

Risks of Occupational Exposures to Hand-transmitted Vibration: VIBRISKS

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Abstract

VIBRISKS seeks to improve understanding of the risk of injury from hand-transmitted vibration and whole-body vibration by means of epidemiological studies supported by fundamental laboratory research. VIBRISKS is a consortium of six partners from six European countries (France, Germany, Italy, Sweden, The Netherlands, UK). The four-year research project, which commenced in 2003, involves three work packages devoted to hand-transmitted vibration and three work packages devoted to whole-body vibration. This paper summarizes the hand-transmitted vibration research. Work package 1 defines methods to be used in studies of disorders caused by hand-transmitted vibration in work package 2 and integrates the results of the epidemiological studies in work package 2 with the results of experimental and modeling studies in WP3 so as to define procedures that can be applied by occupational health workers for minimizing risk, screening exposed individuals and managing individuals with symptoms. Work package 2 involves longitudinal studies in workers exposed to hand-transmitted vibration. Work package 3 involves experimental studies of the acute effects of hand-transmitted vibration on vascular and neurological function and the development of a finite element model of the biodynamic responses of the finger to vibration and force.

Introduction

Occupational exposures to hazardous levels of hand-transmitted vibration are common around the world. Some outcomes of exposure to hand-transmitted vibration are well recognised. For example, finger blanching (vibration-induced white finger) and sensorineural disorders are commonly diagnosed in workers exposed to hand-transmitted vibration and form part of the hand-arm vibration syndrome. For other disorders, such as carpal tunnel syndrome and osteoarthritis, the risks arising from exposure to hand-transmitted vibration are less well established.

The number of persons injured by exposure to hand-transmitted vibration within the European Union is not known, but may be estimated at many millions. This implies a significant negative impact on the well-being of many individual workers. There is a consequent social burden and financial costs to the state and, in some cases, the industry in which the vibration exposures were produced.

Within countries of the European Union, there are large differences in the recognition of the various disorders associated with exposure to vibration. There are also differences in the methods of diagnosing disorders and the means of controlling risk.

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VIBRISKS seeks to improve understanding of the risk of injury from both hand-transmitted vibration and whole-body vibration by means of epidemiological studies supported by fundamental laboratory research. This paper summarizes the hand-transmitted vibration research in VIBRISKS.

Objectives

The objectives of the hand-transmitted vibration studies in VIBRISKS are to:

- advance understanding of acute effects of hand-transmitted vibration on peripheral circulation.
- improve knowledge of the exposure-response relationship between hand-transmitted vibration and the development of chronic vascular and neurological disorders.
- improve understanding of factors that result in the progression of the symptoms and signs of vascular disorders, so as to improve understanding of the benefits of health surveillance.
- improve health surveillance guidelines to minimize risk (primary prevention), the screening of exposed workers, and the management of individuals with symptoms (secondary prevention).

Work package 1: HTV support and integration of results

Work package 1 supports the studies of disorders caused by hand-transmitted vibration in Work package 2 and the experimental and modeling studies in Work package 3 and integrates the findings from these two packages into procedures that can be applied by occupational health workers for minimizing risk, screening exposed individuals and managing individuals with symptoms.

The objectives are to:

- (i) define and agree methods to be used in the epidemiological studies in Work package 2;
- (ii) integrate the findings from epidemiological studies in Work package 2 with the results of experimental studies in Work package 3 so as to define predictive dose-response models;
- (iii) provide improved health surveillance guidance for primary prevention (prevention of injuries in workers exposed to hand-transmitted vibration) and secondary prevention (preventing the progression of disorders).

Task 1.1 Preparation for epidemiological studies of HTV

Research conducted within a previous EU research network (Vibration Injury Network: VINET) resulted in methods of diagnosing disorders caused by hand-transmitted vibration. These methods have been further developed and adopted for the VIBRISKS studies.

A self-administered questionnaire and a questionnaire for administration by health professionals have been defined and translated into appropriate languages. The six-page self-administered questionnaire includes basic questions on personal identification, social history with reference to smoking and drinking habits, and medical history. Self-reported vascular, sensorineural and musculoskeletal complaints in the upper extremities (finger colour changes, tingling, numbness, pain in the neck and upper limbs, and effects of symptoms in the hands and fingers) are also investigated. The clinically-administered questionnaire includes a comprehensive set of questions devoted to personal, occupational, social, medical and symptom histories, as well as a section dedicated to

physical examination with particular reference to vascular, neurological and musculoskeletal systems. Exposure to hand-transmitted vibration and ergonomic risk factors are investigated in a section of the clinically-administered questionnaire. Personal, social and medical histories in the clinical administered questionnaire provide more details than those included in the self-administered questionnaire, whereas questions on symptoms in the finger-hand-arm system are almost identical in both questionnaires. Color charts have been produced to assist the identification of color changes in the fingers. A guide to the diagnosis of carpal tunnel syndrome has also been produced.

For testing peripheral vascular response to cold, the partners are using multi-channel plethysmography (*HVLab* multi-channel plethysmograph), allowing simultaneous measurement of finger systolic blood pressure on four fingers after thermal provocation at $30^{\circ}\text{C} \pm 1^{\circ}\text{C}$ and after thermal provocation at $10^{\circ}\text{C} \pm 1^{\circ}\text{C}$. The test procedure will be consistent with DIS 14835-1 (2004).

For neurological disorders, vibrotactile perception thresholds (at 31.5 Hz and 125 Hz) will be obtained according to ISO 13091-1:2001 (using either the *HVLab* vibrometer or the *HVLab* tactile perception meter). Thermal thresholds for the perception of heat and cold will be obtained using the *HVLab* thermal aesthesiometer. The Purdue pegboard and Jaymar grip meter will also be used.

A diagnostic procedures manual has been produced by the partners to unify their methods of applying the questionnaires and the various tests of vascular and neurological function. This also defines the environmental conditions for testing. The project members involved in the use of diagnostic methods have been trained on the use of the apparatus. The diagnostic procedures manual will be further developed from experience gained during the project and is expected to provide a useful outcome from the research.

Task 1.2 Integration of findings and model development

When the results of the epidemiological studies in work package 2 become available, the partners will collectively interpret the data so as to relate vibration dose and injury, and identify effects of confounding variables. Models will be developed to predict the onset, severity and progression of injuries over time, taking account of confounding variables.

Task 1.3 Provision of health surveillance guidelines

The models provided by Task 1.2 will be used to draft guidelines for occupational health workers.

Work package 2: HTV epidemiological work

Work package 2 involves coordinated longitudinal studies in workers exposed to hand-transmitted vibration.

For primary prevention, dose-response relationships for hand-transmitted vibration are required to allow technical and administrative solutions. Secondary prevention requires understanding of the natural history of vibration-related illness and the factors causing, or predicting, its progression. Hence two categories of investigation are envisaged, emphasizing dose-response and natural history of disorders:

- (i) the investigation of the dose-response relationships between vibration exposure and development of (a) vascular disorders (VWF) and (b) neurological disorders (e.g. numbness, tingling and elevated vibrotactile and thermotactile thresholds) of the upper limb;
- (ii) the investigation of factors causing, or predicting, progression (i.e. natural history) of vascular and neurological disorders; to determine how often mild cases of the hand-arm vibration syndrome get worse and how rapidly; whether those destined to get worse can be predicted (to aid earlier detection), and if so, whether advice can be tailored to individuals; to

determine whether factors resulting in the onset of disorder also predict the development of disorder. It is particularly hoped to improve current understanding of the development of the neurological components of the hand-arm vibration syndrome.

Task 2.1 Dose-response studies of workers exposed to HTV

Workers exposed to hand-transmitted vibration (mainly caused by chain saws, hand-held grinders and impact wrenches) in Italy and Sweden are being surveyed annually. It was considered that different patterns of vibration-induced neurological and vascular disorders between Nordic (e.g. Sweden) and Mediterranean (e.g. Italy) countries could also reflect differences in some socio-demographic and climatic variables.

In the longitudinal studies of vibration-exposed workers, the principal dependent variables will be symptoms and signs of vascular, neurological and musculoskeletal dysfunction in the upper limbs which will be investigated by means of questionnaires and objective tests (finger systolic blood pressures, finger re-warming times, vibrotactile and thermotactile thresholds, manual dexterity and grip strength). A follow-up questionnaire is designed to assess subjectively the possible ameliorating effects of a reduction of vibration exposure. The possible ameliorating effects will be also tested by comparing the vascular response to a cold provocation test with measurements of finger systolic blood pressures during the various follow-up periods. Any ameliorating effects of vibration protectors (e.g. gloves or the adoption of tools with low vibration emission) will be included as both clinical (anamnesic) and objective tools.

The principal independent variables are vibration exposure and postural stressors. The vibration-exposed workers to be investigated were chosen to assess whether exposure to vibration with different spectral characteristics (magnitude and frequency), such as those from chain saws, grinders and other hand-held vibrating tools, may be associated with different patterns and occurrence of vascular and neurological disorders in the upper limbs.

Vibration will be measured and combined with daily exposure durations and years of exposure to form alternative cumulative measures of exposure severity. Postural stressors will be quantified at the workplace in terms of work postures, forces and repetitiveness. Additional independent variables will include personal characteristics (age, anthropometry, use of medicines, smoking, drinking), psychosocial factors, and previous jobs.

Vibration will be measured according to the recommendations of the current international standards (ISO 5349-1 and ISO 5349-2, 2001). In addition to frequency weighting according to ISO 5349, vibration spectra in the frequency range 6.3 to 1250 Hz will be obtained to allow alternative estimates of unweighted acceleration magnitude. Both frequency-weighted and unweighted acceleration magnitudes will be used, together with exposure duration, to obtain measures of cumulative (lifetime) vibration dose. Vibration will be measured on representative samples of tools used by the study workers by applying measurement methods in the field according to ISO 5349-2, 2001.

Using the measures of vibration magnitude and exposure duration, it will be possible to construct, for each subject, various alternative vibration ‘doses’, of the general form:

$$dose = \sum_i [a_i^m t_i]$$

where a_i and t_i are the acceleration magnitude and the exposure duration respectively, for tool i . In these doses, the relative importance of the acceleration, a , (weighted or unweighted) and the total exposure duration, t , depends on the value of m . Doses with $m = 0, 1, 2,$ and 4 will be computed for each subject, with both frequency-weighted acceleration and unweighted acceleration (Griffin et al, 2002).

Task 2.2 Natural-history studies of HTV exposed workers

The natural history of the development of components of the hand-arm vibration syndrome will be studied within existing health surveillance programs in an engineering company in the UK. Using a cross-sectional questionnaire, workers with symptoms will be identified and invited to provide a history of symptoms, risk factors, and exposure to vibration. Vibrotactile and thermal thresholds and vascular function following cooling will be measured in those with VWF considered to be at stage 1 or greater, and in a selection of those with no vascular symptoms. Subjects will be followed-up at annual intervals by questionnaires and those reporting worsening symptoms will be interviewed and tested. Information on the pattern and extent of exposure to hand-transmitted vibration over the period of follow-up will be collected, so that any progression of symptoms can be related to these parameters. Analysis will focus on (i) how often established cases of VWF get worse; (ii) how rapidly they get worse; (iii) whether those destined to get worse can be predicted (to aid earlier detection) by either clinical means or objective testing; and if so, (iv) whether advice can be better tailored to individual circumstances.

Work package 3: HTV experimental work

Work package 3 is designed to support the epidemiological research with experimental and modeling studies.

The establishment of a relationship between exposure to hand-transmitted vibration and injury requires an appropriate means for assessing vibration dose that accounts for the observed effects of vibration magnitude, vibration frequency, vibration duration and vibration direction, as well as factors such as grip force. Previous collaborative work between the partners and others has identified problems with current standardized procedures for the evaluation of hand-transmitted vibration. The specific objectives of work package 3 are:

- (i) to conduct experimental studies of the acute effects of hand-transmitted vibration so as to provide improved 'weightings' for the acute effects of the frequency and duration of hand-tool vibration, and the grip force exerted by operators. These are required for the interpretation of the epidemiological data and the establishment of appropriate dose response models in work package 1.
- (ii) to model the hand-arm system so as to assist the interpretation of the epidemiological studies in work package 2, where the grip force and posture may be important confounding factors not taken into account in previous studies.

Task 3.1 Laboratory studies of vascular and neurological effects of hand-transmitted vibration

Laboratory experiments are investigating acute effects of hand-transmitted vibration on vascular function (finger blood flow) and neurological function (vibration perception thresholds and thermotactile thresholds). The studies are designed to systematically investigate the effects of vibration magnitude, vibration frequency and vibration duration.

Laboratory experiments will be undertaken collaboratively by the University of Southampton and the University of Trieste to investigate the acute effects of hand-transmitted vibration on measures of vascular function (finger blood flow) so as to consolidate current knowledge and better define the effects of vibration magnitude, frequency and duration (see Bovenzi *et al.*, 1998, 1999, 2000, 2001). Complementary studies of the effects of hand-transmitted vibration on neurological function will be performed in Sweden.

In the studies of the effects of hand-transmitted vibration on vascular function, the experiments will investigate the effects of vibration frequency (from 16 to 250 Hz), vibration magnitude (from 1 to 176 ms⁻² r.m.s.), and vibration duration (from 0.03 to 1 hour). Further experiments are planned to explore the effects of intermittent exposure to hand-transmitted vibration. The results will be

combined to develop alternative measures of vibration dose with alternative time-dependencies. The relationships between the various vibration doses and acute vascular effects will be assessed.

Task 3.2 Laboratory studies of effects of hand-transmitted vibration on the detection of symptoms

Laboratory studies will investigate whether prior exposure to vibration on the day of a diagnostic test influences test results. The findings will be used to identify the length of time required between an occupational exposure to hand-transmitted vibration and the commencement of diagnostic testing.

Laboratory studies designed by the University of Southampton and the University of Trieste will investigate whether conditions in the field are likely to influence the results obtained from the vascular objective diagnostic tests used to detect symptoms (i.e. whether prior exposure to vibration on the day of the test influences vascular function). Similar studies with neurological function are planned in Sweden. The findings will be used to establish an improved definition of test conditions, especially the length of time required between the last occupational exposure to tool vibration and the commencement of objective testing.

Task 3.3 Biodynamic modeling of hand-arm system

Two-dimensional and three-dimensional finite element biodynamic models are being developed by INRS in France to represent the applied forces, pressures and internal stresses resulting from contact of a finger with a vibrating surface. The models will take into account bone geometry and joints in addition to the characteristics of the soft tissues.

The models are intended to assist the interpretation of the above laboratory experimental studies of finger blood flow and neurological function with varying characteristics of vibration and contact forces, and will therefore use similar boundary conditions.

Measurements of the mechanical impedance of the finger will be made by INRS and compared to the calculated impedance derived from modal analyses of the three-dimensional finite element model developed in the research.

It is hoped that the modelling studies will improve understanding of the effects of contact force and vibration frequency on mode shapes in the finger, the mechanical impedance of the finger, and pressure maps in the finger. This may assist the interpretation of the various experimental studies of the frequency-dependence of vascular or neurological responses of the finger to hand-transmitted vibration.

Partners

The four partners in VIBRISKS involved in hand-transmitted vibration research are:

1. University of Southampton, UK (Co-ordinator): ISVR and MRC. The VIBRISKS project is coordinated by Professor Michael Griffin and managed by Dr Christopher Lewis in the ISVR. The ISVR also leads workpackage 1 and is a participant in workpackages 2 and 3. Dr Keith Palmer of the MRC Environmental Epidemiology Unit at the University of Southampton is leading a project in workpackage 3.
2. University of Trieste, Italy: Clinical Unit of Occupational Medicine, Department of Public Health Sciences. Professor Massimo Bovenzi of the University of Trieste leads workpackage 2 and is an active participant in workpackages 1 and 3. Dr. Iole Pinto, of the Physical Agents Laboratory at the Department of Prevention, Siena, is subcontracted to assist with measurements of occupational exposures to hand-transmitted vibration in workpackage 2.

3. INRS: Institut National de Recherche et de Sécurité, Vandoeuvre, France. Dr Pierre Lemerle of INRS leads work package 3 and is responsible for the development of biodynamic models.
4. UMH: Department of Biomedical Engineering and Informatics, Umeå University Hospital and Department of Occupational Medicine, Umeå University, Sweden. Professor Ronnie Lundström of UMH, together with Professor Lage Burström of NIWL, Professor Mats Hagberg of Department of Occupational Medicine, Göteborg University and Dr Tohr Nilsson, Department of Occupational Medicine, Sundsvall Hospital are collaborating on epidemiological studies within work package 2. Professor Ronnie Lundström and Professor Lage Burström are also participating in experimental studies within work package 3.

The following partners are collaborating with the above four partners on whole-body vibration research:

5. Bundesanstalt für Arbeitsmedizin, Berlin, Germany: Dr Helmut Seidel, Dr Barbara Hinz and Dr Ralph Blüthner.
6. Coronel Institute, University of Amsterdam, Netherlands: Dr Carel Hulshof and Dr Jos Verbeek.

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Further information on VIBRISKS and VINET may be found via <http://www.humanvibration.com>

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