposure duration (yrs)	1.03 (0.98 – 1.09) 1.3 (p=0.25) QIC=524.6	1.02 (0.95 – 1.11) 0.3 (p=0.56) QIC=297.1	1.01 (0.97 – 1.05) 0.3 (p=0.58) QIC=772.4	0.97 (0.93 – 1.01) 2.1 (p=0.15) QIC=719.5	1.04 (0.98 – 1.10) 1.5 (p=0.22) QIC=299.5

§based on 131 HTV workers
*better fitting model

Table 16b. Odds ratios (robust 95% confidence intervals), adjusted by age, smoking, drinking, and survey, for the association between vibration induced disorders and alternative measures of vibration exposure in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The generalised estimating equations (GEE) method (standard model) was used to account for correlation between repeated measures within subject during the follow up period. The increase in the odds ratio (OR) for each one unit of increase in log vibration dose is shown. The Wald test (p-value) for the OR estimates and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested logistic regression models are also reported. VWF is vibration-induced white finger. CTS is carpal tunnel syndrome. See text for the definition of vibration doses.

Dose definition	Health outcomes				
	VWF (medical history)	VWF§ (colour charts)	Tingling	Numbness	Suspected CTS
Dose 1 (Σt_i, ln(hours))	**1.78 (1.23 – 2.56)** 9.6 (p=0.002) QIC=497.4	**3.47 (1.67 – 7.22)** 11.1 (p=0.001) QIC=250.9	1.14 (0.93 – 1.40) 1.54 (p=0.22) QIC=765.0	1.29 (0.98 -1.68) 3.4 (p=0.07) QIC=718.7	1.37 (0.97 – 1.92) 3.2 (p=0.08) QIC=296.6
Dose 2 ($\Sigma a_{hwvi} t_i$, ln(ms^{-2}h))	**1.98 (1.37 – 2.87)** 13.2 (p<0.0001) QIC=481.4	**3.10 (1.80 – 5.35)** 16.6 (p<0.0001) QIC=255.9	1.21 (0.98 – 1.49) 3.0 (p=0.08) QIC=760.3	1.29 (0.99 – 1.67) 3.7 (p=0.06) QIC=714.7	**1.43 (1.01 – 2.03)** 4.2 (p=0.041) QIC=294.5
Dose 3 ($\Sigma a_{hwvi}^2 t_i$, ln(m^{2}s^{-4}h))	**1.78 (1.33 – 2.39)** 15.0 (p<0.0001) QIC=476.6	**2.53 (1.70 – 3.78)** 20.6 (p<0.0001) QIC=190.0	**1.24 (1.01 – 1.51)** 4.3 (p=0.04) QIC=757.0	**1.25 (1.00 – 1.57)** 3.9 (p=0.048) QIC=713.8	**1.39 (1.02 – 1.90)** 4.4 (p=0.036) QIC=294.0
Dose 4 ($\Sigma a_{hwvi}^4 t_i$, ln(m^{4}s^{-8}h))	**1.33 (1.11 -1.60)** 9.6 (p=0.002) QIC=493.5	**2.67 (1.54 – 4.61)** 12.3 (p<0.001) QIC=202.5	**1.17 (1.01 – 1.35)** 4.6 (p=0.03) QIC=758.7	1.12 (0.97 – 1.28) 2.5 (p=0.12) QIC=714.8	**1.26 (1.02 – 1.55)** 4.6 (p=0.032) QIC=294.2
Dose 5 ($\Sigma a_{huwvi} t_i$, ln(ms^{-2}h))	**1.65 (1.27 – 2.16)** 14.1 (p<0.0001) QIC=480.5	**4.28 (1.84 – 9.97)** 11.4 (p=0.001) QIC=207.3	1.18 (0.99 – 1.40) 3.5 (p=0.06) QIC=759.7	**1.25 (1.02 – 1.55)** 4.5 (p=0.035) QIC=716.6	1.26 (0.99 – 1.61) 4.4 (p=0.064) QIC=296.1
Dose 6 ($\Sigma a_{huwvi}^2 t_i$, ln(m^{2}s^{-4}h))	**1.49 (1.22 – 1.82)** 15.0 (p<0.0001) QIC=475.4*	**3.11 (1.50 – 6.49)** 9.2 (p=0.002) QIC=188.9	**1.19 (1.03 – 1.38)** 5.4 (p=0.02) QIC=754.9	**1.22 (1.04 – 1.44)** 5.9 (p=0.015) QIC=714.1	**1.24 (1.03 – 1.48)** 5.3 (p=0.021) QIC=294.1)
Dose 7 ($\Sigma a_{huwvi}^4 t_i$, ln(m^{4}s^{-8}h))	**1.27 (1.11 - 1.45)** 12.3 (p<0.0001) QIC=479.7	**1.94 (1.29 – 2.90)** 10.3 (p=0.001) QIC=179.9*	**1.14 (1.03 – 1.25)** 6.5 (p=0.011) QIC=754.0*	**1.13 (1.02 – 1.26)** 5.8 (p=0.016) QIC=713.2*	**1.16 (1.03 – 1.31)** 6.1 (p=0.014) QIC=293.5*

§based on 131 HTV workers; *better fitting model

Table 17a. Odds ratios (robust 95% confidence interval), adjusted by age, smoking, drinking, survey, and outcome at time-point *t*-1, for the association between vibration induced disorders, daily vibration exposure and exposure duration in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The generalised estimating equations (GEE) method (standard model) was used to account for correlation between repeated measures within subject during the follow up period. The increase in the odds ratio (OR) for each one unit of increase in vibration dose is shown. The Wald test (p-value) for the OR estimates and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested logistic regression models are also reported. VWF is vibration-induced white finger. CTS is carpal tunnel syndrome. See text for the definition of *A*(8).

Vibration exposure	Health outcomes				
	VWF (medical history)	VWF§ (colour charts)	Tingling	Numbness	Suspected CTS
$A_w(8)$ current (ms^{-2})	**1.22 (1.11 – 1.33)** 10.4 (p<0.0001) QIC=103.0	**1.28 (1.13 – 1.45)** 15.8 (p<0.0001) QIC=68.6	1.03 (0.88 – 1.20) 0.1 (p=0.72) QIC=196.8	1.06 (0.96 – 1.18) 1.3 (p=0.25) QIC=178.3	**1.21 (1.11 – 1.32)** 18.2 (p<0.0001) QIC=138.4
$A_{uw}(8)$ current ($ms^{-2} \times 10^{-1}$)	**1.17 (1.08 -1.27)** 14.4 (p<0.0001) QIC=102.9*	**1.24 (1.13 – 1.35)** 22.9 (p<0.0001) QIC=66.5	1.05 (0.94 – 1.18) 0.8 (p=0.37) QIC=196.8	1.06 (0.98 – 1.13) 2.3 (p=0.13) QIC=177.6	**1.17 (1.09 – 1.25)** 21.5 (p<0.0001) QIC=136.7*
$A_w(8)$ max (ms^{-2})	**1.16 (1.05 – 1.27)** 8.9 (p=0.003) QIC=104.6	**1.25 (1.11 – 1.42)** 13.3 (p<0.0001) QIC=68.3	**1.10 (1.01 – 1.20)** 5.1 (p=0.024) QIC=191.3*	1.06 (0.98 – 1.16) 2.1 (p=0.15) QIC=177.7	**1.13 (1.05 – 1.22)** 9.4 (p=0.002) QIC=144.9
$A_{uw}(8)$ max ($ms^{-2} \times 10^{-1}$)	**1.14 (1.05 – 1.24)** 9.1 (p=0.003) QIC=104.0	**1.25 (1.15 – 1.35)** 30.7 (p<0.0001) QIC=63.8*	1.09 (0.98 – 1.21) 2.5 (p=0.11) QIC=193.6	1.05 (0.97 – 1.14) 1.3 (p=0.26) QIC=178.6	**1.13 (1.06 – 1.20)** 14.9 (p<0.0001) QIC=142.2
Exposure duration (yrs)	1.09 (0.98 – 1.22) 2.5 (p=0.12) QIC=108.9	1.01 (0.94 – 1.08) 0.04 (p=0.85) QIC=85.0	0.99 (0.93 – 1.05) 0.1 (p=0.71) QIC=195.8	0.92 (0.85 – 1.00) 4.0 (p=0.046) QIC=174.7	1.07 (0.99 – 1.16) 3.3 (p=0.07) QIC=148.5

§based on 131 HTV workers
*better fitting model

Table 17b. Odds ratios (robust 95% confidence interval), adjusted for age, smoking, drinking, survey, and outcome at time-point *t*-1, for the association between vibration induced disorders and alternative measures of vibration exposure in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The generalised estimating equations (GEE) method (transition model) was used to account for correlation between repeated measures within subject during the follow up period. The increase in the odds ratio (OR) for each one unit of increase in log vibration dose is shown. The Wald test (p-value) for the OR estimates and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested logistic regression models are reported. VWF is vibration-induced white finger. CTS is carpal tunnel syndrome. See text for the definition of vibration doses.

Dose definition	Health outcomes				
	VWF (medical history)	VWF§ (colour charts)	Tingling	Numbness	Suspected CTS
Dose 1 (Σt_i, ln(hours))	1.48 (0.72 – 3.02) 1.1 (p=0.28) QIC=110.4	**2.02 (1.03 – 3.99)** 4.2 (p=0.042) QIC=80.2	1.08 (0.74 – 1.57) 0.2(p=0.70) QIC=196.6	0.81 (0.57 -1.17) 1.3 (p=0.26) QIC=178.7	**2.25 (1.24 – 4.07)** 7.2 (p=0.007) QIC=143.0
Dose 2 ($\Sigma a_{hwvi} t_i$, ln($ms^{-2}h$))	1.81 (0.92 – 3.57) 2.9 (p=0.09) QIC=107.3	**2.66 (1.38 – 5.12)** 8.62 (p=0.003) QIC=74.1	1.19 (0.80 – 1.79) 0.7 (p=0.40) QIC=195.8	0.83 (0.54 – 1.27) 0.7 (p=0.39) QIC=179.6	**2.27 (1.28 – 4.02)** 7.9 (p=0.005) QIC=140.7
Dose 3 ($\Sigma a_{hwvi}^2 t_i$, ln($m^2s^{-4}h$))	**1.86 (1.10 – 3.14)** 5.3 (p=0.021) QIC=104.5*	**2.67 (1.52 – 4.67)** 11.8 (p=0.001) QIC=69.3	1.32 (0.93 – 1.88) 2.4 (p=0.12) QIC=193.4	0.89 (0.59 – 1.35) 0.3 (p=0.59) QIC=180.6	**1.81 (1.20 – 2.75)** 7.9 (p=0.005) QIC=141.9
Dose 4 ($\Sigma a_{hwvi}^4 t_i$, ln($m^4s^{-8}h$))	**1.46 (1.06 – 2.01)** 5.3 (p=0.021) QIC=104.6	**1.97 (1.46 – 2.66)** 19.9 (p<0.001) QIC=65.3*	**1.30 (1.06 – 1.60)** 6.3 (p=0.012) QIC=189.1	0.94 (0.74 – 1.21) 0.2 (p=0.65) QIC=180.2	**1.35 (1.04 – 1.76)** 5.0 (p=0.025) QIC=146.1
Dose 5 ($\Sigma a_{huwvi} t_i$, ln($ms^{-2}h$))	1.51 (0.96 – 2.38) 3.1 (p=0.08) QIC=107.6	**2.33 (1.41 - 3.83)** 11.0 (p=0.001) QIC=71.6	1.21 (0.89 – 1.64) 1.5 (p=0.22) QIC=194.7	0.95 (0.68 – 1.31) 0.1 (p=0.74) QIC=180.2	**1.83 (1.25 – 2.66)** 9.8 (p=0.002) QIC=140.3*
Dose 6 ($\Sigma a_{huwvi}^2 t_i$, ln($m^2s^{-4}h$))	**1.44 (1.03 – 2.02)** 4.6 (p=0.032) QIC=105.8	**2.08 (1.34 – 3.22)** 10.8 (p=0.001) QIC=67.7	**1.28 (1.02 – 1.61)** 4.4 (p=0.04) QIC=191.0	1.00 (0.78 – 1.29) 0.0 (p=0.99) QIC=180.3	**1.54 (1.17 – 2.04)** 9.4 (p=0.002) QIC=141.1
Dose 7 ($\Sigma a_{huwvi}^4 t_i$, ln($m^4s^{-8}h$))	**1.28 (1.03 – 1.60)** 5.1 (p=0.024) QIC=104.9	**1.66 (1.20 – 2.29)** 9.5 (p=0.002) QIC=65.5	**1.24 (1.07 – 1.43)** 8.4 (p=0.004) QIC=186.1*	1.02 (0.88 – 1.19) 0.1 (p=0.78) QIC=179.9	**1.28 (1.06 – 1.56)** 6.6 (p=0.011) QIC=143.8

§based on 131 HTV workers; *better fitting model

Table 18. Point estimates (95% confidence intervals) of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for the anamnestic diagnosis of finger whiteness by means of a medical history alone, assuming colour charts as the gold standard. Data from workers who participated in both cross-sectional and follow up investigations are reported.

Cross-sectional study (n=146)	Colour charts for finger whiteness		Sensitivity (%)	Specificity (%)
History of finger whiteness	Positive	Negative	88.2 (63-6 – 98.5)	93.8 (88.1 – 97.3)
Positive	15	8	PPV (%)	NPV (%)
Negative	2	121	65.2 (42.7 – 83.6)	98.4 (94.2 – 99.8)

Follow up study (n=146)	Colour charts for finger whiteness		Sensitivity (%)	Specificity (%)
History of finger whiteness	Positive	Negative	94.4 (72.7 – 99.9)	97.7 (93.3 – 99.5)
Positive	17	3	PPV (%)	NPV (%)
Negative	1	125	85.0 (62.1 – 96.8)	99.2 (95.7 – 100)

Table 19. Random-intercept linear regression of $FSBP\%_{10°}$ on continuous and dichotomous predictors in the HTV workers (n=146) who underwent the cross-sectional survey and the 1st follow up investigation. Age, body mass index (BMI), leisure time with vibrating tools, and log-transformed vibration dose are included in the regression models as continuous covariates. Finger whiteness was assessed by either medical history alone or colour charts. Maximum likelihood estimates of regression coefficients (95% confidence intervals), and the Bayesan Information Criterion (BIC) for the two regression models are reported. See text for definition of $FSBP\%_{10°}$.

Predictors	$FSBP\%_{10°}$ (%)	
Intercept	111 (70.3 – 152)	98.1 (59.1 – 137)
Age (yr $\times 10^{-1}$)	4.3 (0.2 – 8.4)	3.7 (-0.1 – 7.5)
BMI (kg/m^2 × 1/5)	2.3 (-2.2 – 6.8)	1.9 (-2.4 – 6.2)
Smoking	-1.1 (-7.6 – 5.5)	-1.8 (-8.0 – 4.3)
Drinking	4.2 (-3.1 – 11.6)	3.5 (-3.4 – 10.4)
Leisure time with vibrating tools (hrs × 10^{-2})	-0.02 (-0.5 – 0.5)	-0.03 (-0.5 – 0.4)
Vibration dose (ln(m^{2}s^{-4}h))	-4.6 (-7.1 – -2.1)**	-3.1 (-5.6 – -0.7)*
Finger whiteness (medical history)	-17.8 (-26.9 – -8.6)†	–
Finger whiteness (colour charts)	–	-29.2 (-39.5 – -19.0)‡
Follow up	1.3 (-2.3 – 4.9)	1.8 (-1.8 – 5.5)
BIC#	2656.0	2641.9

Likelihood ratio test (χ^2, 1*df*): *6.1 (p=0.015); **12.9 (p<0.0005); †14.1 (p<0.0005); ‡28.2 (p<0.0001);
#Difference in BIC=15.1 (i.e. very strong support for the model including finger whiteness assessed by colour charts)

Table 20. Random-intercept linear regression of FSBP$\%_{10°}$ (standard or transition models) on continuous and dichotomous predictors in the HTV workers investigated with medical history and colour charts for finger whiteness (n=131) over the follow up period (2003-2006). Age, log-transformed vibration dose, and FSBP$\%_{10°}$ at time-point *t*–1 are included in the regression models as continuous covariates. Model A (standard model) and model C (transition model) include finger whiteness assessed by medical history alone. Model B (standard model) and model D (transition model) include finger whiteness assessed by colour charts. Maximum likelihood estimates of regression coefficients (95% confidence intervals), and the Bayesan Information Criterion (BIC) for the regression models are reported.

Predictors	Model A (standard)	Model B (standard)	Model C (transition)	Model D (transition)
Intercept	130 (97.0 – 162)	112 (81.7 – 143)	80.1 (48.4 – 112)	81.8 (50.4 – 113)
Age (yr $\times 10^{-1}$)	4.4 (1.1 – 7.8)*	3.5 (0.4 – 6.6)*	1.8 (-1.1 – 4.8)	1.6 (-1.3 – 4.5)
Smoking (no/yes)	0.2 (-5.1 – 5.6)	0.9 (-4.0 – 6.0)	2.0 (-2.9 – 6.9)	2.4 (-2.5 – 7.3)
Drinking (no/yes)	3.1 (-2.7 – 8.9)	3.5 (-2.0 – 9.0)	2.2 (-3.4 – 7.9)	2.6 (-3.1 – 8.3)
Leisure time with vibrating tools (no/yes)	0.4 (-5.6 – 6.3)	0.2 (-5.2 – 5.7)	-1.5 (-6.5 – 3.6)	-0.9 (-5.8 – 4.1)
Vibration dose ($\ln(m^2s^{-4}h)$)	-5.1 (-7.2 – -2.9)‡	-3.4 (-5.5 – -1.4)†	-3.1 (-5.0 – -1.1)†	-3.0 (-4.9 – -1.1)†
Finger whiteness (medical history)	-17.5 (-25.8 – -9.2)‡	–	-11.5 (-20.1 – -2.9)†	–
Finger whiteness (colour charts)	–	-31.0 (-39.8 – -22.1)‡	–	-13.2 (-22.5 – -3.9)†
Survey (2004-05) (2005-06)	1.7 (-2.1 – 5.5) -0.4 (-4.2 – 3.5)	2.5 (-1.3 – 6.2) 0.6 (-3.2 – 4.4)	– -2.9 (-7.4 – 1.6)	– -2.8 (-7.3 – 1.7)
FSBP$\%_{10°}$ at time-point *t*–1	–	–	0.4 (0.3 – 0.5)‡	0.4 (0.3 – 0.5)‡
Log likelihood	-1706	-1694	-1136	-1135
BIC#	3477	3455	2334	2333

*p<0.05; †p<0.01; ‡p<0.001

#Difference in BIC: Model A *vs* B=22 (i.e. very strong support for the model including finger whiteness assessed by colour charts); Model C *vs* D=1 (i.e. weak support for the model including finger whiteness assessed by colour charts).

Table 21. Finger systolic blood pressure (FSBP) indices in the controls and the HTV exposed workers over the follow up period (2003-2006) in Italy. Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Controls (n=107)	HTV workers		
			Forestry workers (n=158)	Stone workers (n=33)	All HTV workers (n=191)
$FSBP\%_{10°}$ (%)	CS	92 (0 – 135)	92 (0 – 113)	80 (0 – 105)†	90 (0 – 113)*
	F1	93 (0 – 133)	93 (0 – 130)	77 (0 – 118)†	92 (0 – 130)**
	F2	92 (40 – 125)	92 (0 – 120)	78 (0 – 109)†	90 (0 – 120)**
$R\text{-}FSBP_{10°}$ (mmHg)	CS	10 (-30 – 128)	10 (-20 – 110)	25 (-5 – 130)†	12 (-20 – 130)*
	F1	10 (-35 – 135)	10 (-30 – 110)	25 (-20 – 115)†	10 (-30 – 115)**
	F2	10 (-25 – 65)	10 (-20 – 85.0)	25 (-10 – 120)†	10 (-20 – 120)**
$DPI_{10°}$ (%)	CS	91 (0 – 114)	92 (0 – 129)	69 (0 – 93)†	86 (0 – 129)*
	F1	84 (0 – 117)	88 (0 – 122)	64 (0 – 92)†	83 (0 – 122)
	F2	91 (35 – 126)	88 (0 – 133)	63 (0 – 90)†	83 (0 – 133)**

Mann-Whitney test (controls *vs* HTV workers): *p<0.05; **p<0.01
Kruskall-Wallis test: †p<0.001 (stone workers *vs* controls; stone workers *vs* forestry workers)

Table 22. Finger systolic blood pressure (FSBP) indices in the controls and the HTV exposed workers over the follow up period (2003-2006) in Italy, according to vibration-induced white finger (VWF) status assessed by medical history alone. Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Controls (n=107)	HTV workers (n=191)	
			VWF – (CS=158), (F1=160), (F2=156)	VWF+ (CS=33), (F1=31), (F2=35)
$FSBP\%_{10°}$ (%)	CS	92 (0 – 135)	91 (0 – 113)	75 (0 – 104)†
	F1	93 (0 – 133)	93 (0 – 130)	75 (0 – 110)†
	F2	92 (40 – 125)	92 (0 – 120)	83 (0 – 111)†
$R\text{-}FSBP_{10°}$ (mmHg)	CS	10 (-30 – 128)	10 (-20 – 100)	28 (-5 – 130)†
	F1	10 (-35 – 135)	10 (-30 – 110)	30 (-12 – 115)†
	F2	10 (-25 – 65)	10 (-20 – 85)	20 (-10 – 120)†
$DPI_{10°}$ (%)	CS	91 (0 – 114)	87 (0 – 129)	69 (0 – 130)†
	F1	84 (0 – 117)	84 (0 – 119)	65 (0 – 122)†
	F2	91 (35 – 126)	85 (0 – 133)	70 (0 – 113)†

Kruskall-Wallis test (VWF+ *vs* controls; VWF+ *vs* VWF –): †p<0.001

Table 23. Finger systolic blood pressure (FSBP) indices in the controls and the HTV exposed workers over the follow up period (2003-2006) in Italy, according to vibration-induced white finger (VWF) status assessed by colour charts. Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Controls (n=107)	HTV workers (n=131)	
			VWF – (CS=117), (F1=116),(F2=187)	VWF+ (CS=14), (F1=15),(F2=18)
$FSBP\%_{10°}$ (%)	CS	92 (0 – 135)	90 (46 – 112)	29 (0 – 95)†
	F1	93 (0 – 133)	92 (19 – 130)	54 (0 – 100)†
	F2	92 (40 – 125)	91 (30 – 120)	67 (0 – 100)†
$R\text{-}FSBP_{10°}$ (mmHg)	CS	10 (-30 – 128)	12 (-20 – 75)	78 (7 – 130)†
	F1	10 (-35 – 135)	10 (-30 – 110)	55 (0 – 115)†
	F2	10 (-25 – 65)	10 (-20 – 80)	37 (0 – 120)†
$DPI_{10°}$ (%)	CS	91 (0 – 114)	84 (32 – 113)	24 (0 – 104)†
	F1	84 (0 – 117)	82 (20 – 118)	43 (0 – 96)†
	F2	91 (35 – 126)	83 (21 – 133)	54 (0 – 109)†

Kruskall-Wallis test: †p<0.001 (VWF+ *vs* controls; VWF+ *vs* VWF –)

Table 24. Finger systolic blood pressure (FSBP) indices in the controls and the HTV exposed workers over the follow up period (2003-2006) in Italy, according to vibration-induced white finger (VWF) score (Griffin, 1990). Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Controls (n=107)	HTV workers (n=191)			
			VWF score 0 (CS=158) (F1=160) (F2=156)	VWF score ≤12 (CS=13) (F1=19) (F2=18)	VWF score 13-24 (CS=11) (F1=6) (F2=11)	VWF score >24 (CS=9) (F1=6) (F2=6)
$FSBP\%_{10°}$ (%)	CS	92 (0 – 135)	91 (0 – 113)	82 (13 – 109)	74 (0 – 100)	60 (0 – 93)*
	F1	93 (0 – 133)	93 (0 – 130)	79 (0 – 110)	65 (15 – 100)	69 (35 – 100)**
	F2	92 (40 – 125)	92 (0 – 120)	89 (0 – 111)	68 (0 – 110)	53 (0 – 100)†
$R\text{-}FSBP_{10°}$ (mmHg)	CS	10 (-30 – 128)	10 (-20 – 100)	25 (-5 – 100)	30 (0 – 130)	60 (10 – 110)*
	F1	10 (-35 – 135)	10 (-30 – 110)	30 (-12 – 115)	40 (0 – 85)	37 (0 – 65)**
	F2	10 (-25 – 65)	10 (-20 – 85)	13 (-10 – 120)	43 (-10 – 110)	60 (0 – 110)†
$DPI_{10°}$ (%)	CS	91 (0 – 114)	87 (0 – 129)	89 (12 – 113)	68 (0 – 108)	63 (0 – 108)*
	F1	84 (0 – 117)	84 (0 – 119)	71 (0 – 122)	49 (12 – 112)	59 (22 – 96)**
	F2	91 (35 – 126)	85 (0 – 133)	70 (0 – 113)	71 (0 – 100)	49 (0 – 91)†

Kruskall-Wallis test: *p<0.001 (VWF score 13-24 & >24 *vs* VWF score 0 & ≤12);
**p<0.001 (VWF score ≤12 & 13-24 *vs* controls & VWF score 0; VWF score >24 *vs* controls);
†p<0.001 (VWF score 13-24 & >24 *vs* controls & VWF score 0; VWF score >24 *vs* VWF score ≤12)

Table 25. Finger systolic blood pressure indices in the HTV exposed workers over the follow up period (2003-2006) in Italy, according to change in vibration-induced white finger (VWF) assessed by medical history alone. Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Never VWF (n=151)	Change in VWF symptoms		
			Improved (n=5)	Stationary (n=28)	Deteriorated (n=7)
$FSBP\%_{10°}$ (%)	CS	92 (0 – 113)	93 (82 – 97)	73 (0 – 104)	88 (73 – 104)
	F1	92 (0 – 130)	96 (75 – 102)	75 (0 – 110)	93 (64 – 118)
	F2	92 (0 – 120)	83 (69 – 92)	71 (0 – 111)	100 (73 – 110)
$R\text{-}FSBP_{10°}$ (mmHg)	CS	10 (-20 – 100)	10 (5 – 25)	30 (-5 – 130)	15 (-5 – 30)
	F1	10 (-30 – 110)	5 (-3 – 30)	30 (-12 – 115)	10 (-20 – 45)
	F2	10 (-20 – 85)	25 (10 – 40)	28 (-10 – 120)	0 (-10 – 32)
$DPI_{10°}$ (%)	CS	87 (0 – 129)	103 (82 – 108)	65 (0 – 113)	88 (70 – 112)
	F1	83 (0 – 119)	92 (64 – 107)	63 (0 – 122)	88 (56 – 118)
	F2	86 (0 – 133)	79 (60 – 109)	68 (0 – 113)	71 (63 – 100)

Table 26. Finger systolic blood pressure indices in the HTV exposed workers over the follow up period (2003-2006) in Italy, according to change in vibration-induced white finger (VWF) assessed by colour charts. Data are given as medians (range). CS is cross-sectional study (2003-2004), F1 is 1st follow up study (2004-2005), and F2 is 2nd follow up study (2005-2006).

Pressure indices	Study	Never VWF (n=114)	Change in VWF symptoms		
			Improved (n=0)	Stationary (n=14)	Deteriorated (n=7)
$FSBP\%_{10°}$ (%)	CS	90 (46 – 112)	–	29 (0 – 95)	87 (81 – 94)
	F1	92 (19 – 130)	–	54 (0 – 100)	74 (64 – 100)
	F2	91 (30 – 120)	–	51 (0 – 100)	89 (73 – 91)
$R\text{-}FSBP_{10°}$ (mmHg)	CS	12 (-20 – 75)	–	78 (7 – 130)	15 (8 – 25)
	F1	10 (-30 – 110)	–	55 (0 – 115)	25 (0 – 45)
	F2	10 (-20 – 80)	–	59 (0 – 120)	10 (10 – 32)
$DPI_{10°}$ (%)	CS	85 (32 – 113)	–	24 (0 – 104)	77 (75 – 100)
	F1	82 (20 – 118)	–	43 (0 – 92)	57 (56 – 96)
	F2	83 (21 – 133)	–	37 (0 – 109)	68 (63 – 91)

Table 27. Random-intercept linear regression of FSBP%$_{10°}$ on finger whiteness status in the HTV exposed workers investigated with medical history and colour charts for finger whiteness (n=131) over with the follow up period (2003-2006). Model A (standard model) and model B (transition model) include finger whiteness assessed by medical history alone. Model C (standard model) and model D (transition model) include finger whiteness assessed by colour charts. The HTV workers who never experienced finger blanching attacks during the study period were assumed as the reference category for the variable finger whiteness. Maximum likelihood estimates of regression coefficients (95% confidence intervals), and the Bayesan Information Criterion (BIC) for the regression models are reported.

Predictors	Model A (standard)	Model B (transition)	Model C (standard)	Model D (transition)
Intercept	103 (71.3 – 135)	72.3 (41.3 – 103)	104 (75.2 – 133)	79.5 (49.6 – 109)
Age (yr ×10^{-1})	5.1 (1.8 – 8.3)†	2.4 (-0.5 – 5.4)	3.1 (0.1 – 6.2)*	1.6 (-1.3 – 4.5)
Smoking (no/yes)	0 (-5.2 – 5.2)	1.9 (-3.0 – 6.8)	0.2 (-4.8 – 5.2)	2.0 (-2.9 – 6.9)
Drinking (no/yes)	3.9 (-1.7 – 9.4)	2.9 (-2.7 – 8.5)	3.9 (-1.4 – 9.3)	2.9 (-2.7 – 8.6)
Survey (2004-05) (2005-06)	2.0 (-1.7 – 5.7) -0.5 (-4.3 – 3.2)	– -3.1 (-1.3 – 7.6)	2.2 (-1.5 – 5.8) -0.2 (-3.9 – 3.6)	– -3.0 (-7.4 – 1.5)
Vibration dose (ln($m^2s^{-4}h$))	-3.1 (-5.3 – -1.0)†	-2.8 (-4.8 – -0.9)†	-2.6 (-4.6 – -0.6)*	-2.6 (-4.6 – -0.7)†
Finger whiteness improved stationary deteriorated	-4.1 (-17.6 – 9.4) -33.4 (-43 – -3.8)‡ 2.9 (-14.3 – 20.1)	-6.8 (-18.6 – 5.0) -15.0 (-24.2 – -5.7)† 5.2 (-9.9 – 20.3)	– -39.3 (-48.6 – -29.9)‡ -2.7 (-19.2 – 13.7)	– -17.6 (-27.7 – -7.6)‡ -3.5 (-18.9 – 11.8)
FSBP%$_{10°}$ at time-point t–1	–	0.4 (0.3 – 0.5)‡	–	0.4 (0.3 – 0.5)‡
Log likelihood	-1694	-1134	-1686	-1134
BIC#	3459	2334	3438	2329

*p<0.05; †p<0.01; ‡p<0.001
#Difference in BIC: Model A *vs* C=21 (i.e. very strong support for the model including finger whiteness assessed by colour charts); Model B *vs* D=5 (i.e. positive support for the model including finger whiteness assessed by colour charts).

Table 28a. Marginal linear regression of FSBP$\%_{10°}$ on either daily vibration exposure or exposure duration in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The estimated regression coefficients (robust 95% confidence intervals) are given. The generalised estimating equations (GEE) method (standard or transition models) was used to account for correlation between repeated measures within subject during the follow up period. The Wald test (p-value) for the regression coefficients and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested linear regression models are also reported. See text for the definition of *A*(8).

Vibration exposure	Model 1 (standard GEE)	Model 2 (standard GEE)	Model 3 (transition GEE)	Model 4 (transition GEE)
$A_w(8)$ current (ms^{-2})	**-2.1 (-3.1 – -1.2)** 21.0 (p<0.0001) QIC=246479	**-2.0 (-2.8 – -1.1)** 20.0 (p<0.0001) QIC=237039	**-1.6 (-2.3 – -0.8)** 17.6 (p<0.0001) QIC=128819	**-1.5 (-2.2 – -0.7)** 14.4 (p<0.0001) QIC=128454
$A_{uw}(8)$ current ($ms^{-2} \times 10^{-1}$)	**-2.0 (-2.8 – -1.2)** 24.3 (p<0.0001) QIC=240344*	**-1.8 (-2.6 – -1.1)** 22.5 (p<0.0001) QIC=232918*	**-1.3 (-1.9 – -0.7)** 17.6 (p<0.0001) QIC=128177*	**-1.2 (-1.9 – -0.6)** 14.4 (p<0.0001) QIC=127867*
$A_w(8)$ max (ms^{-2})	**-1.9 (-2.6 – -1.2)** 26.8 (p<0.0001) QIC=250097	**-1.8 (-2.4 – -1.1)** 26.3 (p<0.0001) QIC=239019	**-1.2 (-1.8 – -0.7)** 18.1 (p<0.0001) QIC=130023	**-1.2 (-1.7 – -0.6)** 15.9 (p<0.0001) QIC=129020
$A_{uw}(8)$ max ($ms^{-2} \times 10^{-1}$)	**-1.8 (-2.5 – -1.1)** 22.8 (p<0.0001) QIC=241349	**-1.7 (-2.4 – -0.9)** 20.8 (p<0.0001) QIC=233222	**-1.1 (-1.7 – -0.5)** 14.6 (p<0.0001) QIC=129625	**-1.0 (-1.6 – -0.5)** 12.3 (p<0.0001) QIC=128998
Exposure duration (yrs)	-0.4 (-0.8 – -0.03) 4.4 (p=0.036) QIC=289541	-0.4 (-0.7 – -0.03) 4.5 (p=0.034) QIC=267068	-0.05 (-0.3 – 0.2) 0.14 (p=0.71) QIC=138859	-0.05 (-0.3 – 0.2) 0.1 (p=0.71) QIC=136906

Model 1: adjusted by age, smoking, drinking, and survey;
Model 2: adjusted by age, smoking, drinking, survey, and VWF score
Model 3: adjusted by age, smoking, drinking, survey, and FSBP$\%_{10°}$ at time-point t–1
Model 4: adjusted by age, smoking, drinking, survey, VWF score and FSBP$\%_{10°}$ at time-point t–1
*best fitting model

Table 28b. Marginal linear regression of FSBP%$_{10°}$ on alternative measures of vibration exposure in the HTV exposed workers (n=191) over with the follow up period (2003-2006). The estimated regression coefficients (robust 95% confidence intervals) are given. The generalised estimating equations (GEE) method (standard or transition models) was used to account for correlation between repeated measures within subject during the follow up period. The Wald test (p-value) for the regression coefficients and the Quasi-likelihood under the Independence model Criterion (QIC) for the comparison between non-nested linear regression models are also reported. See text for the definition of vibration doses.

Dose definition	Model 1 (standard GEE)	Model 2 (standard GEE)	Model 3 (transition GEE)	Model 4 (transition GEE)
Dose 1 (Σt_i, ln(hours))	**-3.3 (-5.9 – -0.7)** 6.3 (p=0.012) QIC=283294	**-2.8 (-5.2 – -0.4)** 5.3 (p=0.022) QIC=264285	-1.6 (-3.4 – 0.2) 2.9 (p=0.09) QIC=137555	-1.4 (-3.2 – 0.5) 2.1 (p=0.15) QIC=135980
Dose 2 ($\Sigma a_{hwvi} t_i$, ln($ms^{-2}h$))	**-5.3 (-8.0 – -2.6)** 15.0 (p<0.0001) QIC=268520	**- 4.7 (-7.1 – -2.2)** 14.2 (p<0.0001) QIC=253492	**-2.8 (-4.5 – -0.7)** 7.0 (p=0.008) QIC=135591	**-2.3 (-4.2 – -0.4)** 5.5 (p=0.019) QIC=134293
Dose 3 ($\Sigma a_{hwvi}^2 t_i$, ln($m^2s^{-4}h$))	**-5.9 (-8.2 – -3.6)** 24.6 (p<0.0001) QIC=254661	**-5.3 (-7.4 – -3.2)** 24.9 (p<0.0001) QIC=242163	**-2.8 (-4.5 – -1.1)** 10.7 (p=0.001) QIC=134163	**-2.6 (-4.3 – -0.9)** 8.8 (p=0.003) QIC=132926
Dose 4 ($\Sigma a_{hwvi}^4 t_i$, ln($m^4s^{-8}h$))	**-4.1 (-5-6 – -2.7)** 29.8 (p<0.0001) QIC=250190	**-3.8 (-5.1 – -2.5)** 31.7 (p<0.0001) QIC=236508	**-1.8 (-2.8 – -0.8)** 12.3 (p<0.0001) QIC=134459	**-1.7 (-2.8 – -0.7)** 10.4 (p=0.001) QIC=132881
Dose 5 ($\Sigma a_{huwvi} t_i$, ln($ms^{-2}h$))	**-4.5 (-6.7 – -2.3)** 15.8 (p<0.0001) QIC=265069	**-4.0 (-6.0 – -2.0)** 15.1 (p<0.0001) QIC=250893	**-2.2 (-3.8 – -0.6)** 7.5 (p=0.006) QIC=135040	**-2.0 (-3.7 – -0.4)** 5.9 (p=0.015) QIC=133820
Dose 6 ($\Sigma a_{huwvi}^2 t_i$, ln($m^2s^{-4}h$))	**-4.3 (-6.0 – -2.5)** 22.9 (p<0.0001) QIC=252809	**-3.9 (-5.5 – -2.3)** 22.8 (p<0.0001) QIC=241012	**-2.1 (-3.5 – -0.8)** 10.1 (p=0.001) QIC=133571	**-2.0 (-3.4 – -0.6)** 8.1 (p=0.004) QIC=132462
Dose 7 ($\Sigma a_{huwvi}^4 t_i$, ln($m^4s^{-8}h$))	**-3.0 (-4.1 – -1.9)** 28.5 (p<0.0001) QIC=246265*	**-2.7 (-3.7 – -1.7)** 29.3 (p<0.0001) QIC=234926*	**-1.4 (-2.2 – -0.6)** 11.9 (p=0.001) QIC=133353*	**-1.3 (-2.2 – -0.5)** 9.4 (p=0.002) QIC=132151*

Model 1: adjusted by age, smoking, drinking, and survey;
Model 2: adjusted by age, smoking, drinking, survey, and VWF score
Model 3: adjusted by age, smoking, drinking, survey, and FSBP%$_{10°}$ at time-point *t*–1
Model 4: adjusted by age, smoking, drinking, survey, VWF score and FSBP%$_{10°}$ at time-point *t*–1
*best fitting model

Table 29. Purdue pegboard scores in the controls and the workers exposed to hand-transmitted vibration (HTV) at the cross-sectional survey. Data are given as means (standard deviations).

	Control workers (n=64)	HTV workers		
		Forestry workers (n=82)	Stone workers (n=33)	Total (n=115)
Dominant hand	14.2 (2.0)	13.5 (1.8)	12.8 (1.7)**	13.3 (1.8)†
Non-dominat hand	13.6 (2.0)	13.0 (1.6)	12.5 (1.4)*	12.8 (1.6)†
Both hands	11.1 (1.8)	10.2 (1.6)	9.9 (1.7)#	10.1 (1.6)‡
Sum of hand scores	39.0 (4.8)	36.3 (4.9)	35.2 (3.9)#	35.9 (4.6)‡
Assembly	30.7 (6.5)	25.5 (7.0)	25.6 (5.4)#	25.5 (6.5)‡

t test (Controls *vs* HTV workers): †p<0.01; ‡p<0.001
Bonferroni test: *p<0.05 (Controls *vs* Stone workers); **p<0.01 (Controls *vs* Stone workers);
#p<0.01 (Controls *vs* Forestry workers; Controls *vs* Stone workers)

Table 30. Random-intercept linear regression of Purdue pegboard scores on individual and occupational variables in the study population (n=179) over one-year follow up period. Maximum likelihood estimates of regression coefficients (95% confidence intervals) are reported. The regression coefficients for the forestry and stone workers are estimated with reference to the controls.

	Dominant hand	Non-dominant hand	Both hands	Sum of hand scores	Assembly
Intercept	16.5 (15.2 – 17.8)	16.3 (15.1 – 17.6)	14.2 (13.1 – 15.4)	46.9 (43.8 – 50.1)	42.1 (37.8 – 46.4)
Age (yr $\times 10^{-1}$)	-0.6 (-0.9 – -0.3)‡	-0.7 (-1.0 – -0.4)‡	-0.8 (-1.0 – -0.5)‡	-2.0 (-2.8 – -1.3)‡	-3.1 (-4.1 – -2.1)‡
Smoking	-0.6 (-1.1 – -0.1)*	-0.2 (-0.7 – 0.3)	-0.2 (-0.6 – 0.3)	-0.8 (-2.0 – 0.4)	1.1 (-0.6 – 2.8)
Drinking	0.1 (-0.4 – 0.6)	0 (-0.4 – 0.5)	0.1 (-0.4 – 0.5)	0.2 (-1.0 – 1.4)	-0.1 (-1.7 – 1.6)
Forestry workers	-0.7 (-1.2 – -0.2)†	-0.5 (-1.0 – -0.1)*	-0.7 (-1.2 – -0.3)‡	-2.1 (-3.4 – -0.9)‡	-4.1 (-5.8 – -2.5)‡
Stone workers	-1.1 (-1.7 – -0.4)†	-0.9 (-1.6 – -0.3)†	-1.3 (-1.9 – -0.7)‡	-3.3 (-4.9 – -1.6)‡	-2.8 (-5.0 – -0.6)†
Follow up	0.4 (0.1 – 0.6)*	0.5 (0.2 – 0.7)‡	0.8 (0.5 – 1.0)‡	1.8 (1.2 – 2.3)‡	2.9 (2.0 – 3.8)‡

*p<0.05; †p<0.01; ‡p<0.001

Table 31. 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) are adjusted by age, smoking, drinking and follow up time.

	Dominant hand	Non-dominant hand	Both hands	Sum of hand scores	Assembly
Tingling	-0.5 (-1.0 – -0.1)*	0 (-0.4 – 0.5)	-0.3 (-0.7 – 0.1)	-1.0 (-2.1 – 0)	-1.5 (-3.0 – -0.1)*
Tingling score (per 10 point-score)	-0.2 (-0.4 – -0.1)†	-0.1 (-0.2 – -0.1)	-0.1 (-0.2 – -0.03)‡	-0.3 (-0.5 – -0.2)‡	0 (-0.3 – 0.2)
Numbness	-0.6 (-1.1 – -0.1)*	-0.6 (-1.1 – -0.1)*	-0.7 (-1.2 – -0.2)†	-2.5 (-3.8 – -1.1)‡	-1.8 (-3.7 – 0.1)
Numbness score (per 10 point-score)	-0.1 (-0.3 – 0.1)	-0.05 (-0.3 – 0.2)	-0.05 (-0.2 – 0.1)	-0.4 (-0.7 – -0.1)*	-0.1 (-0.6 – 0.3)
White finger	-0.5 (-1.2 – 0.2)	-0.8 (-1.5 – -0.1)*	-0.8 (-1.4 – -0.1)*	-1.7 (-3.4 – -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)*	-0.2 (-0.4 – -0.1)*	-0.7 (-1.2 – -0.2)*	-0.4 (-1.2 – 0.4)
Neck musculo-skeletal disorders	0.3 (-0.1 – 0.)	0.2 (-0.2 – 0.6)	0.3 (-0.02 – 0.7)	0.2 (-0.7 – 1.2)	0.4 (-0.9 – 1.8)
Upper limb musculo-skeletal disorders	0.2 (-0.2 – 0.6)	0 (-0.4 – 0.4)	0 (-0.4 – 0.4)	-0.2 (-1.2 – 0.7)	-0.5 (-1.9 – 0.9)

*p<0.05; †p<0.01; ‡p<0.001

Table 32. Random-intercept linear regressions of Purdue pegboard scores on ergonomic risk factors and cumulative vibration dose in the study population (n=179) over one-year follow up time. Maximum likelihood estimates of regression coefficients (95% confidence intervals) are adjusted by age, smoking, drinking and follow up time, assuming no exposure to vibration and no exposure/very low exposure to ergonomic stress as the reference categories.

	Dominant hand	Non-dominant hand	Both hands	Sum of hand scores	Assembly
Model 1					
Neck-upper arm posture					
Low (score 4 – 7)	-0.2 (-0.7 – 0.3)	0.2 (-0.3 – 0.7)	-0.2 (-0-7 – 0.3)	-0.2 (-1.4 – 0.9)	-1.9 (-3.6 – -0.2)*
Medium (score 8 – 10)	-0.1 (-0.6 – 0.5)	0.3 (-0.3 – 0.8)	-0.1 (-0.7 – 0.4)	-0.3 (-1.5 – 1.0)	-3.5 (-5.3 – -1.7)‡
Hard (score 11 – 12)	-0.1 (-0.7 – 0.6)	0.1 (-0.6 – 0.7)	-0.3 (-0.9 – 0.3)	-0.4 (-1.9 – 1.1)	-3.3 (-5.4 – -1.1)†
Vibration dose ($m^2s^{-4}h \times 10^3$)					
Low (0.1 – 1.8)	-0.4 (-1.1 – 0.2)	-0.5 (-1.1 – 0.2)	-0.6 (-1.2 – -0.1)*	-1.5 (-3.1 – 0.03)	-2.4 (-4.6 – -0.3)*
Medium (1.9 – 6.0)	-0.8 (-1.4 – -0.1)*	-0.7 (-1.4 – -0.1)*	-0.8 (-1.4 – -0.2)†	-2.2 (-3.8 – -0.5)†	-3.7 (-6.0 – -1.5)‡
Hard (6.1 – 140)	-1.1 (-1.7 – -0.5)‡	-0.8 (-1.4 – -0.2)†	-1.1 (-1.6 – -0.5)‡	-3.2 (-4.7 – -1.7)‡	-2.2 (-4.2 – -0.2)*
Model 2					
Hand-intensive work					
Low (score 4 – 6)	0.1 (-0.4 – 0.6)	0.2 (-0.3 – 0.7)	0.1 (-0.4 – 0.6)	0 (-1.1 – 1.2)	-1.7 (-3.3 – -0.1)*
Medium (score 7 – 9)	-0.5 (-1.1 – 0.1)	0.2 (-0.4 – 0.8)	-0.1 (-0.6 – 0.5)	-0.2 (-1.5 – 1.1)	-2.8 (-4.7 – -0.9)†
Hard (score 10 – 15)	-0.3 (-0.9 – 0.4)	-0.1 (-0.7 – 0.6)	-0.2 (-0.8 – 0.4)	-0.2 (-1.7 – 1.3)	-2.4 (-4.6 – -0.2)*
Vibration dose ($m^2s^{-4}h \times 10^3$)					
Low (0.1 – 1.8)	-0.3 (-0.9 – 0.4)	-0.4 (-1.0 – 0.3)	-0.6 (-1.2 – 0.1)	-1.3 (-3.0 – 0.4)	-2.0 (-4.3 – 0.4)
Medium (1.9 – 6.0)	-0.5 (-1.2 – 0.2)	-0.7 (-1.4 – -0.1)*	-0.8 (-1.4 – -0.2)†	-2.0 (-3.6 – -0.4)*	-3.3 (-5.5 – -1.1)†
Hard (6.1 – 140)	-0.9 (-1.5 – -0.2)*	-0.9 (-1.6 – -0.2)†	-1.0 (-1.6 – -0.4)†	-3.4 (-5.1 – -1.8)‡	-2.0 (-4.3 – 0.3)
Model 3					
Total ergonomic score					
Low (score 13 – 25)	0.4 (-0.2 – 0.9)	0.5 (0 – 1.1)	0.1 (-0.4 – 0.6)	0.8 (-0.4 – 1.9)	-1.5 (-3.3 – 0.2)
Medium (score 26 – 35)	-0.1 (-0.8 – 0.5)	0.2 (-0.5 – 0.8)	-0.1 (-0.7 – 0.5)	-0.7 (-2.2 – 0.9)	-3.1 (-5.3 – -0.9)†
Hard (score 36 – 57)	0 (-0.8 – 0.8)	0.3 (-0.5 – 1.1)	0.1 (-0.7 – 0.8)	-0.4 (-2.2 – 1.3)	-3.0 (-5.5 – -0.4)*
Vibration dose ($m^2s^{-4}h \times 10^3$)					
Low (0.1 – 1.8)	-0.4 (-1.1 – 0.4)	-0.4 (-1.1 – -0.4)	-0.6 (-1.3 – 0)	-1.0 (-2.8 – 0.8)	-2.1 (-4.6 – 0.4)
Medium (1.9 – 6.0)	-0.6 (-1.4 – 0.1)	-0.7 (-1.4 – 0)	-0.9 (-1.6 – -0.2)†	-1.8 (-3.5 – -0.1)*	-3.1 (-5.5 – -0.6)*
Hard (6.1 – 140)	-1.0 (-1.7 – -0.2)†	-0.9 (-1.6 – -0.2)†	-1.1 (-1.7 – -0.4)‡	-2.9 (-4.6 – -1.2)‡	-1.1 (-3.4 – 1.3)

*p<0.05; †p<0.01; ‡p<0.001